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Emotion Suppression and Pain Perception: An Analysis Over Time

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Agnes Steinböck BSc

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Pain is a multidimensional phenomenon that can have major impact on human life. It affects not only physical, but also social and psychological well-being (Penny et al., 1999) and can lead to decreased quality of life (Mantyh, 2006). Chronic pain in particular is associated with great suffering and massive costs to society (e.g. costs to economies, health services and benefits agencies) (Phillips, 2009).

The International Association for the Study of Pain (IASP) defines pain in its 2020 revised definition as "an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage'' and points out that ''pain is always a personal experience" (Raja et al., 2020). This definition highlights the fact that pain is not only associated with physical pathology, but that its experience and duration also depend on psychological aspects like emotions. Nevertheless, the affective component of pain is often given little consideration in research and clinical practice (Dahlke et al., 2017).

Studies indicate that emotions and pain are closely intertwined and influence each other bidirectionally. The link between pain and emotions becomes clear in terms of anatomical features: According to the Dual System Theory of Pain physical and emotional aspects of pain engage in overlapping neural pathways and common structures in the brain. While both components rely on a separate system, their pathways converge on the anterior cingulate and insular cortices. These brain regions, in turn, are connected to the prefrontal cortex and influence the behavioural response (Dahlke et al., 2017). Empirical data support this theory: On the one hand, studies have shown that the anterior cingulate and insular cortices play an essential role in emotional processing (Deak, 2011). On the other hand, a meta-analysis by Peyron et al. (2000) points out that these structures count to the areas that are most consistently activated when experiencing pain. In addition, the comorbidity of pain and mental illness also demonstrates the connection between emotions and pain. Studies show a correlation between pain conditions and psychiatric disorders such as affective and anxiety disorders (Antonaci et al., 2011; Bair et al., 2008).

Due to this interplay of pain and emotions, it is essential to examine both constructs together to gain a complete understanding of pain and its optimal treatment (Dahlke et al., 2017). The question arises as to what extent the regulation of emotions is related to the perception of pain and its development over time.

Theories on the Development of Pain

Over time, various people with different backgrounds have developed several models of how pain arises, and which aspects are involved. Looking back at these different models throughout history shows that emotional aspects were not always considered significant for the experience of pain (Hadjistavropoulos & Craig, 2004).

The biomedical approach of pain goes back hundreds of years. According to this view, physical damage (caused by illness or injury) leads to the stimulation of certain pain receptors and thus generates a sensory experience (Hadjistavropoulos & Craig, 2004). While social and psychological aspects are left out, the focus is mainly on physiological factors like biochemical imbalances and neurophysiological abnormalities (Bevers et al., 2016). Diseases are attributed to a single cause lying within the body and mental disorders are regarded as separate problems (Wade & Halligan, 2017). "Thus the biomedical model embraces both reductionism, the philosophic view that complex phenomena are ultimately derived from a single primary principle, and mind body dualism the doctrine that separates the mental from the somatic" (Engel, 1977, p. 130).

Another unidimensional conceptualization comes from the psychodynamic perspective. In comparison to the biomedical approach, it sees psychological rather than physical aspects as the central factors in the development of pain. Psychodynamic pain models refer mainly to chronic instead of acute pain. According to this perspective the appearance of chronic pain is viewed as an expression of emotional conflicts (Hadjistavropoulos & Craig, 2004).

In contrast to these approaches, Melzack and Wall (1965) managed to unite both physical and psychological aspects with their Gate Control Theory. In their model, they postulate a hypothetical gating mechanism in the dorsal horn of the spinal cord that can influence the transmission of nociceptive information from the periphery to the brain by allowing or disallowing the information to pass. The model suggests that various psychological factors such as emotions can affect the gate control system and thus influence the perception of pain (Melzack & Wall, 1965). The Gate Control Theory had major influence on our current understanding of pain and served as the foundation for the development of the biopsychosocial model (Bevers et al., 2016; Hadjistavropoulos & Craig, 2004).

It is currently assumed that the biopsychosocial model provides the best foundation for comprehensive pain treatment (Bevers et al., 2016). The biopsychosocial perspective was

introduced by Engels (1977) as a reaction to the biomedical model. According to the biopsychosocial model biological, psychological (e.g. emotion regulation) and social factors and their interaction with each other influence the perception of pain. It represents a complex and multidimensional view and is applicable to both acute and chronic pain (Hadjistavropoulos & Craig, 2004). Literature now provides plenty of evidence for the usefulness of this approach (Wade & Halligan, 2017), especially for chronic pain (Hadjistavropoulos & Craig, 2004). Given the predominant reliance on the biomedical model within the Western healthcare systems, there are various problems (e.g. costs or patient-reported outcomes) that make the application of the biopsychosocial model urgently necessary (Wade & Halligan, 2017). However, the biopsychosocial model is not free from criticism. For instance, it is criticized that there is a lack of representation of the interactions between the different factors (biological, psychological, and social). Additionally, there is criticism regarding the persistent dichotomy between biological and psychological aspects (Tavakoli, 2009), along with ambiguity concerning the prioritization of subsystems (Ghaemi, 2009). Hence, further research is needed to continue to improve the explanation and treatment of pain. Nevertheless, the biopsychosocial approach should serve as a basis of the present work.

Pain Over the Course of Time

Pain is usually categorized into acute and chronic pain. Acute pain is seen as a warning signal and an almost everyday experience. It lasts from a few seconds to a few weeks and usually has an identifiable trigger. If this trigger is stopped, pain normally subsides. With chronic pain, on the other hand, the trigger is often unknown, or the identifiable damage is unproportional to the pain experienced. According to ICD-10, pain lasting 6 months or more is considered chronic. This includes both recurrent and persistent pain (Freyberger et al., 2019). While acute pain is usually easy to localize, chronic pain is often described as less specific (Kröner-Herwig, 2011). The experience of pain can change over time and turn from acute to chronic pain (Feizerfan & Sheh, 2015). Habituation and sensitization are two non-associated learning processes that significantly influence the course of pain over time (Kröner-Herwig, 2011).

Habituation

"Habituation is defined as a behavioral response decrement that results from repeated stimulation and that does not involve sensory adaptation/sensory fatigue or motor fatigue" (Rankin et al., 2009, p. 136). It is found in various species and stimuli, including painful events (De Paepe et al., 2019). A distinction can be made between complete and partial habituation, with the former enabling the person to function even in painful situations. In contrast, partial habituation leads to a lower intensity of pain, but is accompanied by an awareness of a potentially dangerous stimulus (Ginzburg et al., 2015). Moreover, habituation can not only be a short-term (minutes or hours) effect but can also last for days or weeks. In this context, the term "long-term habituation" is used (Rankin et al., 2009). It is assumed that the weaker the intensity of the stimulus, the faster and more pronounced the decrease in the behavioral response. In addition to the intensity, the context is also decisive for the habituation outcome. While constant temporal and spatial conditions seem to be the most advantageous, changes in the context, on the other hand, can hinder long-term habituation (De Paepe et al., 2019).

The exact mechanisms of how habituation takes place are still unclear. It is argued that several processes are involved (Rankin et al., 2009). For instance, pain habituation is associated with increased activity in the subgenual anterior cingulate cortex. As this area is involved in endogenous pain control, it suggests that the antinociceptive system is significantly involved during pain habituation (Bingel et al., 2007). Furthermore, habituation to pain is associated with decreased activity of areas that are important for pain processing (Bingel et al., 2007; Paul et al., 2021). However, Paul et al. (2021) show that this is not a specific phenomenon of pain habituation: Not only habituation to painful stimuli but also to non-painful stimuli lead to decreased activity in these areas (e.g. anterior insula, secondary sensory cortices). In contrast, the anterior midcingulate cortex (aMCC) only shows reduced activity when it comes to the habituation to painful stimuli. This suggests that habituation to pain involves both a general habituation to repetitive somatosensory stimuli but also a more specific process. It is discussed that this specific phenomenon of reduced activity in the aMCC is possibly related to emotional processes and indicates a reduction in the affective-motivational response to the pain stimulus (Paul et al., 2021).

Habituation is thought to help in keeping the processing as well as attention load low (De Paepe et al., 2019) and avoid overstimulation or loss of energy (Cecchini et al., 2003). In addition, it serves to relieve pain and possibly also contributes to prevent chronic pain

(Bingel et al., 2007). This is supported by studies showing that people with chronic pain exhibit deficits regarding habituation (Cecchini et al., 2003; Flor et al., 2004; Valeriani et al., 2003).

Sensitization

Sensitization is seen as the opposite of habituation. Regarding pain stimuli it is considered the much more investigated phenomenon (De Paepe et al., 2019). Sensitization is defined as an increase in the behavioural response which occurs particularly with strong, noxious, or new stimuli. In contrast to habituation, sensitization is less dependent on repetition and more on the intensity of the stimulus (Peeke & Petrinovich 1984 as cited in Prescott, 1998). As with habituation, sensitization can be short-term (less than an hour) and long-term (hours and months). Both forms are characterized by a decrease in the pain threshold, exaggerated reactions to noxious stimuli and pain induction caused by harmless stimuli (Baranauskas & Nistri, 1998). Animal data show that long-term sensitization occurs particularly at higher stimulus intensities and occurs faster and to a greater extent at an increased frequency (Groves et al., 1969).

Sensitization can be divided into central and peripheral sensitization. The former includes changes that occur in the central nervous system and the latter those in the peripheral nervous system (Bhave & Gereau, 2004). Central sensitization is defined by increased excitability of dorsal horn neurons. It leads to enlarged receptive fields, enhanced spontaneous activity and an increase in response mediated by both large- and small-caliber primary afferent fibers (Li et al., 1999). In addition to neuronal mechanisms, the activation of glial cells by neurotransmitters, for instance, can also influence central sensitization (Staud & Smitherman, 2002). In peripheral sensitization, tissue damage leads to a local change in the sensitivity of the sensory fibres, resulting in a reduced stimulation threshold of nociceptive afferent receptors (Treede et al., 1992). In the course of this, also normally silent receptors can be activated. Inflammatory mediators such as prostaglandins play an important role regarding these processes (Kröner-Herwig, 2011).

