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Music and Pain – the Influence of Music-Selection on Music-Induced Analgesia

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**Table of Contents**

## Introduction

The pain definition, which is most commonly used in the relevant literature, is taken from the International Association for the Study of Pain (IASP): „Pain is an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage." (Kumar & Elavarasi, 2016, p. 87). This definition overlooks many subjective aspects of experiencing pain and thus doesn't consider phenomenological aspects of pain (Cohen et al., 2018). Pain can stem from various causes (injuries, stress, chronic illnesses, etc.) and if the painful experience is not treated accordingly it can lead to negative outcomes regarding an individual's quality of life (Choi et al., 2018; Kumar & Elavarasi, 2016). Existing research on the one hand concerns mechanisms and causes of pain, while possibilities for treatment and intervention are discussed on the other. Psychological research focuses on non-pharmaceutical approaches to treatment, out of which music-listening interventions seem like a promising approach. Music is a safe and effective method, which can be administered at a low cost and individually fitted to one person's needs (Bicego et al., 2021; Lu et al., 2021). Empirical results show that listening to music improves pain management and can also reduce the intensity of pain; this phenomenon has been labelled as *music-induced analgesia (MIA)* in the literature (Garza-Villarreal et al., 2017). Some studies point toward the lack of controlled studies with strict designs and non-clinical populations in order to identify and understand how and why music can improve pain management, since existing studies offer varying explanations and mechanisms behind the found effects (Lu et al., 2021). Previous studies have postulated mechanisms such as distraction (Finlay & Anil, 2016; Garza Villarreal et al., 2012), emotional valence/ emotional associations (Roy et al., 2008; Warmbrodt et al., 2022) and choice over music (Howlin & Rooney, 2021; Johnson & Elkins, 2020), while other results question the analgesic effects of music (Bally et al., 2003; Matsota et al., 2013). The following thesis aimed to answer the question of whether self-chosen music leads to superior analgesic outcomes compared to researcher-chosen music, thus investigating the mechanism of choice over music within an RCT. A specific theoretical focus was put on chronic pain and music as an adjunct to pain management for (chronic) pain conditions.

## Pain

Pain, as defined in the introduction, is the definition commonly used by health care professionals and researchers in those fields (psychology, medicine, etc.). Pain is always a subjective experience, associated with actual or potential tissue damage and the individual application of the term is shaped through "experiences related to injury in early life" (Raja et al., 2020, p. 13). While it is a physical sensation a lot of the times, the unpleasantness of the feeling carries an emotional component. Furthermore, people also report pain in the absence of tissue damage or obvious pathophysiological causes, usually due to psychological reasons. The individual, subjectively reported experience of pain in those instances does not differ from painful experiences stemming from physiological issues (Raja et al., 2020). Psychological pain is defined as "a lasting, unsustainable, and unpleasant feeling resulting from negative appraisal of an inability or deficiency of the self" (Meerwijk & Weiss, 2011, p. 410). While psychological and emotional pain and its consequences for health care systems are a relevant consideration, the following thesis will focus on physiological pain first and foremost, in line with the methodological aspects of the study (see *Methods*) and reasons of feasibility.

The IASP definition of pain has been criticized for not considering certain aspects of pain, for example cognitive and social aspects involved in painful experiences, while also putting a lot of focus on the verbal self-report of individuals, thus neglecting populations with language impairments, neonates or the elderly (Anand et al., 1999; Williams & Craig, 2016; Wright & Aydede, 2017). Raja et al. (2020) describe how these and other oversights in the original IASP definition needed more attention and how the IASP went about updating the definition over the course of two years (2018-2020). The task force set up with the task of updating the definition pursued three main goals: (1) the definition should apply to all pain conditions (chronic and acute), (2) it should be applicable not only to humans, but also non-human animals and (3) it should include the perspective of the one experiencing the pain, not an external observer. Through a two-year iterative process involving the original task force, professionals from other fields (such as linguists or philosophers) and a big survey provided to pain populations, the following definition was officially introduced in 2020: Pain is "an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage." (Raja et al., 2020, p. 14). While the definition itself is rather similar, the additional notes now include more potentially relevant factors (biological, psychological, and social), a mention of potentially negative outcomes (i.e., psychological well-being), expressions of pain that are not verbal, and it explicitly states that ones' experience of pain, no matter the cause, should be respected. The last point is especially relevant when considering recent findings regarding the invalidation of pain. Boring et al. (2023) carried out two studies and found similar effects, stating that the invalidation of pain by either health care professionals or family member leads to a significant underreporting of pain experiences when seeking care and treatment. Interestingly, this effect was not found when friends invalidated pain (Boring et al., 2023), once more emphasizing not only physical aspects, but also social and environmental factors.

The following sections will first differentiate pain regarding acuteness and chronicity, to then discuss outcomes for global health systems and then provide an overview of pain management and analgesia. Chronic pain is discussed very detailed here, since the experimental pain induction (CPT; see Operationalization) is said to mimic chronic pain conditions effectively (Mitchell et al., 2004).

**Acute versus Chronic Pain**

Pain is commonly classified as either acute or chronic. Acute pain refers to a painful condition frequently including a rather quick onset and which is usually of short duration, while chronic pain similarily implies a painful condition yet the duration is longer, “persisting beyond the normal time of healing“ (Feizerfan & Sheh, 2015, p. 1). Chronic pain was also one of the points of criticism towards the original IASP definition, in which pain is classified as a symptom first and foremost. Yet, pain has been argued to be more than just a symptom, specifically in chronic pain conditions, which can be defined as a disease with specific clinical courses, research and intervention needs (Raja et al., 2020). Acute and chronic pain can exist on their own, yet some people experience both simultaneously (e.g. sickle cell disease; Connolly & Hardy, 2023).

Acute pain can be caused by tissue injury (for example through heat, cold or chemicals) leading the pain receptors (nociceptors) to be stimulated and homeostasis to be interrupted. Homeostasis, once out of balance, can be restored through complex interactions of endocrine, immune, autonomic and nervous systems (Feizerfan & Sheh, 2015). The authors state that biochemical changes occurring after acute tissue damage can usually be reverted to the original state of homeostasis in ones’ body, once the tissue healing is completed (which also implies the end of the pain process). Acute pain can also stem from non-tissue-damaging causes, for example in discrete migraines or menstrual cramps (Connolly & Hardy, 2023).

One of the physiological aspects involved in acute pain is the activation of inflammatory processes. If homeostasis cannot be reverted to the original state, chronic inflammatory processes can lead to a reduction in pain threshold (Feizerfan & Sheh, 2015). This change in pain adaptation processes during the (potential) transition from acute to chronic pain conditions can occur through repeated exposure to painful stimuli. This kind of repeated exposure can have one of two outcomes, habituation on one hand and sensitization on the other (Jepma et al., 2014). Habituation leads to a decreased experience of pain while sensitization describes the heightened reactions to painful stimuli. Jepma et al. (2014) attest this to site-specific versus site-non-specific stimulation, wherein stimuli applied to the same body part lead to habituation, while stimuli applied to varying parts of the body tend to lead to sensitization. While habituation leads to decreased brain activity in the areas involved in pain perception and lower subjective ratings of pain, sensitization leads to heightened activity in the brain and higher subjective ratings (Paul et al., 2021). Both of these processes seem to be involved in the transition from acute to chronic pain, with habituation as the preventative, adaptive process leading to better health outcomes. Sensitization on the other hand tends to lead to chronic pain conditions (Feizerfan & Sheh, 2015).