The purpose of sensitization is to rapidly increase the response to a stimulus that is perceived as highly informative (Cecchini et al., 2003; Prescott, 1998). While habituation is considered a preventive factor for the development of chronic pain (Bingel et al., 2007), sensitization is associated with the experience of chronic pain (Bhave & Gereau, 2004).

In summary, sensitization, and habituation processes both have a significant effect on the duration of pain. It is discussed that sensitization is the default setting and that habituation only occurs under specific conditions (e.g. low pain intensity) (Greffrath et al., 2007). Individual differences are observed regarding both phenomena. Painful stimuli that lead to habituation in one person may not lead to a decrease or may even lead to an increase in pain in another person. This fact suggests that at least some of the differences can be explained by psychological factors such as emotional processing (De Paepe et al., 2019).

When exploring the concepts of habituation and sensitization, it becomes evident that these processes can significantly influence changes in pain perception in studies examining pain over time. Therefore, it is crucial to consider the effects of habituation and sensitization in the current study when interpreting changes in pain intensity or tolerance observed during repeated pain assessments.

Emotion Regulation

The connection between pain and emotions makes it seem obvious that emotion regulation may play an important role in the context of pain perception. Emotion regulation "focuses on people's attempts to influence emotions, defined as time-limited, situationally bound, and valenced (positive or negative) states." (McRae & Gross, 2020, p.1). Depending on the regulation goal, emotion regulation involves the upward and downward regulation of positive or negative emotions. This can refer both to influencing one's own emotions and to influencing emotions of others (McRae & Gross, 2020).

There are two conceptualizations of emotion regulation: trait/habitual emotion regulation and state/momentary emotion regulation. The former refers to general patterns in how emotions are regulated across various situations (Maxwell et al., 2019). State emotion regulation, on the other hand, refers to emotion regulation processes in a specific situation. It focuses on short-term and momentary regulation which depends on current circumstances and goals (e.g. to hide one's emotions) (Maxwell et al., 2019; Thompson, 1994).

Gyurak et al. (2011) postulate with their Dual Process Theory that emotion regulation can be both explicit and implicit. Explicit regulation requires a certain amount of effort to initiate regulation and a certain degree of awareness and monitoring during the process. With implicit regulation, on the other hand, the regulation process is automatically triggered by the stimulus and can take place without awareness or monitoring. Although research used to focus primarily on explicit emotion regulation (Gyurak et al., 2011), there are now a number

of studies providing empirical support for implicit emotion regulation processes (Hopp et al., 2011; Quirin et al., 2011).

Based on the Process Model postulated by Gross (2002), emotion regulation is a dynamic process that unfolds over time. According to this model the different strategies for emotion regulation can be categorized by when they occur in the process of emotion development. A distinction is made between antecedent-oriented and response-oriented regulation. While antecedent-oriented regulation happens during the emotion-generating process and before the emotional reaction takes place, response-oriented regulation modulates the emotional reaction after an emotion has been experienced. Since response-oriented regulation strategies are associated with several negative consequences, it is widely believed that their frequent use is maladaptive (Tyra et al., 2023). This includes, for example, the strategy of expressive suppression (Abler & Kessler, 2009).

Expressive Suppression

"Expressive suppression [...] is a response-oriented regulation strategy that involves suppressing behaviour and expression as a result of emotional experience [...]" (Abler & Kessler, 2009, p.2). It counts as one of the most frequently used strategies in everyday life (Abler & Kessler, 2009).

While the frequent use of this strategy is hardly related to intelligence and personality, it is linked to the construct of inauthenticity. Individuals who often suppress their emotions state that they are aware of deceiving others about their true feelings and that they do so mainly out of fear of being less accepted (John & Gross, 2004). Expressive suppression is seen as a demanding form of self-regulation that requires self-related cognitions and consumes attentional resources (Richards & Gross, 1999). In this context, Richards and Gross (1999) show that both recall and recognition memory are deficient during suppression. While the memory of the emotional reaction increases, content of conversations and socially relevant information are less well remembered. These factors can in turn have a negative effect on social interactions (John & Gross, 2004; Richards et al., 2003). Suppression is associated with elevated blood pressure in social partners, being less liked, decreased social support (Gross, 2002) and decreased closeness (John & Gross, 2004). Regarding the effects on emotional experience itself, suppression leads to fewer positive emotions and has hardly influence on negative emotions or even increases negative emotional experience (Gross, 2002; John & Gross, 2004). In general, this emotion regulation strategy is associated with a

lower sense of well-being (Kwon & Kim, 2019). For instance, people who report using this strategy more often have higher levels of perceived stress (Caramanica et al., 2023). Additionally, suppression is associated with lower mental health (John & Gross, 2004) and is linked to depressive symptoms (Nolen-Hoeksema & Aldao, 2011). In terms of physical health, suppression is correlated with increased sympathetic activation (Gross, 2002). For instance, experimentally induced suppression is associated with elevated cardiac, hemodynamic, and neuroendocrine parameters. Furthermore, also self-reported trait suppression leads to increased neuroendocrine reactivity, resulting in a stronger cortisol response (Tyra et al., 2023). In this context, suppressors are quite aware that they experience increased stress. However, trying to alleviate their distress by suppressing emotions remains ineffective (Tamagawa et al., 2013).

Despite the predominantly adverse consequences of suppression, it can also be beneficial in certain situations. For instance, individuals who outperform others may elicit more positive social reactions by suppressing their positive emotions (Schall et al., 2016). Additionally, Thuillard and Dan-Glauser (2020) show that the combined use of suppression with the strategy "situation selection" can have a positive effect on physiological activation.

Expressive Suppression and Pain

Data from a systematic review show that there is also an association between maladaptive emotion regulation strategies such as expressive suppression and pain perception (Koechlin et al., 2018). It is discussed that suppression of emotions and thoughts leads to an increased awareness of suffering and pain (Gilliam et al., 2010).

Studies using the Cold Pressure Test (CPT) to experimentally induce pain (which is also used in the present study) indicate that suppression has a negative effect on pain perception. In the CPT, participants are required to keep their hand submerged in cold water for as long as possible. For instance, in a study by Masedo and Rosa Esteve (2007), the suppression group presented the shortest tolerance time and the highest subjective pain ratings compared to groups that used acceptance or spontaneous coping as strategies. Moreover, regarding particularly the suppression of anger, empirical data also indicate an association between expressive suppression and increased subjective pain intensity (Quartana et al., 2007, 2010). While these studies using the CPT indicate negative effects of suppression on pain, there is also evidence that in specific situations, such as when pain is induced by very brief electrical stimuli, suppression can also reduce pain (Braams et al., 2012).

With regard to the possible influence of suppression on pain over time, existing literature seems limited and contradictory: While a study on hypothalamic-pituitary-adrenal (HPA) axis habituation shows that neither state nor trait suppression has an influence on the habituation process (Roos et al., 2019), empirical data indicate a direct association between maladaptive emotion regulation strategies and chronic pain (Koechlin et al., 2018). For instance, patients with chronic conditions such as chronic back pain or fibromyalgia show higher suppression scores (Esteves et al., 2013; Van Middendorp et al., 2008). This in turn would suggest that suppression might inhibit habituation and possibly promote sensitization processes.

Regardless of suppression, research indicates that repeated exposure to the CPT leads to habituation. For example, repeated CPT exposure within one day results in individuals enduring colder temperatures and showing habituation in cardiovascular measurements (e.g. heart rate, mean arterial pressure or cardiac output) (Smith et al., 2009). Habituation processes are also observed if the exposures take place on different days. For example, pain tolerance and pain threshold become significantly higher with repeated exposure over several days (Savitha et al., 2022). For subjective pain ratings, data appear to be less clear. While Bullock et al. (2023) show that the subjective rating of pain intensity decreases, Savitha et al. (2022) find no habituation effect.

Summary and Derivation of Research Questions

In summary, existing studies suggest that suppression is associated with an elevated pain experience. In terms of pain over time, empirical data indicate that repeated exposure to the CPT results in a decreased pain response, indicating habituation. Whether there is a relationship between suppression and the progression of pain over time is still largely unexplored.

Existing literature is, in some cases, contradictory. Some studies only refer to one specific emotion (anger) and there are generally only a few studies that focus on suppression and pain perception, using the CPT to experimentally induce pain. Given these circumstances, this work is intended to supplement the existing literature and thus contribute to a better understanding of pain. Since pain has far-reaching consequences for society and the individual, research into pain and related constructs is highly relevant.

Pain perception is a multifaceted phenomenon that is often assessed using pain tolerance scores or subjective pain ratings. Existing literature emphasizes that subjective pain

ratings and pain tolerance are different phenomena. For instance, research demonstrates only a weak correlation between tolerance temperature measured with the CPT and subjectively perceived pain severity (Lue et al., 2018). Moreover, empirical evidence from a sample of over 500 individuals found no statistically significant correlation between self-reported pain sensitivity and pain tolerance (Edwards & Fillingim, 2007). Additionally, Nayak et al. (2000) observed comparable pain intensity ratings following the CPT in both US and Indian samples, despite significant differences regarding their pain tolerance. Given these findings, this work aims to include both parameters (pain tolerance and pain intensity).

The aim of this study is to explore the relationship between suppression and pain and to analyse the temporal course of pain and its potential relationship with suppression. Based on this theoretical background and the current state of empirical studies, the following research questions (Q) and hypotheses (H) are addressed:

- Q1: Is there a connection between suppression and pain perception?
  H1a: There is a correlation between suppression and pain tolerance.
  H1b: There is a correlation between suppression and pain intensity.
- Q2: Does pain perception change over time?
  H2a: Pain tolerance changes over three time points (baseline, post and follow-up).
  H2b: Pain intensity changes over three time points (baseline, post and follow-up).
- Q3. Is there a correlation between the change in pain perception over time and suppression?
  H3a: There is a correlation between the difference in pain tolerance from time point 1 (baseline) to time point 3 (follow-up) and suppression.
- H3b: There is a correlation between the difference in pain intensity from time point 1 (baseline) to time point 3 (follow-up) and suppression.

Method

Study Design

The present work was part of the study on Music-Listening Interventions in Reducing Pain (MINTREP), which aims to assess the impact of different music conditions on pain perception and biological and subjective stress parameters. The MINTREP study is a (double-) blind, randomized, controlled laboratory trial.

At the beginning of the study, initial inclusion criteria were assessed through a telephone screening. If individuals fulfilled the initial criteria, they were provided with detailed information about the study via email, along with a link to confirm their participation and access to a comprehensive online survey to check for more detailed inclusion criteria. If individuals met all requirements, they were randomly allocated to one of the following three music listening-interventions: frequency-modulated researcher-selected, non-modulated researcher-selected and non-modulated self-selected music. An independent researcher ensured block randomization with gender stratification. Within three weeks, participants took part in ten music listening sessions and a baseline and post assessment that were administered as promptly as possible. A follow-up assessment was conducted after another four weeks. The ethics committees of the University of Marburg (2016-27k) and the University of Vienna (00331) have granted approval for this study. For further insights into the MINTREP study, additional information can be found in the paper by Feneberg et al. (2020).

Due to potential methodological overlaps with other Master's theses, it should be mentioned that several theses have already been conducted on the MINTREP study. It is particularly noteworthy that two students, Marta Pariasek and Simon Ludigs, were involved in the MINTREP study at the same time as I was and are also writing their Master's theses using the data of this project.

In the course of the MINTREP study, a variety of variables were measured, including expressive suppression, pain tolerance and pain intensity ratings. In the present work, these three variables were investigated, and the focus was on baseline, post, and follow-up appointments. The different music conditions were not of interest for my work. Therefore, all three groups were merged and analyzed together. As it is possible that the three music interventions had different effects on pain perception, statistical analysis for Q2 and Q3 were additionally carried out separately for each intervention group.

Sample

For the MINTREP study healthy volunteers between the ages of 18 and 35 with a body mass index ranging from 18.5 to 30 kg/m², who are fluent in both spoken and written German, were recruited. To avoid unwanted influences and to minimize the risk for participants, a number of exclusion criteria had been established: Individuals who were currently experiencing severe anxiety or depression disorder, individuals with a current or past history of substance abuse within the last 2 years, individuals with a current or past history of eating disorders within the last 5 years and individuals with current or past psychosis, bipolar disorder, or schizophrenia were not permitted to participate in the study. Furter exclusion criteria were premenstrual syndrome, pregnancy, breastfeeding, irregular menstrual cycle, chronic pain disorders, regular use of pain medication or psychotropic drugs, habitual or problematic alcohol intake, incapacity to abstain from smoking for longer than 2.5 hours, inability to identify as male or female, Raynaud syndrome, diabetes, severe visual impairment, artery occlusive disease, cardiovascular disease and hyper-or hypotension. With regard to the music intervention, individuals who were professionally or academically involved in the field of music, as well as those possessing perfect pitch or experiencing hearing impairments, were also excluded from participation.

Recruitment for the MINTREP study was started in Marburg in 2016 and was extended to Vienna in 2018, where it continues to this day. Participants were recruited through distributing flyers on noticeboards at the university, advertising on social media websites, posting classified ads online and announcing in academic classes (see Appendix C). Hence, the sample is considered a convenience sample. Each participant received 80 euros for their entire participation. If they quit earlier, they were paid proportionally. Participation in the study was entirely voluntary. All participants provided informed consent before taking part in the study.

The MINTREP study aims to recruit a total of 90 participants. All data sets collected up to January 15, 2024, were considered in the present work. Individuals with missing values for more than one of the variables of interest were excluded from the analysis. Consequently, one individual was excluded from the entire analysis and six others were excluded from Q2 and Q3. For one person with all values except the Emotion Regulation Questionnaire (ERQ), the suppression score was imputed using the mean value of the remaining participants. Also, for another individual with complete data except the pain intensity rating at baseline, the missing value was imputed using the mean value of the others (see Appendix D).

This yielded a sample of 31 participants for Q1. Of these, 19 individuals (61.29%) identified as female and 12 (38.71%) as male. The age at the time of study participation ranged from 19 to 33 years (M = 23.87, SD = 3.62). The majority, 25 participants (80.65%) held German citizenship, while 2 held Austrian citizenship (6.45%), and 4 (12.90%) reported having "other" citizenships. All participants (100%) were university students.

For Q2 and Q3, analysis included 25 participants, of which 15 individuals (60%) identified as female and 10 (40%) as male. Their ages ranged from 20 to 33 years (M = 24.20, SD = 3.63). Among these 21 participants (84%) held German citizenship, 1 (4%) held Austrian citizenship, and 3 (12%) had "other" citizenships. Again, all participants (100%) were university students. Regarding the three music interventions, 9 (36%) were allocated to the frequency-modulated researcher-selected, 8 (32%) to the non-modulated researcher-selected and 8 (32%) to the non-modulated self-selected intervention group.

Operationalization

Pain Tolerance: Cold Pressure Test (CPT)

To measure pain tolerance the CPT was used. The CPT was originally developed to clinically test how the cardiovascular system reacts when a hand is placed into cold water. The procedure leads to a gradual increase in cold pain and is often used in experimental studies on children and adults to induce nociceptive pain (Koenig et al., 2014). A high correlation (r = .70) of pain intensity ratings obtained after the CPT and after a contact thermode-based testing device indicate convergent validity (Ruscheweyh et al., 2010). Moreover, performing the CPT in a two-week interval shows high test-retest reliability (ICC > .75) (Koenig et al., 2014).

In the MINTREP-study, a plastic bucket was used to perform the CPT. The bucket was filled with cold water and crushed ice. A metal grid was inserted into the bucket to keep the ice at the base. Furthermore, an electric pump was included to circulate the water, ensuring a consistent temperature. Participants were instructed to place their dominant hand up to their wrist in the bucket which contained cold water at a temperature of 1 °C. A thermometer was used to control the temperature. Participants were told not to move their hand or make a fist and to keep it in the water for as long as possible. They were instructed to verbalize when they released their hand from the water so that the examiner could stop the time with a stopwatch. For safety reasons, participants had to release their hand from the water after a maximum of three minutes. This limit was set to prevent possible tissue damage.

During the test the examiner turned away and the participant faced a wall to minimize the influence of social desirability. Pain tolerance was operationalized by the number of seconds the hand could be kept in cold water. A longer duration indicates a higher pain tolerance.

Pain Intensity: Visual Analog Scale (VAS)

Immediately after the CPT, the pain intensity was assessed using the VAS. The VAS is a widely used and easy to administrate method for measuring pain (Gallagher et al., 2002). Following exposure to CPT, the VAS demonstrates high to very high correlations with other pain rating scales (Verbal Rating Scale (VRS), the Numerical Rating Scale (NRS) and the Faces Pain Scale-Revised (FPS-R); r = .79-.96) indicating convergent validity (Ferreira-Valente et al., 2011). Moreover, research by Bijur et al (2001) demonstrates that VAS ratings taken one minute apart exhibit high reliability in acute pain situations (ICC = 0.95-0.98).

In the MINTREP study, participants were asked to respond to the following sentence: "The test was painful" on a paper-and-pencil VAS. The scale ranged from 0-100 on a 10-centimeter line, with 0 representing no agreement with the statement and 100 complete agreement. Participants were instructed to indicate their subjective perception of pain intensity by making a vertical mark on the line. For evaluation the distance in millimetres from the starting point to the vertical mark was measured.

The CPT was carried out at baseline, post and follow-up assessment and at the 1st, 3rd and 6th music listening session. Pain tolerance and pain intensity were recorded for each of these sessions. However, for the purpose of my analysis, only data from baseline, post, and follow-up assessments were taken into account.

Suppression: Emotion Regulation Questionnaire (ERQ)

For question one and three, emotion suppression was measured with the subscale Suppression of the German version of the Emotion Regulation Questionnaire (ERQ) by Abler and Kessler (2009). The translation is based on the English version by Gross and John (2003 as cited in Abler & Kessler, 2009), which is based on the Process Model formulated by Gross (2002). The ERQ assesses preferences for the habitual use of the two strategies suppression and reappraisal. The questionnaire is applied, for instance, to study neural correlates associated with the use of specific emotion regulation strategies, to assess psychotherapeutic interventions, or to explore anxiety disorders (Abler & Kessler, 2009).

Regarding the reliability of the suppression subscale the German version of the ERQ shows an acceptable internal consistency (α = .76). Indications of convergent validity are provided by correlative analysis of the ERQ with the German translation of the "Ambivalence over Emotional Expressiveness Questionnaire" (AEQ; Deighton & Traue, 2006) and the Symptom-Checklist-90 (SCL-90; Franke, 2002 as cited in Abler & Kessler, 2011). The suppression subscale shows a positive correlation with the "Competence Ambivalence" subscale of the AEQ (r = .41). This subscale assesses uncertainty in expressing emotions due to self-doubt. Additionally, there is a positive correlation with the "Effect Ambivalence" subscale of the AEQ, measuring insecurity to show emotions due to fear of possible consequences (r = .38) and the "Depressiveness" subscale of the SCL-90 (r = .31) (Abler & Kessler, 2011).

The ERQ consists of 10 self-related items that focus on dealing with positive and negative emotions. The suppression subscale reflects the avoidance and inhibition of behavioral (gestural, mimic, verbal, etc.) expression of emotional experience and contains four items (e.g. “Ich halte meine Gefühle unter Kontrolle, indem ich sie nicht nach außen zeige.”). On a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree) respondents indicate how much they agree with the statements. Scores for the subscales are built, by coding the answers with values from 1 to 7 and averaging them over all items of a scale. High scale values indicate a strong manifestation of the respective strategy. Conducting the ERQ takes 5-10 minutes.

The ERQ was assessed during the online survey (prior to the laboratory appointments) as well as during the post and follow-up assessment. In this study, only ERQ data from the online survey were of interest. As participants did not know that the online survey also served to check for detailed inclusion and exclusion criteria, a possible bias in favour of fulfilling inclusion criteria was not to be expected.

Music Listening-Interventions

In order to address the possible influence of the different music conditions, separate statistical analyses were also carried out for Q2 and Q3 for each group. As described earlier, participants in the MINTREP study were randomly allocated to one of three music interventions. Each intervention involved 10 music listening sessions. During these sessions, participants were seated on lounge chairs and listened to music through headphones for 60 minutes.