Chronic pain in general is hard to define or explain, considering the lack of anatomic defects or tissue damage (van Wilgen & Keizer, 2012), but any pain that lasts three months or longer is categorized as chronic pain (Nahin et al., 2023). Chronic pain usually manifests as acute pain and then progresses to chronic pain (Dey & Vrooman, 2023). Common chronic pain conditions are fibromyalgia, chronic lower back pain, arthritis, chronic migraines, etc (Connolly & Hardy, 2023; van Wilgen & Keizer, 2012). Chronic pain management, compared to acute management (which usually aims at decreasing in-the-moment pain perception), usually involves a heavy focus on reducing its impact on daily activities and the individuals' quality of life (Connolly & Hardy, 2023). While pharmaceutical approaches alleviate acute pain well, patients with chronic pain conditions often experience an inefficacy of pain killers, especially if they have taken high quantities over a prolonged period of time (Matsota et al., 2013; Petersen et al., 2021). This is especially relevant for high impact chronic pain, which is associated with substantial restrictions in daily life (Nahin et al., 2023).

**Outcomes for the Global Health Systems**

Pain, irrespective of the etiology or manifestations, can have detrimental influences on the global health systems. Psychological pain, for example, has been identified as one of the most frequently mentioned reasons for suicide (Meerwijk & Weiss, 2011).

Chronic pain affects many people and comes with huge financial burdens on health care systems; in Europe, the annual costs of chronic pain conditions are estimated to be in the billions (Breivik et al., 2013; Gustavsson et al., 2012; Raftery et al., 2012). Since chronic pain management comes with such high costs for the health care systems, a big concern in the field of pain management and prevention is the pipeline from acute to chronic pain (Feizerfan & Sheh, 2015; Voscopoulos & Lema, 2010). Whether or not acute will lead to chronic pain conditions is hard to estimate for practitioners – commonly named determining factors are the size and depth of the injury causing the acute pain (e.g. a cut or burn), whether or not noxious stimuli are experienced repeatedly (e.g. exposure to toxins at the workplace) and what kind of social, cognitive and economic resources the patient at hand has (Feizerfan & Sheh, 2015).

Nahin et al. (2023) studied a sample of N > 10.000 people regarding their subjective pain levels over the course of one year in the United States. Even though the US healthcare system run vastly different to the European ones, their results depict the relevance for finding pain remedies and the burden pain has on the health systems quite well. At the baseline assessment, about 20% of participants reported chronic pain, while about 40% reported non-chronic pain. Of those with non-chronic pain, about 15% progressed to chronic pain, yet of those with chronic pain, about 10% fully recovered. While recovery is possible, incidence rates remain higher than recovery rates, pointing towards the rising number of (chronic) pain patients. This is a relevant issue, considering the authors (2023) found higher prevalence rates in adults over the age of 50. This effect of age on pain reports was also found in a Swedish sample with higher prevalence rates for adults over the age of 85 (Larsson et al., 2017), as well as a Danish sample, in which younger age was a significant predictor for pain recovery (Eriksen et al., 2004). Considering the world populations' median age is expected to keep rising in the future (especially in high-income countries like the US and most European countries, etc.), the prevalence of chronic pain might increase with the demographic shifts (Ritchie & Roser, 2019). This would in theory produce a large population of pain patients needing increased health care. Lastly, Nahin et al. (2023) point to the fact that incidence rates for chronic pain surpass those for other chronic diseases (i.e., diabetes, depression and hypertension), emphasizing the high disease burden of chronic pain and the need for prevention and early intervention.

## Analgesia

The alleviation of pain, physical or psychological, is one of the responsibilities of health care professionals. Although effective treatments for some conditions are available, a lot of chronic pain patients fail to achieve adequate reduction in experienced pain (Whitten, 2005). Chronic pain treatment plans usually revolve around multimodal management strategies, which include medications, exercises, physical therapy, pain psychology, lifestyle modifications and more (Dey & Vrooman, 2023). Pharmaceutical approaches usually involve either opioid analgesics or cyclooxygenase (COX)-2 (coxibs) analgesics, both of which have proven effective in relieving pain and increasing the patients' quality of life (Dey & Vrooman, 2023; Katz, 2002). Yet, there is reporting of a high prevalence of insufficiently managed chronic pain (Longo et al., 2021), partly due to pain killers being insufficient in reducing experienced pain (Matsota et al., 2013). Furthermore, the use of opioids specifically carries the risks of overdose and addiction, while long-term efficacy of opioid therapy in chronic pain has not been researched thoroughly (Dey & Vrooman, 2023). For these reasons, alternative treatment approaches like physical therapy, behavioral therapy or music interventions have recently been studied more. In the following paragraphs some of these non-opioid/non-coxib approaches will be discussed, in no specific order. Due to reasons of feasibility not all available approaches will be discussed (e.g., Transcutaneous Electric Nerve Stimulation; for an overview of non-opioid treatments see: Dey & Vrooman, 2023). Here it is necessary to make note of the current state-of-the-art treatment, which is usually a multimodal treatment plan that is iteratively adapted to patients' experiences with their conditions; generally, pharmaceuticals are administered in combination with one or more of the following approaches (Hylands-White et al., 2017; Whitten, 2005).

### *Alternative Treatment Approaches*

**Antidepressants.** Apart from coxibs and opioids, other medications can be used in treating chronic pain conditions (e.g. anticonvulsants, corticosteroids, etc.). One common group is that of antidepressants; specifically SNRIs (serotonin and norepinephrine reuptake inhibitors) and tricyclic antidepressants are used in pain management. They are advantageous not only in treating pain, but also effectively manage co-occurring mood and sleep issues, therefore improving the patients' quality of life (Dey & Vrooman, 2023).

**Exercise, Physical Activity and Physical Therapy.** A lot of patients with chronic lower back pain (CLBP) are referred to some type of physical therapy, yet there is little consensus on which are the most effective and cost-efficient strategies (Godfrey et al., 2020). Generally, physical activity can reduce the severity of pain, improve function, quality of life and mental health (Dey & Vrooman, 2023; Hylands-White et al., 2017). These approaches are generally seen as having few adverse side effects and therefore seem to be a safe option in treating chronic pain (Geneen et al., 2017).

**Cognitive Behavioral Therapy (CBT).** Chronic pain can be accompanied by negative thinking and negative behavioral patterns relating to painful stimuli (i.e., catastrophizing, maladaptive thinking; Dey & Vrooman, 2023). These maladaptive thoughts and behaviors are targeted and through cognitive restructuring are replaced by adaptive thoughts and behaviors (Hylands-White et al., 2017). CBT has been proven to be an effective intervention for CLBP (Godfrey et al., 2020). The strategies and methods applied in CBT usually don't decrease the pain per se, but rather reduce another plethora of symptoms, which in turn leads to better mental health outcomes, higher quality of life and better pain management (Hylands-White et al., 2017).