In the frequency-modulated researcher-selected music intervention, participants were exposed to several selected music pieces from different genres. In this condition the music was modulated using the "Audiovisuelle Wahrnehmungsförderung" (AVWF) method. The music underwent audible frequency modulation in the range of 50-4,000 Hz. According to a pilot study, the frequency modulation was not perceptible to the participants (Feneberg et al., 2020). In the unmodulated researcher-selected music intervention, participants listened to the same sequence of music pieces as in the frequency-modulated condition. However, no frequency modulation occurred in this intervention. In the unmodulated self-selected music condition, participants listened to their preferred music, regardless of genre. Again, the music was unmodulated in this group.

The examiner, who interacted directly with the subjects, remained blinded with respect to frequency modulation. Hence, a separate independent research assistant, who was not blinded, was responsible for music settings and replay.

Procedure

Since the study is being continued in Vienna, all appointments were conducted at the "Music and Health Lab" located at Liebiggasse 5. To consider the influence of circadian rhythms on stress and pain perception, appointments were scheduled between 12 p.m. and 6 p.m. On the assessment days, participants were requested to wear comfortable clothes and not to apply any body lotion or oily substances to the chest area or take any painkillers. Moreover, 1 hour before the appointment they were not allowed to consume alcoholic or high-energy food or drinks, perform relaxation techniques, smoke, or engage in excessive exercise. Prior to the assessments, it was noted whether participants slept poorly or only briefly the previous night, whether they were experiencing a stressful phase or were currently ill.

In the present work, only ERQ data from the online survey (prior to the laboratory appointments) and pain data (pain tolerance and pain intensity) from baseline, post and follow-up appointments were considered. Therefore, a brief description is given of how baseline, post and follow-up appointments took place: At the beginning of these appointments, participants filled out several psychometric questionnaires and devices to measure heart rate variability (HRV) and electrodermal activity (EDA) were applied. Subsequently, participants engaged in a 10-minute resting phase watching a video. During this phase, EDA and HRV data were recorded in the resting state. Afterwards, the CPT was

administered. Before and after the CPT, momentary stress and pain intensity ratings were assessed. Throughout the CPT, measurements of EDA, HRV, and pain tolerance were conducted. During the baseline and follow-up appointments also hair samples for hair cortisol analyses were collected. At the end of the session HRV and EDA devices were removed, and participants were sent off. If individuals had participated in the entire study, the debriefing took place at the end of the follow-up appointment.

Data Analysis

The statistical analysis was conducted using IBM SPSS Statistics (Version 28). All analyses were performed using two-sided testing, and a significance level of $p < .05$ was considered statistically significant. If assumptions for parametric tests were not met, non-parametric methods were used. To assess suppression for Q1 and Q3, the total score of the suppression scale was calculated for all participants. To measure the pain difference for Q3, pain tolerance or pain intensity at the follow-up time point were subtracted from pain tolerance or pain intensity at the baseline time point.

For the analysis of Q1, Spearman rank correlation was conducted using the variables suppression and pain tolerance (H1a) and suppression and pain intensity (H1b). To analyze pain intensity over time, the Friedman test was used regarding H2a. For H2b a one-way repeated measure ANOVA (analysis of variance) was calculated. Pain intensity represented the dependent variable and time (baseline, post, and follow-up) the within-subject factor. A Spearman rank correlation was conducted for Q3 using the variables suppression and difference in pain tolerance (H3a) and suppression and difference in pain intensity (H3b).

For Q2 and Q3, pain data collected after the music interventions were considered. Therefore, it was theoretically possible that the three music interventions had varying effects on the perception of pain and thus influenced the results. Due to the small sample size, testing for pain differences between the groups was considered insufficiently robust. Existing differences may not have been detected due to low test power. Therefore, if a group comparison would not have found any differences, the conclusion that the groups did not differ would have been inappropriate.

To address this issue, all three groups were examined collectively as well as separately for Q2 and Q3. Analyzing the combined groups provides greater statistical power due to the larger sample size and offers insights into the results, under the assumption that the three groups did not differ. However, if differences existed among the groups, the separate

analyses provide insights into the effects for each intervention group individually (see Appendix E).

Results

For all hypotheses, descriptive results are presented and the examination of assumptions as well as the conducted inferential statistical tests are reported. The following presents only the combined results of all groups. Analyses for each music group individually can be found in Appendix E. At baseline, the sample including all groups exhibited a mean score of 3.48 for suppression. The mean pain tolerance amounted 67.21 s, and the mean pain intensity 42.32 mm (see Table 1).

Table 1

Descriptive Statistics for Q1

	M	SD	Range
Suppression	3.48	1.39	1.25-6.50
Pain tolerance in s	67.21	54.37	9.70-180
Pain intensity in mm	42.32	23.85	2-99

Note. Mean, standard deviation and range are reported for the combined group for suppression, pain tolerance and pain intensity at baseline.

To analyze Q1, assumptions of the Pearson correlation were tested. All variables (suppression, pain tolerance and pain intensity) were at the metric scale level, and the analysis of box plots showed no outliers. However, the scatterplot analysis indicated no linear relationship between suppression and pain tolerance as well as between suppression and pain intensity. Additionally, the Shapiro-Wilk test fell below the significance level of $p = .05$ for the variable pain tolerance ($p < .001$), indicating that the variable was not normally distributed. Conversely, suppression and pain intensity appeared to be normally distributed (suppression $p = .316$, pain intensity $p = .183$). Regarding H1a the assumption for linearity was not met and pain tolerance was not normally distributed. Hence, Spearman rank correlation was used. Results indicated no significant correlation between suppression and pain tolerance ($r_s = -.03$, $p = .866$). As the linearity assumption was violated for H1b, the Spearman rank correlation was calculated also for the second hypotheses. Again, no significant correlation was found between suppression and pain intensity ($r_s = -.04$, $p = .842$).

For Q2, descriptive statistics indicated a decline in pain tolerance across all three time points (see Table 2 and Figure 2). In contrast, pain intensity ratings decreased from baseline to post assessment, then rose from post to follow-up assessment, exceeding the baseline rating (see Table 2 and Figure 3).

Table 2

Descriptive Statistics for Q2

	M	SD	Range
Pain tolerance in s (baseline)	68.71	54.61	9.70-180
Pain tolerance in s (post)	54.37	40.15	10.10-180
Pain tolerance in s (follow-up)	49.91	44.76	12.48-180
Pain intensity in mm (baseline)	43.08	24.60	2-99
Pain intensity in mm (post)	40.60	24.91	0-97
Pain intensity in mm (follow-up)	45.96	24.62	0-96

Note. Mean, standard deviation and range are reported for the combined group for pain tolerance and pain intensity at baseline, post and follow-up.

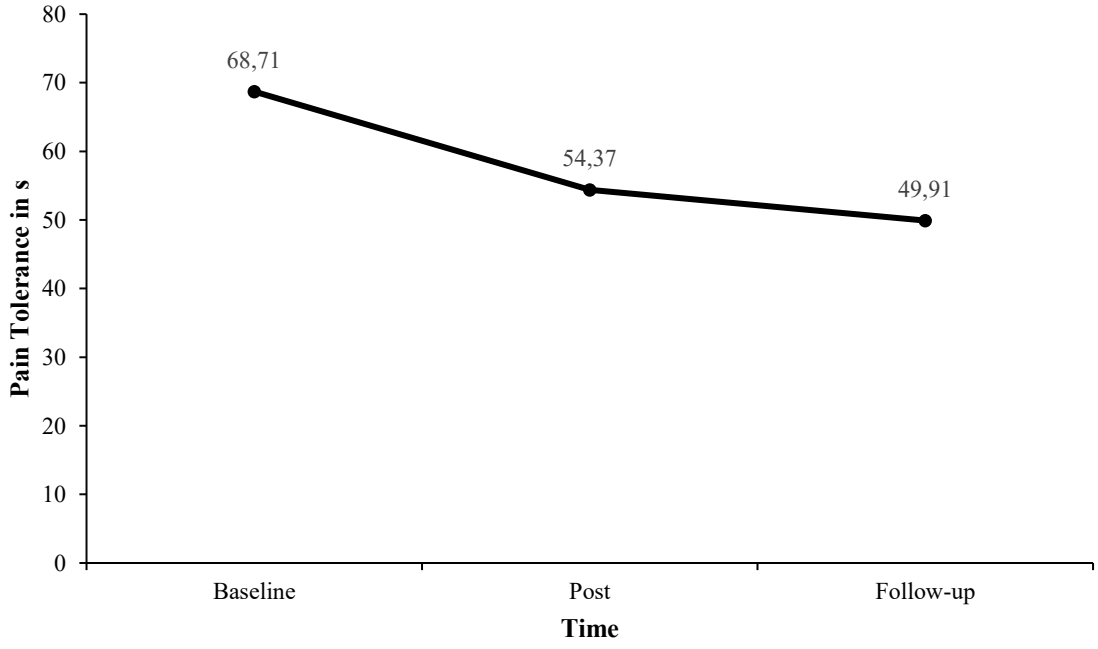

Figure 1. Pain Tolerance Over Time.