**Acceptance and Commitment Therapy (ACT).** ACT approaches usually focus on the improvement of functioning by using acceptance and mindfulness strategies (Godfrey et al., 2020). Here, in contrast to CBT (though ACT is a form of CBT), the thoughts and behaviors themselves are not the targets, but rather how an individual responds to these (Hylands-White et al., 2017). Mindfulness techniques focus on paying attention to the present moment, without attaching meaning or judgement to upcoming thoughts. A review of the existing literature concerning ACT came to the conclusion, that ACT is efficacious in enhancing physical functioning and decreasing distress (Hann & McCracken, 2014).

**Cannabinoids.** The use of cannabinoids in treating chronic pain is becoming a growing area of interest, yet its efficacy has not been well established. Longo et al. (2021) reviewed existing literature and concluded that patient-perceived benefits do exist with moderate analgesic effects, while other treatment effects show inconsistent findings. One of the benefits of cannabinoids are the few severe side effects, which is why the authors see potential for this kind of treatment, if researched and studied further.

**Music-interventions.** Music-based interventions have been around since the Antiquity (Bernatzky et al., 2011), with empirical interest for its effects starting in the middle of the 20$^{th}$ century (Gardner et al., 1960). More recent studies have tried to disentangle the mechanisms that could be at work while listening to music. The following chapter will discuss music-induced analgesia in detail, as well as the existing literature concerning effects on pain outcomes.

## Music-Induced Analgesia (MIA)

Historically, people have been using music in traditional treatments dating back to ancient Romans and Greeks. They employed musicians to play in spas in order to facilitate healing and alleviate emotional distress (Bernatzky et al., 2011). One of the first empirical accounts of music-induced analgesia can be found in the works of Gardner et al. (1960). They recruited and observed 5.000 patients scheduled to undergo dental surgery. After being exposed to a procedure involving music and sounds, they found that 90% of the patients had experienced pain-reducing effects after the auditive intervention. Research has since broadened, with some studies focusing on varying characteristics of music (frequency, valence, familiarity, preference, etc.; Basiński et al., 2018; Choi et al., 2018; Finlay & Anil, 2016) and others focusing more on the timing and application of the music interventions (MIA in preoperative/ perioperative/ postoperative phases, MIA in chronic pain populations, etc.; Lu et al., 2021; Matsota et al., 2013).

Studies have found that music can reduce the amount of pain experienced, as well as increase an individuals' pain tolerance, compared to control groups without music-interventions (Finlay & Anil, 2016; Garza Villarreal et al., 2012). Music has been found to reduce acute, as well as chronic pain (Garza Villarreal et al., 2012). If music is administered during diagnostic tests (e.g. colonoscopy), it can alleviate pain and reduce the amount of pain killers needed (Matsota et al., 2013). Following surgeries (post-operative phase), music can decrease the stress and anxiety experienced by patients (self-reports; Igawa-Silva et al., 2007; Matsota et al., 2013). Overall, the most recent meta-analyses and literature reviews point toward a medium effect size of music reducing pain (e.g. Lu et al., 2021). Music-based interventions are a promising approach in the area of pain management, since they are easy to administer, cost-effective (most people already have access to their favorite music and own listening devices), individually adaptable to peoples' preferences and/ or specific disorders and are also presumably safe to administer to all subpopulations (no side effects have been found; Bicego et al., 2021; Lu et al., 2021). Specifically for subpopulations struggling with chronic pain this seems promising, since on one hand the inefficacy of pharmaceutical interventions has been known as a burden on individuals as well as the health care systems (Matsota et al., 2013) and the administration can be done by the patients themselves and on-the-go (adaptable to daily life, work schedules, etc.).

**Potential mechanisms**

Due to its relatively long empirical research interest, MIA has been widely researched and authors have postulated a plethora of mechanisms behind music-induced analgesia. For reasons of feasibility and clarity/ traceability, these possible mechanisms will be discussed along three categories: distraction, emotional associations/ familiarity, and choice/ preference. Researchers make mention of the interplay of mechanisms at work (Cassidy & Macdonald, 2010; Finlay et al., 2016; Finlay & Anil, 2016; Ho & Loo, 2023; Tan et al., 2012; Warmbrodt et al., 2022), so more studies differentiating these effects are needed.

***Distraction***

Many studies investigating MIA, specifically the earlier ones, postulate distraction as a cognitive mechanism behind analgesic effects. For example, Garza-Villarreal et al. (2012) found that a distracting task (mental arithmetic; unrelated to music) leads to a significant reduction in pain. If an individual is distracted (irrespective of whether music is involved or not), their perception of time changes (time feels like it's passing quicker) and their pain tolerance is increased, meaning they can endure pain longer (Finlay & Anil, 2016). Effective distraction also influences the distribution and redistribution of attentional resources, hence decreasing the perception of pain, if an individuals' attentional resources are focused on something else (Finlay et al., 2016). Under this notion, any study postulating music-induced analgesic effects could be subsumed under the mechanism of distraction. Some studies focus not only on music but also sounds and other auditive stimuli and still find similar effects to conditions using musical stimuli (*audio-analgesia*), giving reasonable evidence supporting the notion that distraction can lead to analgesia, through many different kinds of auditory stimuli (Finlay et al., 2016; Garza Villarreal et al., 2012; Lu et al., 2021). Investigations have also been carried out in regards to more invasive procedures and chemotherapies, with authors describing effective distraction from the procedural aspects (Igawa-Silva et al., 2007; Matsota et al., 2013).

Even though distraction can account for most of the effects found in early studies concerning music-induced analgesia, some results question this notion. If study participants, for example, listen to sad music, their perceived control over the painful experience diminishes and results are similar to conditions without music (Finlay & Anil, 2016). One has to consider that most of the studies only compared the effects of a music-condition to those of a non-music condition, leading to distraction as the most generally usable explanation for the analgesic effects (Roy et al., 2008). Mitchell et al. (2006) compared the effects of preferred music (chosen by participants) to two types of distracting conditions (mental arithmetic task and humorous auditory condition), which had been found effective within previous studies. They found that music leads to significantly longer pain tolerance results than either of the distracting conditions, leading to the assumption that, while distraction can be effective in pain reduction, other mechanisms are presumably also at play, when it comes to music-induced analgesia.

***Emotional Associations/ Familiarity***

Pain is a highly subjective and complex experience influenced by genetic, environmental, cognitive and emotional factors (Lu et al., 2021), which can cause intense emotional experiences for the individual (Lundqvist et al., 2009). Music on the other hand can regulate and influence emotional states, which makes apparent the reasoning behind focusing on music for analgesic purposes (Warmbrodt et al., 2022). In trying to find music for analgesic purposes, one has to keep in mind the individual preferences and autobiographical and emotional associations with music that can lead to varying outcomes in different people (Finlay & Anil, 2016).

Taking this into consideration lead to some authors focusing on the valence of the music or on the emotions the music evokes in participants. One factor of music-induced analgesia is attributed to the fact that music can evoke strong positive emotions (Roy et al., 2008). If participants listen to happy music their pain tolerance is increased compared to conditions with sad music – yet the highest pain tolerance comes from listening to relaxing music. In conditions with relaxing music, participants experience the pain as less intense while simultaneously describing lower levels of stress and anxiety (Finlay & Anil, 2016). Authors do point towards a potential bias regarding relaxing music; individuals usually associate relaxing pieces of music with massages or other relaxation techniques, thus potentially confounding the effects of MIA.

Generally, pleasant emotions have the potential to decrease pain, while unpleasant emotions can even lead to an increase in pain (not-significant, yet shown; Roy et al., 2008). This also elaborates further on why distraction cannot be the only explanation for music-induced analgesia – unpleasant music and unpleasant emotions should theoretically also work as a distraction, yet pain has been found to be slightly increased after exposure to unpleasant stimuli, disproving distraction as sole or main explanation for the found effects. Roy et al. (2008) found the greatest effect (i.e., highest reduction in pain) with those individuals, who experienced the biggest increase in valence, so considering musical valence and the emotions elicited by the music seems to offer a valid explanation for music-induced analgesia.

Familiarity seems to work in tandem with emotional aspects of MIA. If a person is familiar with a music piece, they tend to have emotional associations with said piece, confounding the analgesic effect (Garza Villarreal et al., 2012).

***Choice/ Preference***

Apart from emotional factors and associations, the effect of having the choice over music is often discussed as a cognitive explanation for music-induced analgesia. Effects of music-interventions on pain tolerance and intensity are usually found to be stronger, when people choose the music used for their own intervention (*self-selected music*), rather than the research teams choosing (*other-selected/ researcher-selected music*; Basiński et al., 2018). Self-selected music is generally found to be the strongest predictor for the effects of music-interventions, with authors attesting this to perceived control over the music (Howlin & Rooney, 2021; Johnson & Elkins, 2020). Irrespective of the mechanisms at play, one should always consider that musical preferences of a person usually depend not only on individual preferences, but also on the cultural, social and generational background; this makes it hard for research teams to find music pieces that would work universally for people from different backgrounds (Matsota et al., 2013).

Individual music preference concerns the likeability of listening to specific music and the choice of listening to said music over others, with empirical data showing positive effects of music preference on pain tolerance (Ho & Loo, 2023). Since listening to preferred music usually involves the choice over music and having the choice over music usually leads to people listening to their preferred music, the results concerning choice and preference are hard to differentiate. Perceived control has been shown to be higher in preferred music conditions compared to other distracting conditions (humorous condition, mental arithmetic; Mitchel et al., 2006). Howlin & Rooney (2021) investigated the cognitive role of perceived control over music choice, while statistically controlling for participants' enjoyment. They came to the conclusion that increased perceived choice leads to an increase in pain tolerance, irrespective of enjoyment/ preference. Yet, an increase in enjoyment was also related to increased pain tolerance and decreased pain intensity. Warmbrodt et al. (2022) found that selection alone did not lead to significant effects (similar results for self-selected and researcher-selected music), which they attested to the participants' enjoyment of the researcher-selected music pieces. Results seem to suggest a strong interplay between preference for and choice over music in regards to pain management outcomes.

As mentioned above, relaxing music leads to better results than sad and even happy music. When instructing participants to choose their own relaxing music, the effects are even stronger, the better participants know the pieces and this heightened familiarity has been found to lead to lower levels of stress and anxiety (Finlay & Anil, 2016; Tan et al., 2012). Familiarity has, in newer studies, been regarded as a negligible mechanism, since familiarity effects seem to be overlapping with emotional valence and music preference (Ho & Loo, 2023). It has also previously been mentioned that music can make the passing of time feel a lot faster while distracted by it and this is exacerbated if participants also choose their own music beforehand (Cassidy & Macdonald, 2010). Self-selected music tends to produce stronger perceived emotions, higher average joy and engagement ratings and comes with higher preference for the individual music pieces than other-selected music (Warmbrodt et al., 2022). Considering the amplification of effects when researchers examine mechanisms like distraction, valence and choice in tandem (i.e., self-selected, relaxing music shows better effects than other-selected, happy music), it becomes apparent that for using music-interventions, research needs to examine these and other mechanisms further to figure out the exact interplay of the effects.

**High Variability of MIA**

Previously mentioned studies found analgesic effects of music on pain outcomes, yet some studies, particularly some of the clinical ones, were unable to show similar results. This suggests a high variability in the effects of music interventions, which could potentially be explained by the above-mentioned mechanisms (i.e., music valence, involved emotions, preference of the music, etc.; Garza-Villareal et al., 2012).

In one study, patients undergoing sigmoidoscopy were investigated with the intervention group listening to their preferred music, while the control group received care as usual (Meeuse et al., 2010). Authors found no effects of the music-listening condition on pain outcomes, thus questioning results from similar previous investigations (e.g. Matsota et al., 2013). Su & Yeh (2021) found that music interventions for coronary procedures are not superior in improving pain compared to regular care, making mention of the high variability of studies and results (no music-induced analgesic effects in some studies, e.g.: Bally et al., 2003).

Most studies make mention of further factors that could influence and confound the analgesic effects of music. Roy et al. (2008) for example mention expectations that participants have due to study instructions or their own associations. If participants expect the music to lead to a reduction in pain, experimentally induced pain can usually be endured a bit longer. Garza-Villareal et al. (2012) also mention *cognitive style* as a potential individual variable, contributing to the high variability of analgesic effects. Cognitive styles, such as being systematic and focusing on analytic structures can influence how people perceive situations and where their attention focuses on a stimulus. This, in turn, will influence how and which music-interventions show effects. Others discuss the presence or absence of lyrics, music tempo or frequency (Feneberg et al., 2020; Ho & Loo, 2023).

In summary, while analgesic effects of music interventions have been found, some studies question the effects. The body of literature concerning MIA shows a high variability in effects, some of which may be attributable to study designs, type of music and individual characteristics. It is unclear how and which mechanisms lead to the postulated analgesic effects, which is why RCTs in subclinical populations are necessary (Lu et al., 2021).

## Aims and Research Question

The study surrounding this thesis (MINTREP study; Feneberg et al., 2020) aims at investigating the effects of frequency-modulated and unmodulated music, both of which are researcher-selected. With the inclusion of the third study arm of self-selected music and equal study procedures across all three study arms, a direct comparison of the effects on measures of pain is possible. Through further measures of biomarkers regarding pain and stress-related biological and subjective markers, possible mechanisms involved in music-induced analgesia will be investigated and ideally differentiated. Few empirical works have considered frequency-modulation as a potential mechanism, therefore the MINTREP project, once concluded, will close one of the few existing literature gaps in MIA.

This thesis itself first and foremost aimed at replicating existing studies. Due to the high variability of effects, some authors have pointed to the need for controlled studies with strict designs and non-clinical populations (Lu et al., 2021), which the study design at hand provides. In comparing the conditions of self-chosen versus researcher-chosen music, this thesis aimed to verify whether previously found effects can be replicated in a smaller, German-speaking sample. Previous studies have often used single intervention designs (e.g.: Garza Villarreal et al., 2012; Johnson & Elkins, 2020; Meeuse et al., 2010), lacking information regarding the stability of MIA. The underlying longitudinal design allows for testing of the stability of effects. Due to the small sample size (see Participants), an analysis of frequency-modulation or involved indirect effects seemed unfeasible a priori, leading to the following research question:

RQ: Does self-chosen music lead to better pain management than researcher-chosen music?