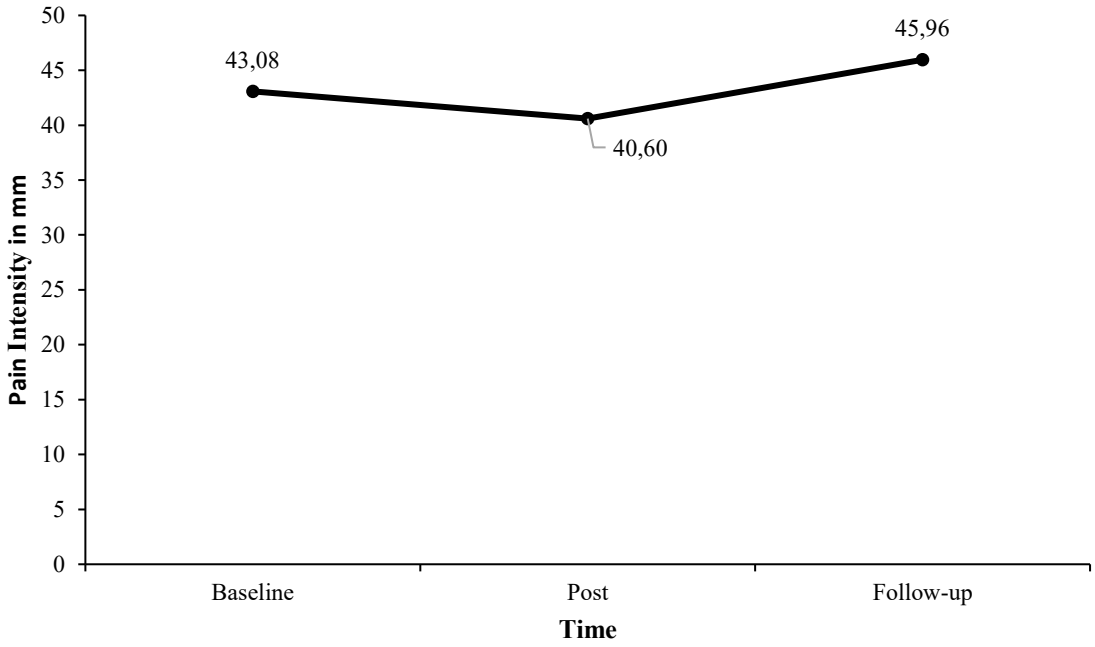

Figure 2. Pain Intensity Over Time.

For inferential statistical analysis, the assumptions for the one-way repeated measures ANOVA were tested. Due to the repeated measurements, current data met the assumption of dependent measures. The dependent variables (pain tolerance and pain intensity) were scaled metrically. Furthermore, the within-subject factor (time) constituted a nominal-scaled variable with three categories. The Shapiro-Wilk test indicated that pain tolerance deviated from normal distribution across all three time points (baseline $p < .001$, post $p < .001$, follow-up $p < .001$). However, pain intensity was normally distributed across time (baseline $p = .300$, post $p = .342$, follow-up $p = .939$). Analysis of boxplots for pain tolerance revealed one extreme (more than 3 times the interquartile range) and one mild (more than 1.5 times the interquartile range) outlier at the post assessment and two extreme and one mild outlier at the follow-up assessment. In contrast, no outliers could be identified for pain intensity. The assumption of sphericity was violated for both pain tolerance ($p = .004$) and pain intensity ($p = .049$). As assumptions of normal distribution and sphericity were not met and there were three extreme outliers in the case of pain tolerance, the Friedman test was calculated for the analysis of H2a. Results showed that there was no significant difference in pain tolerance across the three time points ($\chi^2(2) = 4.08$, $p = .130$). With regard to H2b, all assumptions were met with the exception of sphericity. Therefore, the one-way repeated measures ANOVA was calculated, and the Greenhouse-Geisser correction was used. Again, there was

no significant difference in pain intensity ratings across time ($F(1.63, 39.01) = 0.70$, $p = .475$, $\eta p2 = .03$).

Regarding Q3, the mean score of suppression amounted 3.52 at baseline. The mean difference in pain tolerance from baseline to follow-up was 18.80 s, and the mean difference in pain intensity was -4.56 mm (see Table 3).

Table 3

Descriptive Statistics for Q3

	M	SD	Range
Suppression	3.52	1.42	1.25-6.50
Difference in pain tolerance in s	18.80	41.70	-78.38-113.76
Difference in pain intensity in mm	-4.56	31.57	-92-37

Note. Mean, standard deviation and range are reported for the combined group for suppression at baseline, difference in pain tolerance from baseline to follow-up and difference in pain intensity from baseline to follow-up.

For the examination of Q3, the assumptions for Pearson correlation were examined. Suppression, difference in pain tolerance, and difference in pain intensity met the assumption of metric scale level. While according to the Shapiro-Wilk test, suppression was normally distributed ($p = .386$), this assumption was not fulfilled for difference in pain tolerance ($p = .028$) and difference in pain intensity ($p = .031$). Furthermore, the scatter plot analysis did not indicate a linear relationship between suppression and difference in pain tolerance, as well as between suppression and difference in pain intensity. When analyzing outliers using box plots, three mild outliers were found for the variable difference in pain tolerance and one mild outlier for the variable difference in pain intensity. No outliers were identified regarding suppression. Hence, for H3a and H3b, the assumption of normal distribution and linearity was not met. Due to these violations, the Spearman rank correlation was used for both hypotheses. The results indicated no significant correlation between suppression and the difference in pain tolerance from baseline to follow-up ($r_s = .08$, $p = .711$). Similarly, in the case of pain intensity, there was also no significant correlation between suppression and the difference in pain intensity from baseline to follow-up ($r_s = -.03$, $p = .872$).

Discussion

The objective of this study was to investigate whether suppression is related to pain. Additionally, the study aimed to explore the progression of pain over time and determine if it is linked to suppression.

The present results show no statistically significant correlation between suppression and pain tolerance or pain intensity. Therefore, both Hypotheses H1a and H1b are rejected (There is a correlation between suppression and pain tolerance; There is a correlation between suppression and pain intensity). As neither pain tolerance nor pain intensity changed over the course of three time points hypothesis H2a and H2b are also rejected (Pain tolerance changes over three time points (baseline, post, and follow-up); Pain intensity changes over three time points (baseline, post, and follow-up)). Moreover, there was no statistically significant correlation between suppression and the development of pain tolerance or pain intensity over time. Consequently, hypotheses H3a and H3b are rejected (There is a correlation between the difference in pain tolerance from time point 1 (baseline) to time point 3 (follow-up) and suppression; There is a correlation between the difference in pain intensity from time point 1 (baseline) to time point 3 (follow-up) and suppression).

The comparison between the analyses conducted on the entire group and those performed on individual music groups revealed similar outcomes. Although there were slight discrepancies in the descriptive statistics, none of the inferential statistical tests yielded significant results across all hypotheses (see Appendix E). Consequently, it can be inferred that all hypotheses are rejected for both the analysis of the entire group and the analysis of each individual group. However, it should be noted that potential differences in the results may not have been detected due to low statistical power.

Regarding Q1, the present study did not find any relationship between suppression and pain perception. Existing literature regarding this topic presents conflicting findings. While Masedo and Rosa Esteve (2007) as well as Quartana et al. (2007, 2010), who induced pain using the CPT, found a positive relationship between suppression and pain perception, Braams et al. (2012), who induced pain using electric stimuli, found that suppression even reduces pain. Maybe the differences in the pain induction methods accounts for the disparity of these studies. However, the present study did not find any correlation.

This could be because the present study focuses on habitual emotion regulation, whereas the others have measured momentary emotion regulation. Consequently, the present work did not investigate whether participants actually attempted to suppress emotions during the pain

situation. Maxwell et al. (2019) suggest that habitual emotion regulation is associated with momentary emotional experiences. Nevertheless, it is still questionable whether results relating to momentary emotion regulation are comparable to the outcomes of the present study. Apart from that, it is also conceivable that the sample size in our study was too small to detect any correlation.

While in the present analysis pain tolerance did not change over time, existing studies found habituation following repeated CPT exposure. These contrasting results may be due to different intervals between CPT exposures. For example, in the study by Smith et al. (2009), which found that increasingly colder temperatures are endured following repeated CPT exposure, measurements were conducted at 30-second intervals. Moreover, a study by Savitha et al. (2022) found that habituation was significantly stronger on seven consecutive days than when it only took place on day 1 and day 7 and that no habituation occurred after an interval of 14 days. In the MINTREP study, CPT measurements were always a few days apart and the interval between post and follow-up was as long as four weeks. It is possible that the intervals between the CPT measurements, especially regarding the period between post and follow-up appointment, hindered the habituation process. Similarly to pain tolerance, no change was found regarding pain intensity ratings. This aligns with the study by Savitha et al. (2022), which also found no habituation effect in pain intensity ratings. However, Smith et al. (2009) did find habituation regarding subjective pain ratings using repeated CPT exposures within one day. Hence, shorter intervals might also be crucial for the occurrence of habituation processes. Aside from the differing intervals, low test power could also be the reason why no change in pain tolerance or pain intensity over time was observed.

In light of the descriptive statistics of H2a, pain tolerance declined over time, indicating a potential sensitization process rather than habituation. Apart from sensitization it is also possible that other factors like motivation could have influenced this trend. Given that participants must sacrifice a lot of time to come to the laboratory on 13 dates, most of the time for more than an hour, it is conceivable that motivation to endure the Cold Pressor Test (CPT) was lower in the last appointments. However, it is important to note that the inferential statistical analysis did not identify any significant changes over time. Therefore, these considerations are relevant only if a decline was not detected due to the small sample size.

Regarding hypotheses H3a and H3b, there is hardly any literature available. To compare statistical results, reference is made to a study that explores the relationship between suppression, assessed with the ERQ and HPA-axis habituation (measured via salivary cortisol) after stress induction (Trier Social Stress Test (TSST)). This study also found no

connection between the two constructs (Roos et al., 2019). Existing literature indicates that salivary cortisol levels increase in response to the CPT exposure, indicating that HPA axis is also involved in pain experience (Koenig et al., 2015). However, as HPA-axis habituation was examined after stress induction (Trier Social Stress Test (TSST)) (Roos et al., 2019) and not after pain exposure the compatibility of the studies is limited. Contrary to these findings, empirical data suggest that individuals with chronic pain exhibit higher suppression levels (Esteves et al., 2013; Van Middendorp et al., 2008). This indicates an association between suppression and the development of pain over time. It is possible that a relation between suppression and the change in pain over time only exists at higher levels of suppression. Since our sample consists only of healthy individuals without pain conditions, and only a few individuals report high suppression values, it is conceivable that a possible correlation has gone unnoticed. Apart from that, it could also be the case that the sample size was simply too small to detect an existing effect.

Limitations

The present study is not without limitations. Hence, several aspects should be considered when interpreting the results. As already noted, the sample size in the present study was small, and it is possible that effects may have gone unnoticed due to low test power. Since the study design could not be changed and a given sample had to be used, no prior power analysis was conducted to determine sample size. However, to assess how large the sample should have been to detect possible effects, power analysis was conducted afterwards. To do so the program G*Power (Version 3.1.9.7) was used. For all analysis α was set at .05 and β at .20. Effect sizes were derived from existing literature.