H1: Listening to self-chosen music increases pain tolerance more than listening to researcher-chosen music.

H2: Listening to self-chosen music decreases pain intensity more than listening to researcher-chosen music.

# Methods

The following sections provide an overview over the methodological aspects, for the thesis at hand and also for the broader research project it is a part of. For reasons of feasibility, only the measurements relevant to the thesis and research question at hand will be discussed in detail, while measurements relevant to the broader project will solely be mentioned.

## Study Design

The MINTREP study (*Music-INTerventions in REducing Pain*; Feneberg et al., 2020) systematically tests and compares the effects of frequency-modulation and choice over music regarding pain and stress outcomes. Recruitment and testing started in December 2016 in Marburg, Germany. The lab then moved to Vienna, Austria in January 2018, causing a nine-month long break. Then, in October of 2018, recruitment and testing continued. As of February 2024, the project is still running and data collection has not been finished.

Three students, including the author of this thesis, were working on the same project and are all currently writing and handing in their Master's theses. The students involved apart from the author of this study (Marta Pariasek) are Agnes Steinböck and Simon Ludigs. This is mentioned here to avoid plagiarism issues, as there will presumably be some methodological overlaps. While all three students worked independently, there may be some similarities in the theses.

In this study, participants first attended a baseline assessment, followed by 10 music-listening sessions carried out during three consecutive weeks (M1-M10). Afterwards, participants attended one post and one follow-up assessment. In total, participants underwent seven cold pressor trials (baseline, M1, M3, M6, M10, post, follow-up). The MINREP study is a laboratory-based, randomized controlled trial with three parallel arms: unmodulated self-selected music, unmodulated researcher-selected music and frequency-modulated researcher-selected music. A total of N = 90 participants was aimed at (N = 30 in each of the conditions); the sample size was determined based on the main research questions of the MINTREP study. Participants were randomly assigned to one of the three conditions after the screening process and before they attended the baseline assessment. The randomization procedure was performed by an independent researcher unrelated to the study, by using a "block randomization stratified by gender using the blockrand package and the statistical software R, version 3.4.2" (Feneberg et al., 2020, p. 8). This resulted in 90 computer-generated notes stating gender and experimental condition, which were sealed in separate envelopes and stored in a locked cabinet. Once a participant was included, a member of the research team (not the experimenter) drew an envelope and provided it to the person in charge of the music-delivery systems.

**Procedure**

All 13 sessions (baseline assessment, M1-M10, post-intervention assessment, follow-up assessment) were held in a laboratory located within the faculty of psychology (University of Vienna, Austria). According to previous research, stress and pain parameters fluctuate due to circadian rhythms (Deng et al., 2022; Hagenauer et al., 2017), therefore all the appointments with participants were scheduled exclusively during 12 and 6 p.m. (12:00-18:00). The intervention period (music-listening sessions M1-M10) was conducted within three consecutive weeks; the baseline and post assessments were scheduled as close in time as possible (right before and after the intervention period, respectively). The follow-up was held four weeks after the post assessment. If a participant completed all 13 sessions, they were compensated with 80€. In case of early termination (Drop-Out), they were compensated proportionally.

Once prospective participants finished the telephone-based screening and upon their inclusion into the study, the appointment for the baseline session was set and they received an email with their individual code (DDMMYY_XX001). They also received a link for the online screening and baseline questionnaires. They were asked to enter their individual code to start the screening. First, they were provided with an informed consent. Over a period of 30 - 40 minutes, participants then provided information about demographic variables and then filled out the following questionnaires: Patient Heath Questionnaire – German (PHQ-D; Gräfe et al., 2004), Beck's Depression Inventory (BDI-II; Hautzinger et al., 2006), questions regarding the menstrual cycle and premenstrual syndrome (self-report, only female participants), Screening-Scale of Chronic Stress (SSCS; P. Schulz et al., 2004), Multidimensional Fatigue Inventory (MFI-20; Smets et al., 1995), Berlin Social Support Scales (BSSS; U. Schulz & Schwarzer, 2003), Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989), Perceived Stress Reactivity Scales (PSRS_CD; Schlotz et al., 2011), Music Preference Questionnaire (MPQ; Nater et al., 2005), Music-Empathizing-Music-Systemizing Inventory (ME/MS; Linnemann et al., 2018), Emotion Regulation Questionnaire (ERQ; Abler & Kessler, 2009), Brief Music in Mood Regulation Scale (B-MMR; Saarikallio, 2012) and finally the Big Five Inventory (BFI-10; Rammstedt & John, 2007).

The aforementioned email also contained instructions to comply with before each the study appointments, to ensure no interferences with behavioral and physiological measures. The instructions were as follows:

- No intake of analgesic medication on days of study appointments.
- No use of body lotion or other fatty agents in the chest area (before the appointment) to minimize artifacts in ECG recordings on days of study appointments.
- No consumption of alcoholic and/or energizing beverages or food, no smoking, no excessive exercise or relaxation techniques (i.e., meditation, yoga) for at least 1 hour prior to study appointments.
- Wearing of comfortable clothing during appointments.

At the beginning of each of the appointments, participants were asked whether they had participated in any of the behaviors mentioned in the instructions (drinking alcohol or energizing beverages, smoking, etc.). The examiner also documented whether or not participants were currently in a stressful phase (i.e., exams), had poorer sleep quality/ duration or had any current illnesses. Female participants are asked to give a self-report on their current menstrual cycle phase.

Participants allocated to the self-selected music condition also received an additional email attachment asking them to prepare a portable device containing 120 minutes of their favorite music pieces. This music compilation was to be brought to the baseline session and handed to the examiner. At the baseline assessment, participants also signed the informed consent provided during the screening process. Once the baseline assessment was done, examiner and participant scheduled the music-listening sessions (M1-M10) for the subsequent three weeks. The post assessment was scheduled during M10, and the follow-up was scheduled at the post assessment. Table 1 shows the protocols and timelines for all of the 13 sessions.

**Table 1**

*Protocol and Timelines of Individual Sessions*

| Protocol and timeline at Baseline, Post and Follow-Up Assessments | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equip with HRV-, EDA-devices | → | VAS 1 | → | Resting (10-minute video) | → | VAS 2 | → | CPT (max. 3 min.) | → | VAS 3 | → | Hair cortisol[a] | → | Take off HRV-, EDA-devices |

| Protocol and timeline at M1, M3, M6 and M10 |
|---|
| Equip with HRV-, EDA- devices → VAS 1 → Music-listening (60 min.) → VAS 2, music-related questions → VAS 3 → CPT (max. 3 min.) → VAS 4 → Take off HRV-, EDA- devices |
| **Protocol and timeline at M2, M4, M5, M7 and M9** |
| Equip with HRV-, EDA- devices → VAS 1 → Music-listening (60 min.) → VAS 2, music-related questions → Take off HRV-, EDA- devices |

*Note.* HRV = Heart Rate Variability. EDA = Electrodermal Activity. VAS = Visual Analogue Scale (pain and stress). CPT = Cold Pressor Test. Own work.

[a] Hair for the analysis of cortisol levels was collected at baseline and follow-up only.