Regarding Q1 the study by Quartana et al. (2010) found that self-reported suppression correlates with pain intensity ratings with $r = .39$. According to Cohen's benchmarks (0.1 = small, 0.3 = medium, 0.5 = large), this would suggest a medium effect size. Furthermore, Quartana et al. (2007) also found a medium effect of $\eta^2 = .11$ (0.01 = small, 0.06 = medium, 0.14 = large). In the context of their study, this indicates that 11% of the variance in pain intensity could be explained by differences between the suppression and control groups. Additionally, Braams et al. (2012) found a large effect of $d = 0.85$. Pain ratings significantly decreased in the suppression group when comparing the regulated block (instructed to suppress) with the unregulated block (not instructed to suppress). In contrast to the present work, these studies refer to momentary emotion regulation and use different study designs.

Therefore, limited comparability must be taken into account. Since effect sizes for pain tolerance had not been reported previously, a medium effect size was assumed for both hypotheses. The analysis with G*Power indicated that for H1a und H1b, a sample size of 84 individuals would have been necessary to detect a medium effect. This contrasts with the actual sample size of 31 individuals.

Regarding Q2, Bullock et al. (2023) found a significant interaction between condition (cold pressure vs. control) and trial, indicating that pain intensity decreased in the cold pressure group over time. The effect of $\eta^2 = .18$ is interpreted as large. Due to the absence of further studies reporting effect sizes, a cautious approach was chosen, and a medium effect size was assumed for both H2a and H2b. For Q2, the analysis with G*Power indicated that a sample size of 28 individuals would have been required to detect a medium effect. However, the actual sample size was 25 individuals for H2a and H2b.

As Q3 is, to the author's knowledge, the first study to investigate this question, a medium effect size was also adopted for hypotheses H3a and H3b. Similarly to Q1, the analysis with G*Power suggested a necessary sample size of 84 individuals. In contrast, the present study used a sample size of 25 individuals for H3a and H3b.

Apart from the size itself, it is also worth criticizing that the sample was a homogeneous convenience sample: It consisted exclusively of young and healthy volunteers, predominantly from Western culture, and predominantly female. Furthermore, the sample only included university students, thus exhibiting a certain level of education. The flyers used for recruiting volunteers contained the information that a pain test was carried out during study participation (see Appendix C). Therefore, it is possible that people who consider themselves as very pain sensitive and are afraid of pain exposure were more likely not to take part in the study. This notion aligns with findings from a review indicating that fear of pain often leads to avoidance of pain-related stimuli (Asmundson et al., 1999). Consequently, such tendencies would have further bolstered the homogeneity of the sample.

Moreover, existing literature shows that factors such as age, gender or culture can influence both pain perception and suppression. For instance, as individuals age, their pain tolerance tends to decrease (Gibson & Farrell, 2004), while their pain intensity appears to remain constant (Wettstein et al., 2019). Regarding suppression, the use of this regulation strategy appears to increase with age. However, suppression is only associated with higher levels of psychological distress in younger individuals. Hence, suppression might be a useful strategy in older age (Brummer et al., 2014).

Regarding gender differences, men typically demonstrate higher pain tolerance (Woodrow et al., 1972) and report lower pain intensity scores across various rating scales such as the NRS, VRS, and the FPS-R. However, this gender difference is not observed when pain intensity is assessed using the VAS (Ferreira-Valente et al., 2011). Moreover, compared to women, men more often use expressive suppression (Abler & Kessler, 2009).

Also, cultural perspectives play a significant role in the perception of pain and coping strategies. Rahim-Williams et al. (2012) underscore with their review the variability across cultures in experiencing experimentally induced pain. Furthermore, research suggests that the effects of suppression can vary depending on cultural norms. While studies discussed in this work focus primary on Western culture, studies involving individuals from Asian cultures indicate different findings. In Asian cultures, the act of suppressing emotions is often viewed favourably as it contributes to social harmony. Conversely, in European cultures, emotional expression is often valued, and suppressing emotions is perceived more negatively. This cultural distinction likely accounts for the finding that in Asian cultures suppression is not associated with negative psychological consequences (Tsai & Lu, 2018). Hence, it is important to note that conclusions drawn from our sample cannot be generalized to the broader population.

Furthermore, it should be mentioned that the present study design is not ideal for exploring the hypotheses at hand. The present study was conducted in the course of the MINTREP study, which primarily focuses on investigating the effect of three different music interventions on stress and pain parameters. Accordingly, the study design was tailored to the research questions of the MINTREP study. Since the music interventions took place between the baseline and post-assessment, they might have influenced the results of Q2 and Q3. Existing meta-analysis indicate a positive effect of music on pain perception (Kühlmann et al., 2018; Lee, 2016; Ting et al., 2022). Due to the absence of a placebo group without any music intervention, it is impossible to determine how the results of Q2 and Q3 would have been when participants did not listen to any music.

Moreover, it is plausible that the different music interventions had different effects on pain perception. Based on the literature to date, it remains uncertain whether differences between the groups should be presumed. Regarding the aspect of frequency modulation, research is still in its infancy with no randomized controlled trials conducted on the effect on pain perception. For instance, the “Hauptverband der österreichischen Sozialversicherungsträger” advises against using the AVWF method for medical treatment due to its questionable effectiveness (Maringer, 2013). Additionally, research shows mixed

findings regarding the efficacy of self-selected versus externally selected music for pain management. Some studies suggest no difference in effectiveness (Reynaud et al., 2021; Siedliecki & Good, 2006), while Mitchell & MacDonald (2006) indicate that self-selected music may lead to higher pain tolerance compared to externally selected music.

There are also some aspects to criticize regarding the operationalization. For instance, the water used for the CPT, should have maintained a temperature of 1 °C. However, in some cases, this was not fulfilled. For Q1 temperatures ranged from 0.6 °C to 4.5 °C and for Q2 and Q3 from 0.6 °C to 5 °C. According to Mitchell et al. (2004) already small changes in water temperature can significantly impact pain intensity ratings and pain tolerance. Therefore, it can be assumed that these fluctuations may have influenced the results of the present study. Regarding the measurement of pain intensity and suppression, it is important to highlight that the VAS and ERQ are based on self-evaluation and therefore easy to manipulate (intentionally as well as unintentionally). For instance, one's self-perception (e.g., "I am someone who can tolerate pain very well") could have influenced pain ratings. Furthermore, regarding the VAS, the vertical line for indicating pain intensity was drawn with the non-dominant hand. As drawing with the non-dominant hand is less accurate and more error-prone (Van Mier, 2006), this may have affected the accuracy of the VAS data.

Furthermore, when conducting parametric tests, mild outliers (less than three times the interquartile range) were included, which may have biased the results. Additionally, two missing values were imputed. These values are only estimated and may therefore deviate from the true values.

Relevance and Practical Implications

Despite these limitations, the present study also offers several advantages. Firstly, due to strict inclusion criteria, numerous variables that might have influenced the results were excluded from the beginning (e.g., pain conditions, consumption of pain medication, or drug use). As the assessments were conducted in a laboratory setting, contextual factors such as time of day, noise, and spatial environment could be kept constant. Moreover, this controlled setting ensured a certain level of safety standard. For instance, the duration of hand immersion in cold water could be precisely timed, and all participants were instructed to remove their hand from the cold water no later than three minutes.

By considering pain tolerance and pain intensity, the study captured both an objective and a subjective parameter of pain. Furthermore, it is noteworthy that the present study

considered the progression of pain over time. This emphasizes the dynamic nature of pain, which is not static but can evolve over time, even leading to chronic pain conditions (Feizerfan & Sheh, 2015). By examining the temporal dimension, it is possible to gain insights into the progression of pain development and its impact on longer-term outcomes.

In general, research in the field of pain is highly relevant, as advancing our understanding can lead to improved pain treatment. Pain not only causes significant suffering but also imposes substantial costs on society (Penny et al., 1999; Phillips, 2009). Current pain therapy options are sometimes insufficient and medication intake may come with side effects (Al Abyah et al., 2023; Gold & Gebhart, 2010). Therefore, it seems reasonable to examine the temporal development of pain and explore pain in conjunction with other relevant factors to develop additional treatment options beyond pharmacological pain management. Given the interplay between pain and emotions (Dahlke et al., 2017), it seems plausible that emotion regulation could offer a meaningful avenue in pain treatment. However, the results of the present study did not reveal a change of pain perception over time nor a connection between suppression and pain, thus no practical implications are drawn.

Even if this work does not focus on the effectiveness of the music interventions, it still aims to contribute to the MINTREP study itself. For example, by addressing the issue of sensitization and habituation, the present work highlights that, in addition to the music intervention, factors such as habituation or sensitization can also contribute to changes in pain over time. Furthermore, critical considerations regarding the study design (e.g. homogeneity of sample) and operationalization (e.g. CPT temperature) also apply to the MINTREP study itself and should therefore be taken into account when interpreting the final results of the MINTREP study.

Directions for Future Research

Given the limitations and the current gaps in the literature, there is a clear need for further research in this area. The following implications are derived from the present study: Firstly, upcoming research should test larger sample sizes to enable adequate test power. Additionally, to make statements about the wider population, it is necessary to carry out studies with people of different cultures, genders, age groups and educational levels. Specifically, investigating individuals with high suppression scores or clinical samples (e.g., individuals with chronic pain conditions) could provide further insights into the relationship between suppression and pain perception.

Furthermore, future research should use study designs specifically constructed for investigating the relationship of pain and suppression as well as the progression of pain over time. A study design without music listening sessions or other additional interventions can provide more accurate findings regarding this issue. Additionally, including motivation to endure pain as a variable could provide valuable insights into its potential influence on changes in pain perception over time. Apart from that, it is essential for future studies to focus on assessing suppression within the context of habitual emotion regulation. Previous research has predominantly concentrated on momentary emotion regulation and sometimes only considered one specific emotion. Considering the varying results from studies using different pain tests, future research could focus on the influence of different pain types. This could lead to a better understanding of whether the type of pain is a determining factor in how suppression is associated with pain. Furthermore, regarding the development of pain future studies should conduct repeated pain exposures using different intervals to provide insight into when pain habituation processes occur.

Moreover, field studies could make an important contribution to understanding pain and suppression. While laboratory studies exhibit good internal validity, they lack generalizability regarding other situations, locations, or contexts (Renner et al., 2012). For instance, a study on patients in hospital settings experiencing "real", not experimentally induced pain may provide additional insights into this topic.

Conclusion

Given the interconnectedness between pain and emotions and the dynamic nature of pain, it is crucial to explore both constructs together and to take into account the temporal progression of pain. The present study aimed to shed light on this topic. However, the results did not indicate a significant relationship between pain and suppression. Furthermore, there was no change in pain over time and suppression did not correlate with the development of pain over time. It is important to note that limitations of the present study (e.g. statistical power) constrain the interpretability of the findings. Therefore, it should not be ruled out that emotion regulation could serve as a point of intervention in pain treatment to complement pharmaceutical approaches. The present work highlights the need for further research and offers implications for future studies.

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List of Abbreviations

AEQ	Ambivalence over Emotional Expressiveness Questionnaire
aMCC	anterior midcingulate cortex
ANOVA	analysis of variance
AVWF	Audiovisuelle Wahrnehmungsförderung
CPT	Cold Pressure Test
EDA	electrodermal activity
ERQ	Emotion Regulation Questionnaire
FPS-R	Faces Pain Scale-Revised
H	hypothesis
HPA-axis	hypothalamic-pituitary-adrenal axis
HRV	heart rate variability
MINTREP	Music-Listening Interventions in Reducing Pain
NRS	Numerical Rating Scale
Q	research question
SCL-90	Symptom-Checklist-90
VAS	Visual Analog Scale
VRS	Verbal Rating Scale

Appendix

Appendix A: Abstract

This study aimed to investigate whether suppression is associated with pain perception (pain tolerance and pain intensity) and to examine the progression of pain over time and its relation to suppression. The study was conducted as part of the Music-Listening Interventions in Reducing Pain (MINTREP) study, an experimental laboratory trial. Participants engaged in ten music listening sessions over three weeks, along with a baseline, post, and a follow-up assessment after four weeks. For the present work, only assessments from baseline, post, and follow-up appointments were used. Data of 31 healthy participants were utilized to explore the association between suppression and pain perception. To examine the progression of pain over time and its relation to suppression a subset of 25 participants was selected. Suppression was measured using the subscale Suppression of the Emotion Regulation Questionnaire (ERQ). Pain tolerance was assessed using the Cold Pressure Test (CPT), and pain intensity was evaluated with a Visual Analog Scale (VAS) administered after the CPT. The results revealed no significant correlation between pain tolerance or intensity and suppression. Furthermore, neither pain tolerance nor intensity changed across time, and there was no statistically significant correlation between suppression and changes in pain tolerance or intensity over time. These findings suggest no association between suppression and pain perception, nor any changes in pain over time following repeated CPT exposure. However, the small sample size limits the interpretability of these findings, highlighting the need for further investigation in this area.

Appendix B: Zusammenfassung

Die vorliegende Studie hatte zum Ziel eine mögliche Beziehung zwischen der emotionalen Unterdrückung und der Schmerzwahrnehmung (Schmerztoleranz und Schmerzintensität) zu untersuchen. Weiters sollte der Verlauf von Schmerzen über die Zeit sowie dessen Beziehung zur Unterdrückung analysiert werden. Die Studie wurde im Rahmen des Music-Listening Interventions in Reducing Pain (MINTREP)-Projekts, einer experimentellen Laborstudie, durchgeführt. Die Versuchspersonen nahmen über drei Wochen an zehn Musik-Hörsitzungen teil, sowie einer Vor- und Nachuntersuchung und einer Folgeuntersuchung nach vier Wochen. Für die vorliegende Arbeit wurden nur Messungen des Vor-, Nach- und Folgetermins verwendet. Daten von 31 gesunden Versuchspersonen wurden genutzt, um den Zusammenhang zwischen der Unterdrückung und der Schmerzwahrnehmung zu erforschen. Zur Untersuchung des Verlaufs von Schmerzen über die Zeit und dessen Beziehung zur Unterdrückung wurde eine Untergruppe von 25 Versuchspersonen herangezogen. Die emotionale Unterdrückung wurde mit der Skala Unterdrückung des Emotion Regulation Questionnaires (ERQ) gemessen. Die Schmerztoleranz wurde mit dem Cold Pressure Test (CPT) erhoben und die Schmerzintensität mit einer Visual Analog Scale (VAS) direkt nach dem CPT. Die Ergebnisse zeigten keine signifikante Korrelation zwischen der Schmerztoleranz oder -intensität und der Unterdrückung. Darüber hinaus änderten sich weder die Schmerztoleranz noch die -intensität im Laufe der Zeit, und es gab keine Korrelation zwischen Unterdrückung und der Veränderungen der Schmerztoleranz oder -intensität über die Zeit. Diese Ergebnisse deuten darauf hin, dass es weder einen Zusammenhang zwischen Unterdrückung und Schmerzwahrnehmung gibt noch eine Veränderung des Schmerzes im Zuge wiederholter CPT-Exposition. Die geringe Stichprobengröße begrenzt jedoch die Aussagekraft der Ergebnisse und unterstreicht die Notwendigkeit weiterer Untersuchungen in diesem Bereich.

Appendix C: Flyer for Recruitment

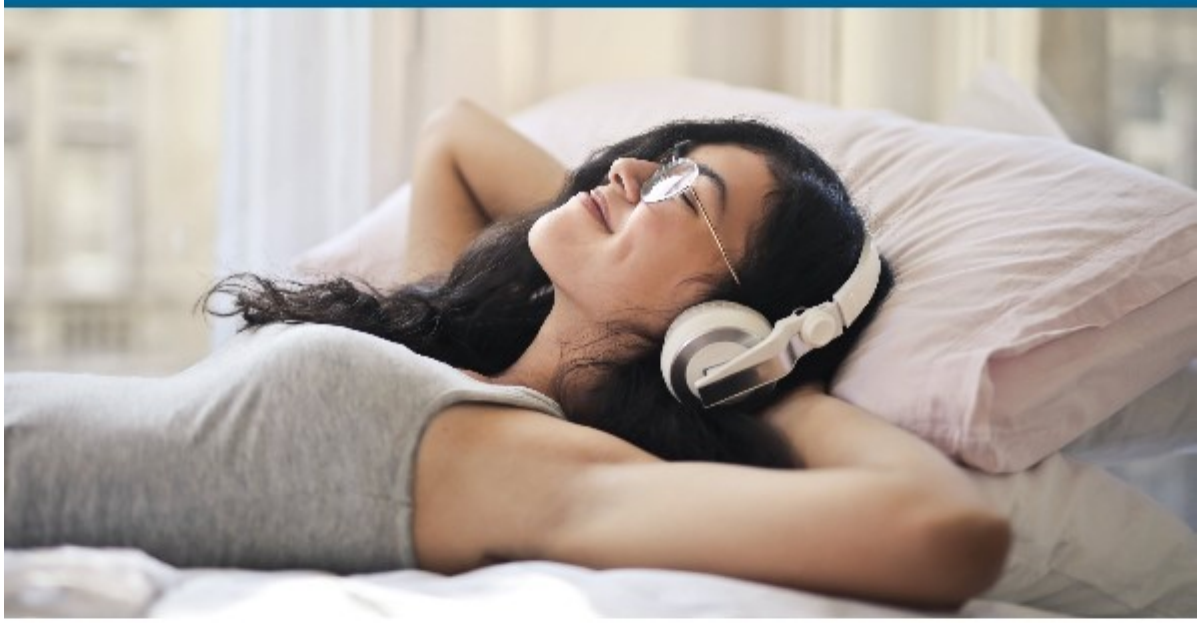
universität wien

Music and HealthLab

ProbandInnen gesucht!

Musik und Stressmanagement:

Eine musikalische Interventionsstudie



Die Studie umfasst insgesamt 13 Termine:

- 1 Vortermin & 2 Nachtermine (à ca. 60 min.)
- 10 Musikhörtermine (à ca. 75 min.) innerhalb von drei aufeinanderfolgenden Wochen
- Erhebung biologischer Maße und Ausfüllen von Fragebögen
- Zusätzlich bei einigen Terminen: Durchführung eines (völlig unbedenklichen) Schmerztests

Studienleitung: Univ.-Prof. Dr. Urs M. Nater

Studienkoordination: Agnes Steinböck
Simon Ludigs
Marta Pariasek

Teilnahmevorraussetzungen:

- Zeit, innerhalb von 3 Wochen 10 Termine wahrzunehmen
- Alter: 18 bis 35 Jahre
- Normalgewicht
- Ausreichende Deutschkenntnisse
- Psychische und körperliche Gesundheit
- Keine regelmäßige Einnahme von Schmerzmedikamenten
- Keine momentane Schwangerschaft oder Stillen

Für Ihren zeitlichen Aufwand erhalten Sie eine angemessene Entschädigung. Bei Interesse melden Sie sich bitte unter ***music10healthlab@univie.ac.at*** mit Angabe von **Name, Telefonnummer und Erreichbarkeit.**

Appendix D: Imputation

- Participant 19013: Suppression score at baseline was imputed by the mean value of the other participants (1303 / 31 = 42.03)
- Participant 19010: Pain intensity score at baseline was imputed by the mean value of the other participants (106.25 / 31 = 3.43)

Appendix E: Analysis of Q2 and Q3 for Separate Groups

In the following the results of Q2 and Q3 are presented for each group. The descriptive analysis revealed that for the non-modulated researcher-selected music group, pain tolerance decreased from baseline to post and then increased from post to follow-up (see Table E1). In contrast, in the frequency-modulated researcher-selected music group and the non-modulated self-selected music group, pain tolerance decreased across baseline, post and follow-up assessment (see Table E2 and Table E3). For the non-modulated researcher-selected music group, pain intensity increased across all three time points (see Table E1). Regarding the frequency-modulated researcher-selected music group and the non-modulated self-selected music group, pain intensity decreased from baseline to post and then increased again from post to follow-up (see Table E2 and E3).