### *Music-Listening Interventions*

Each of the three study arms (unmodulated self-selected music, unmodulated researcher-selected music and frequency-modulated researcher-selected music) consisted of ten music-listening sessions (M1-M10) within three consecutive weeks. There was no prescribed minimum number of sessions to be held per week, to ensure the sessions could be fitted to the participants' schedules. Each music-listening session encompassed 60 minutes of music listening and an additional 10-20 minutes for further data assessments before and after listening to the music (see Table 1). Sessions were held individually, with the participant lying in a reclined position on a lounge chair.

**Unmodulated self-selected music.** Participants in this condition received an email before their baseline appointment, instructing them to compile 120 minutes of their favorite music (irrespective of genre or musical characteristics, like tempo). Participants were informed that their selection would not be judged in any way and they should choose music they would enjoy listening to for 60 minutes. The music was then to be brought to the baseline appointment on a portable device (i.e., a USB stick), where a member of the research team could transfer the files onto the study server and the music-delivering system without modulating features. During each of the music-listening sessions (M1-M10) the music was played in shuffle mode, to ensure a variation across and within sessions. The order of the current playlist was documented by a member of the research team via screenshots and then saved in separate folders for each of the participants.

**Frequency-modulated researcher-selected music.** The researcher-selected music consisted of six different mixes from varying genres (classical, pop, instrumental, rock, and world music; see Table 2), each lasting about 60 minutes. Three of those mixes have been composed and recorded by the developer of the AVWF method. The music was modulated within the audible frequency range (50–4000 Hz) via a software and then transferred to a music delivery system. This system allowed for successive increasing of the modulation (for further information, see Feneberg et al., 2020). According to the developer, the modulations of frequency are not detectable by people with average hearing abilities. The specific modulations used here were in line with research postulating that said modulations lead to improved stress regulation and benefit the autonomic nervous system (Borg & Counter, 1989).

**Unmodulated researcher-selected music.** This condition consisted of the same music pieces as the frequency-modulated researcher-selected condition (see Table 2). The pieces were presented via the music-delivery system without any modulations features.

**Table 2**

*Overview of the Music used in each Music-listening Session in the Researcher-selected Music Conditions*

| Music-listening Session | Title of Album(s) | Artist(s) |
|---|---|---|
| 1 | Well – balanced | Oliver Shanti |
| 2 | AVWF – Classics I | AVWF® |
| 3 | QE2; Earth Moving | Mike Oldfield |
| 4 | Violine Volume I | AVWF® |
| 5 | The Beatles; The Beatles | Munich Symphonic Sound Orchestra; Classic Dream Orchestra |
| 6 | See session 1 | |
| 7 | See session 4 | |
| 8 | See session 5 | |
| 9 | See session 3 | |

| | | |
|---|---|---|
| 10 | Guitar I | AVWF® |

*Note.* Participants listened to a mix of music pieces of the specified album and artist for 60 minutes in each session. Frequency modulation increased with session number in the frequency-modulated researcher-selected music-listening condition. From: Feneberg et al. (2020).

**Ethical Considerations**

The MINTREP study has been approved by the relevant Ethics Committee of the University of Vienna (Nr.: 00331). Participants signed an Informed Consent and were informed about the procedure and aims of the study. They were made aware of the possibility to withdraw from the study at any point in time without the need to offer an explanation. After withdrawal or completion, participants were debriefed. The CPT pain induction was aimed at experimentally inducing pain, yet participants could take their hand out of the water at any time and the maximum time of immersion was three minutes to avoid potential tissue injuries.

**Study Population**

The MINTREP study aimed at investigating N = 90 participants, N = 30 (15 men, 15 women) in each condition (unmodulated self-selected music, unmodulated researcher-selected music and frequency-modulated researcher-selected music), in order to achieve a medium effect ($f = 0.25$, $\alpha = 0.05$, power $(1-\beta) = 0.80$) for the main research questions. Before participants could start the screening process, some eligibility criteria had to be met; participants had to be between the ages of 18 and 35, have a body mass index (BMI) between 18.5 and 30 kg/$m^2$, be able to fluently speak and read German and have the availability to come to the laboratory for 10 appointments in three consecutive weeks.

The following exclusion criteria were applied to ensure the accurate delivery of the music-listening interventions: participants who had perfect pitch, were pursuing music-related studies (i.e., university level education) and professions or have impairments of hearing capabilities (e.g. hearing loss, acute or chronic tinnitus) were excluded.

As some of the outcome measures in this study were susceptible to lifestyle and health factors (Barutcu et al., 2005; Zale et al., 2015), and in order to minimize any potential risks to participation in the study the following additional exclusion criteria were applied based on participants' self-reports:

- Cardiovascular disease

- Artery occlusive disease
- Hyper-/ Hypotension
- Diabetes
- Extreme visual impairment
- Chronic pain condition
- Raynaud syndrome
- Irregular menstrual cycle
- Pregnancy or breastfeeding
- Inability to refrain from smoking for more than 2.5h
- Regular and problematic alcohol consumption
- Regular intake of pain medication and/ or psychotropic drugs
- Mental disorders: current major depression/ anxiety disorder; current eating disorder or eating disorder within the past 5 years; current substance abuse or substance abuse within the past 2 years; current or previous psychosis, schizophrenia, or bipolar disorder
- Premenstrual syndrome
- Inability to self-identify as a man or woman.

Recruitment was conducted by advertising for the study on social media sites, public notice boards and via announcements in university classes. The study flyer (see Appendix B) included an email address, which interested potential participants were asked to send their phone number to, in order to proceed with the telephone screening.

**Participants**

As of February 2024, data from N = 32 participants existed. Not all participants finished the study up to and including the follow-up and these N = 7 Drop-Outs were excluded from analyses. The final sample therefore comprised data from N = 25 participants, ranging from 20 to 33 years ($\bar{x} = 24.2$, $SD = 3.628$). 60% of participants were female (N = 15), and 40% were male (N = 10). Of the final sample, N = 12 (48%) participants were tested in Marburg, Germany and N = 13 (52%) participants were recruited and tested in Vienna, Austria. All participants had at least finished Highschool or equivalent educations and were students at the time of their investigations. Table 3 shows age and gender dispersions for the whole sample, as well as the three groups.

**Table 3**

*Descriptive Statistics concerning Gender and Age*

| | Total sample | | Self-selected unmodulated music | | Researcher-selected unmodulated music | | Researcher-selected modulated music | |
|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % |
| Participants | 25 | 100% | 8 | 100% | 8 | 100% | 9 | 100% |
| Male | 10 | 40% | 3 | 37.5% | 3 | 37.5% | 4 | 44.44% |
| Female | 15 | 60% | 5 | 62.5% | 5 | 62.5% | 5 | 55.56% |
| | Min-Max, $\bar{x}$, SD | | Min-Max, $\bar{x}$, SD | | Min-Max, $\bar{x}$, SD | | Min-Max, $\bar{x}$, SD | |
| Age | 20 – 33, $\bar{x}$ = 24.2, SD = 3.628 | | 20 – 33, $\bar{x}$ = 23.375, SD = 4.533 | | 22 – 31, $\bar{x}$ = 25.25, SD = 3.412 | | 20 – 28, $\bar{x}$ = 24, SD = 3.082 | |

*Note.* $\bar{x}$ = Mean value. SD = Standard Deviation. Own work.

## Operationalization and Equipment

The following subsections provide information about the equipment and operationalization of the main outcome variables (pain tolerance, pain intensity). Further, measures and variables included in the MINTREP study will be mentioned for reasons of reproducibility (for further information see Feneberg et al., 2020).

### *Music-Delivery Systems*

The music was provided to participants via over-ear headphones (beyerdynamic, Heilbronn, Germany). Two different (commercially not available) music delivery systems were used – one playing the frequency-modulated music and the other playing music without alterations (for further information see Olbrich & Näher, 2017). Both systems consisted of a computer with a touch display and an amplifier built into a wooden box. On the PC, music was played via Windows media player software.

### *Pain Tolerance: Cold Pressor Test*

The Cold Pressor Test (CPT) is a simple and validated test, widely used in research as a safe and reliable method to experimentally induce pain and physiological stress (Basiński et al., 2018; Lamotte et al., 2021). Mitchell et al. (2004) compared studies using CPT pain induction and suggest that it mimics chronic pain conditions effectively due to its unpleasantness. The CPT apparatus is a plastic bucket filled with ice and water into which participants put either hands or feet (depending on the study design). Inside, there is a metal grid and an electrical pump allowing constant circulation of the water to keep it at a certain temperature. Once the aimed at temperature was reached (here, 1°C), the participants immersed their dominant hand into the cold water (up to their wrist, without making a fist) and kept it there for as long as possible. In this study, the participants looked at a wall while the examiner turned away, to avoid potential biases regarding social desirability. The maximum immersion time was three minutes, after which they were instructed to take out their hand, in order to prevent tissue damage. Participants were timed (time of immersion in seconds = pain tolerance) and only after filling out the VAS, participants were handed a towel to dry their hands. In order to avoid anticipation effects, participants only found out after the music-listening, whether or not the session at hand involved a CPT trial.

***Pain Intensity: Visual Analogue Scales (VAS)***

Pain intensity was operationalized through a subjective paper-pencil format, a visual analogue scale. Participants were instructed to draw a mark on a 100mm line, according to how intense their subjective pain was at the time of filling out the VAS. The ends were marked with 0 and 100 respectively, a mark at zero indicating participants felt no pain whatsoever, while 100 would mean they were in maximum pain. The relevant item on the VAS was “I am in pain” (“Ich habe Schmerzen”). The distance (in mm) from the left end of the line (0 mm) to where the mark was set, indicated the pain intensity participants experienced. Participants filled out the VAS before and after listening to music (VAS 1 & 2), as well as before and after the CPT was administered (VAS 3 & 4). VAS 4 had an additional item concerning the CPT, which stated “The test was painful” (“Der Test war schmerzhaft”). Here, participants rated not the pain they were feeling at the time of setting the mark, but rather the pain they felt during administration of the CPT.

***Further Outcome Measures***

*Heart Rate Variability* (HRV) was documented through an electrocardiogram (ECG), using Equivital EQ02 Life Monitors and Equivital Life Shirts (Hidalgo Limited, Cambridge, UK). *Electrodermal Activity* (EDA) was recorded through the same equipment as HRV with corresponding EQ-ACC-034 EDA sensors. EDA was measured on the index and middle finger of the non-dominant hand, using pregelled Biopac EL507 electrodes (Biopac Systems Inc., Goleta, CA, USA). At the baseline and follow-up assessments, hair samples were taken from participants, in order to analyze the levels of *hair cortisol*. The analysis will be conducted in a specialized laboratory once data from N = 90 participants has been collected. *Subjective stress* was also measured through setting a mark on a VAS (subjective pain and subjective stress were provided to participants on the same piece of paper). *Chronic stress* was measured by the SSCS and stress reactivity by the PSRS_CD, both of which were filled out by participants at baseline, post and follow-up assessments. These measures function as secondary outcomes in the MINTREP project.

**Statistical Analyses**

Statistical Analyses were run with IBM SPSS Statistics for Windows (IBM Corp., 2021). Analyses were run with the available data, as of February 2024 comprising N = 25 participants in total. An alpha-level of $\alpha = .05$ was chosen for all analyses.

In the current sample, some data was missing. Most of the missing data was due to either Drop-Outs or the examiners not having participants fill out all the relevant questionnaires, leading to the assumption that the missing data was Missing at Random (MAR). Since the VAS- and CPT- data points were, apart from a few Drop-Outs (which were excluded before running statistical analyses), relatively complete, no data was imputed.

To answer the first hypothesis, a mixed ANOVA was chosen in order to account for within-subject differences, as well as between-subject differences. The independent variable was to be the condition participants were in (group), while the dependent variable was to be pain tolerance (i.e., CPT time of immersion in seconds).

As for the second hypothesis, a mixed ANOVA was chosen for the same reason. For this, the new variable "VAS_Diff" was calculated (difference between the VAS given before and the VAS given after the CPT; VAS 3 and VAS 4, respectively), which was then to be used as a dependent variable operationalizing the pain intensity.

## Results

The following subchapters concern the results of the statistical analyses. First, results regarding H1 will be presented, then results for H2. Additionally, some exploratory analyses were run, which are described at the end of the chapter. Previous to running analyses, N = 7 participants were excluded from the data files due to them being Drop-Outs. No data was imputed.

**Hypothesis 1**

For testing hypothesis 1, the prerequisites for one-way ANOVAs with repeated measures were tested. Kolmogorov-Smirnov tests could not show normal distribution in the current sample. Since Mauchly's Test of Sphericity was also significant ($p < .001$), the variances of differences were assumed not to be equal. Repeated measures ANOVAs are particularly susceptible to this type of violation, potentially leading to too liberal an estimate of significance (increase in Type-1 error rate). Therefore, the data regarding H1 was analyzed through non-parametrical tests. Since one outlier was found, but no data was to be excluded, the choice of working with tests using rank order was made, so as for the outlier not to bias the results. A Kruskal-Wallis-Test was run, in order to compare the three groups regarding their pain tolerance. Pain tolerance ratings did not significantly differ between the three groups at any of the timepoints. Table 4 shows means and standard deviations of each time point across all three groups, to emphasize the high variation irrespective of group. Chi-squared values, degrees of freedom and asymptotic significance values show results for the group comparisons. Average pain tolerances per group across all time points were $\bar{x} = 42.481$ seconds (SD = 27.257) in the researcher-selected unmodulated condition, $\bar{x} = 58.350$ seconds (SD = 38.136) in the researcher-selected frequency-modulated condition, and $\bar{x} = 52.893$ seconds (SD = 43.787) in the self-selected unmodulated condition. Average pain tolerance (in seconds) per group for each of the individual timepoints are provided in Figure 1.