Table E1

Descriptive Statistics for Q2: Non-Modulated Researcher-Selected Music

	M	SD	Range
Pain tolerance in s (baseline)	58.94	55.69	9.70-180
Pain tolerance in s (post)	40.32	23.80	10.10-81.43
Pain tolerance in s (follow-up)	45.10	34.88	12.48-119
Pain intensity in mm (baseline)	31.50	17.15	11-55
Pain intensity in mm (post)	35.38	26.01	15-94
Pain intensity in mm (follow-up)	42.38	27.14	9-92

Note. Mean, standard deviation and range are reported for the non-modulated researcher-selected music group for pain tolerance and pain intensity at baseline, post and follow-up.

Table E2

Descriptive Statistics for Q2: Frequency-Modulated Researcher-Selected Music

	M	SD	Range
Pain tolerance in s (baseline)	77.73	51.36	24.51-177
Pain tolerance in s (post)	65.41	40.32	24.03-126
Pain tolerance in s (follow-up)	53.34	49.39	13.90-173
Pain intensity in mm (baseline)	41.67	26.56	2-72
Pain intensity in mm (post)	39.56	22.38	0-66
Pain intensity in mm (follow-up)	42.33	22.33	0-77

Note. Mean, standard deviation and range are reported for the frequency-modulated researcher-selected music group for pain tolerance and pain intensity at baseline, post and follow-up.

Table E3

Descriptive Statistics for Q2: Non-Modulated Self-Selected Music

	M	SD	Range
Pain tolerance in s (baseline)	68.34	62.40	20.48-180
Pain tolerance in s (post)	56.00	52.12	23-180
Pain tolerance in s (follow-up)	50.86	53.11	21.42-180
Pain intensity in mm (baseline)	56.25	24.90	10-99
Pain intensity in mm (post)	47	28.28	4-97
Pain intensity in mm (follow-up)	53.63	25.93	17-96

Note. Mean, standard deviation and range are reported for the non-modulated self-selected music group for pain tolerance and pain intensity at baseline, post and follow-up.

Regarding the inferential statistical analysis for Q2, the assumptions for the one-way repeated measures ANOVA were tested for each group separately. The assumption of the metric scale level of the dependent variables (pain tolerance and pain intensity) and the nominal scale level of the within subject factor (time) was considered fulfilled for all groups. In the case of the non-modulated researcher-selected music group, the Shapiro-Wilk test indicated a deviation from normal distribution for pain tolerance at baseline ($p = .040$). At post and follow-up assessments normal distribution was observed (post $p = .830$, follow-up p

= .078). For pain intensity, normal distribution was given at baseline and follow-up assessment (baseline p = .169, follow-up p = .623), but not at post assessment (p = .006). Analysis of boxplots revealed one mild outlier at both baseline and the follow-up assessment for pain tolerance, and one mild outlier at post assessment for pain intensity. The assumption of sphericity was violated only for pain tolerance (p = .030) but not for pain intensity (p = .555). As assumptions of normal distribution and sphericity were not met, the Friedman test was calculated for the analysis of H2a. Results showed that there was no significant difference in pain tolerance across the three time points ($\chi2(2) = 0.75$, p = .687). Similarly, for H2b, normal distribution was not observed for all time points. Thus, the Friedman test was applied again, revealing no significant difference in pain intensity ratings across time ($\chi2(2) = 1.75$, p = .417).

In the frequency-modulated researcher-selected intervention group, the Shapiro-Wilk test indicated a deviation from normal distribution for pain tolerance at the follow-up assessment (p = .004). However, normal distribution was given for the other two time points (baseline p = .227, post p = .109). Contrary, normal distribution was observed for pain intensity at all time points (baseline p = .220, post p = .611, follow-up p = .894). Boxplot analysis revealed one mild outlier at the follow-up assessment for both pain tolerance and pain intensity. Sphericity was confirmed for both variables (pain tolerance p = .084, pain intensity p = .078). Due to the deviation from normal distribution, the Friedman test was used for H2a, revealing no significant difference in pain tolerance across time ($\chi2(2) = 6.00$, p = .050). The assumptions for hypothesis H2b were sufficiently fulfilled, therefore the one-way repeated measures ANOVA was calculated. Again, there was no significant difference in pain intensity ratings across time ($F(2, 16) = 0.05$, p = .948, η_p^2 = .01).

For the non-modulated self-selected music group, pain tolerance did not exhibit normal distribution across the three time points according to the Shapiro-Wilk test (baseline p = .006, post $p < .001$, follow-up $p < .001$). Conversely, normal distribution was observed for pain intensity across all time points (baseline p = .505, post p = .977, follow-up p = .681). Boxplot analysis identified one extreme outlier at both post and follow-up assessments for pain tolerance, and two mild outliers at baseline for pain intensity. Sphericity was not met for either variable (pain tolerance $p < .001$, pain intensity p = .035). Given these violations, the Friedman test was conducted for H2a, which revealed no significant difference in pain tolerance across time ($\chi2(2) = 2.00$, p = .368). For H2b, all assumptions were met except for sphericity. Therefore, the one-way repeated measures ANOVA was applied, using the

Greenhouse-Geisser correction, indicating no significant difference in pain intensity ratings across time ($F(1.20, 8.37) = 0.76$, $p = .432$, $\eta p2 = .10$).

In relation to Q3, the non-modulated researcher-selected group exhibited a mean suppression score of 3.63, a mean pain tolerance score of 13.84, and mean pain intensity score of -16.13 (see Table E4). The frequency-modulated researcher-selected music group displayed a mean suppression score of 3.61, a mean pain tolerance score of 24.40, and a mean pain intensity score -0.67 (see Table E5). In the non-modulated self-selected music group, the mean suppression score was 3.30, the mean pain tolerance score 17.48, and the mean pain intensity score 2.63 (see Table E6).

Table E4

Descriptive Statistics for Q3: Non-Modulated Researcher-Selected Music

	M	SD	Range
Suppression	3.63	1.52	2-5.50
Difference in pain tolerance in s	13.84	28.86	-20.87-61
Difference in pain intensity in mm	-16.13	32.48	-92-11

Note. Mean, standard deviation and range are reported for the non-modulated researcher-selected music group for suppression at baseline, difference in pain tolerance from baseline to follow-up and difference in pain intensity from baseline to follow-up.

Table E5

Descriptive Statistics for Q3: Frequency-Modulated Researcher-Selected Music

	M	SD	Range
Suppression	3.61	1.29	2.25-6
Difference in pain tolerance in s	24.40	54.63	-78.38-107.27
Difference in pain intensity in mm	-0.67	34.54	-52-37

Note. Mean, standard deviation and range are reported for the frequency-modulated researcher-selected music group for suppression at baseline, difference in pain tolerance from baseline to follow-up and difference in pain intensity from baseline to follow-up.

Table E6

Descriptive Statistics for Q3: Non-Modulated Self-Selected Music

	M	SD	Range
Suppression	3.30	1.63	1.25-6.50
Difference in pain tolerance in s	17.48	40.61	-18.06-113.76
Difference in pain intensity in mm	2.63	27.70	-58-36

Note. Mean, standard deviation and range are reported for the non-modulated self-selected music group for suppression at baseline, difference in pain tolerance from baseline to follow-up and difference in pain intensity from baseline to follow-up.

For Q2, the assumptions for the Pearson correlation were assessed individually for each group. For all groups, suppression, difference in pain tolerance, and difference in pain intensity met the assumption of metric scale level. In the non-modulated researcher-selected music group, according to the Shapiro-Wilk test, suppression as well as difference in pain tolerance were normally distributed (suppression $p = .052$, difference in pain tolerance $p = .623$). However, this assumption was not met for the difference in pain intensity ($p = .006$). Furthermore, the scatter plot analysis did not indicate a linear relationship between suppression and difference in pain tolerance, as well as between suppression and difference in pain intensity. When analyzing outliers using box plots, one extreme outlier for the variable difference in pain intensity was detected. Suppression and pain tolerance had no outliers. As for H3a the assumption of linearity was not met the Spearman rank correlation was calculated. The results indicated no significant correlation between suppression and the difference in pain tolerance from baseline to follow-up ($r_s = .01$, $p = .978$). Regarding H3b, the assumption of normal distribution and linearity was not met, and pain intensity had one extreme outlier. Therefore, the Spearman rank correlation was also conducted for H3b. In the case of pain intensity, there was also no significant correlation between suppression and the difference in pain intensity from baseline to follow-up ($r_s = -.13$, $p = .756$).

The Shapiro-Wilk test revealed that all variables in the frequency-modulated researcher-selected music group displayed a normal distribution (suppression $p = .327$, difference in pain tolerance $p = .481$, difference in pain intensity $p = .074$). However, the scatter plot analysis did not demonstrate a linear relationship between suppression and the difference in pain tolerance, nor between suppression and the difference in pain intensity. Examining outliers using box plots identified one mild outlier for the variable difference in

pain tolerance, while suppression and pain intensity showed no outliers. Since the assumption of linearity was not met for both cases, Spearman rank correlation was employed for both H3a and H3b. The findings revealed no significant correlation between suppression and the difference in pain tolerance from baseline to follow-up (r_s = -.49, p = .185) as well as between suppression and the difference in pain intensity from baseline to follow-up (r_s = -.12, p = .763).

In the non-modulated self-selected music group, the Shapiro-Wilk test indicated that suppression and the difference in pain intensity followed a normal distribution (suppression p = .329, difference in pain intensity p = .064). However, this assumption was not met for the difference in pain tolerance (p = .002). Additionally, the scatter plot analysis did not show a linear relationship between suppression and the difference in pain tolerance, nor between suppression and the difference in pain intensity. Upon examining outliers using box plots, one extreme outlier was identified for the variable difference in pain tolerance and one for difference in pain intensity, while one mild outlier was observed for the variable suppression. Given that the assumptions of normal distribution and linearity were not met for H3a, and since pain tolerance exhibited an extreme outlier, Spearman rank correlation was employed. The results showed no significant correlation between suppression and the difference in pain tolerance from baseline to follow-up (r_s = .47, p = .243). For H3b, the assumption of linearity was not met, and pain intensity had one extreme outlier. Consequently, Spearman rank correlation was used again. In the case of pain intensity, there was also no significant correlation between suppression and the difference in pain intensity from baseline to follow-up (r_s = .02, p = .955).