**Table 4**

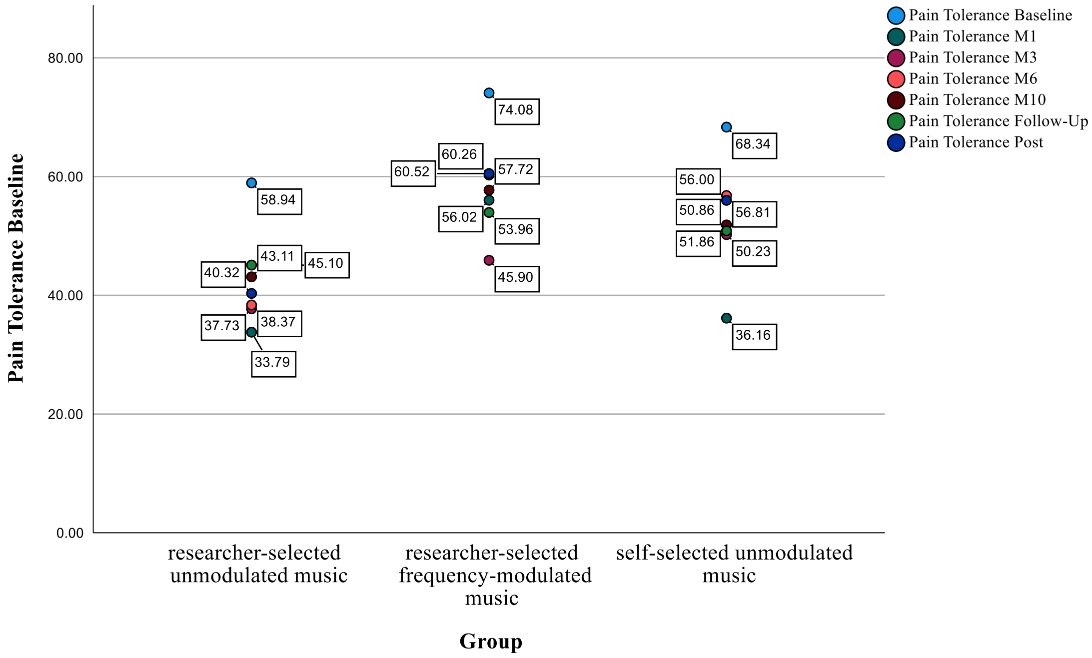
*Descriptives and Kruskal-Wallis-Test regarding Pain Tolerance (H1)*

| | Baseline | M1 | M3 | M6 | M10 | Post | Follow-up |
|---|---|---|---|---|---|---|---|
| Mean ($\bar{x}$) | 68.711 | 44.110 | 45.792 | 52.115 | 50.894 | 54.371 | 49.907 |
| SD | 54.605 | 30.063 | 40.340 | 40.275 | 39.022 | 40.147 | 44.755 |
| Chi-sq. ($\chi^2$) | 1.153 | 1.593 | 0.091 | 1.343 | 0.755 | 1.508 | 0.109 |
| df | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| p | .562 | .451 | .956 | .511 | .686 | .470 | .947 |

*Note.* SD = Standard Deviation. df = degrees of freedom. Mean provided in seconds. P-values are asymptotic significance values. Own work.

**Figure 1**

*Average Pain Tolerance (in sec) per Group*




*Note.* Average pain tolerance provided in seconds. Own work.

**Hypothesis 2**

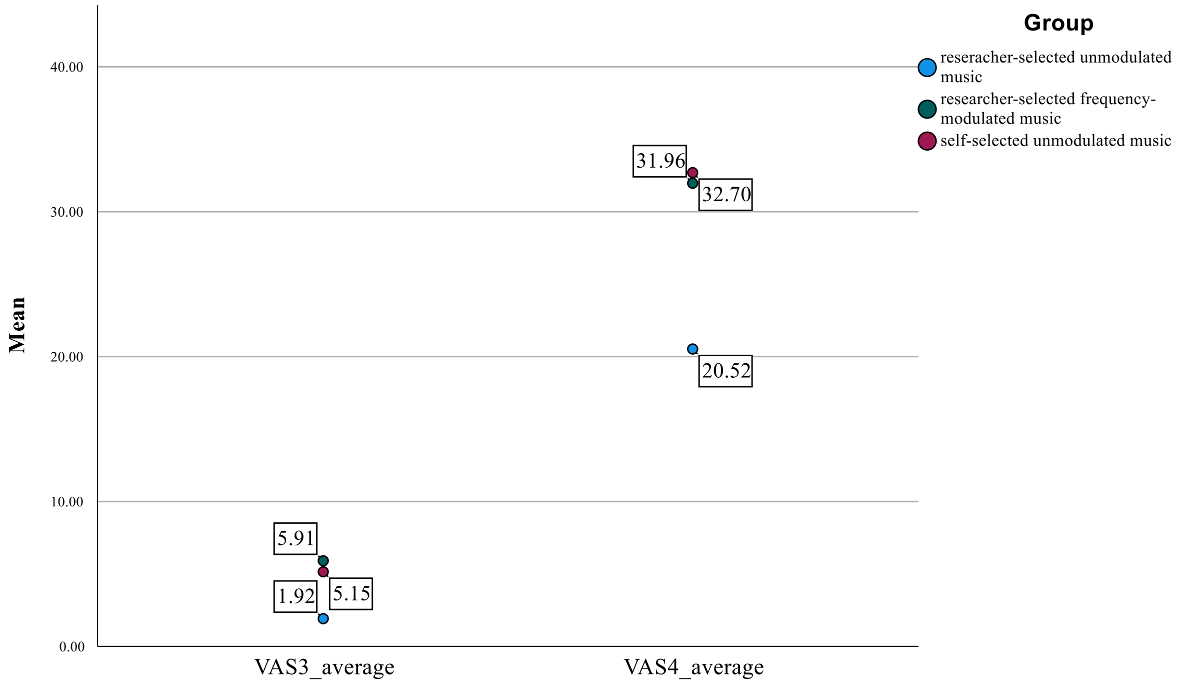
For Hypothesis 2, first the prerequisites were tested, once again leading to significant results, meaning some of the prerequisites could not be met in the available sample. Thus, non-parametrical tests were used to answer H2. First, in order to compare the VAS 3 values (before CPT) between the groups, a Kruskal-Wallis-Test was run. Non-significant results show that there are no differences between the groups concerning the pain intensity rating before being exposed to the CPT. A further Kruskal-Wallis-Test was run using the VAS 4 values (after CPT) as dependent variable. Non-significant results were found for each of the timepoints, meaning pain intensity ratings after the pain induction also did not differ between the three groups. The additional item ("The test was painful") on the VAS 4 was also used as a dependent variable in a Kruskal-Wallis-Test, to see whether the three groups perceived the pain induction at different levels of painfulness. Non-significant results showed that in the current sample, ratings of painfulness did not significantly differ.

A Wilcoxon-Test for two dependent samples was used to compare VAS 3 and VAS 4 (before and after CPT exposure) for each of the timepoints in each of the groups. Results here showed a significantly higher pain intensity rating after being exposed to the CPT, meaning the CPT pain induction was successful. Figure 2 shows mean VAS ratings before and after the

CPT per group, to emphasize the difference between VAS 3 and VAS 4. The self-selected unmodulated condition showed asymptotic significance values of p = .012 for each of the timepoints. In the researcher-selected frequency-modulated condition, asymptotic p-values ranged from .012 – .018. The researcher-selected unmodulated condition produced asymptotic p-values from .027 – .043.

**Figure 2**

*Mean Pain Intensity Ratings before and after CPT (VAS 3 & 4)*

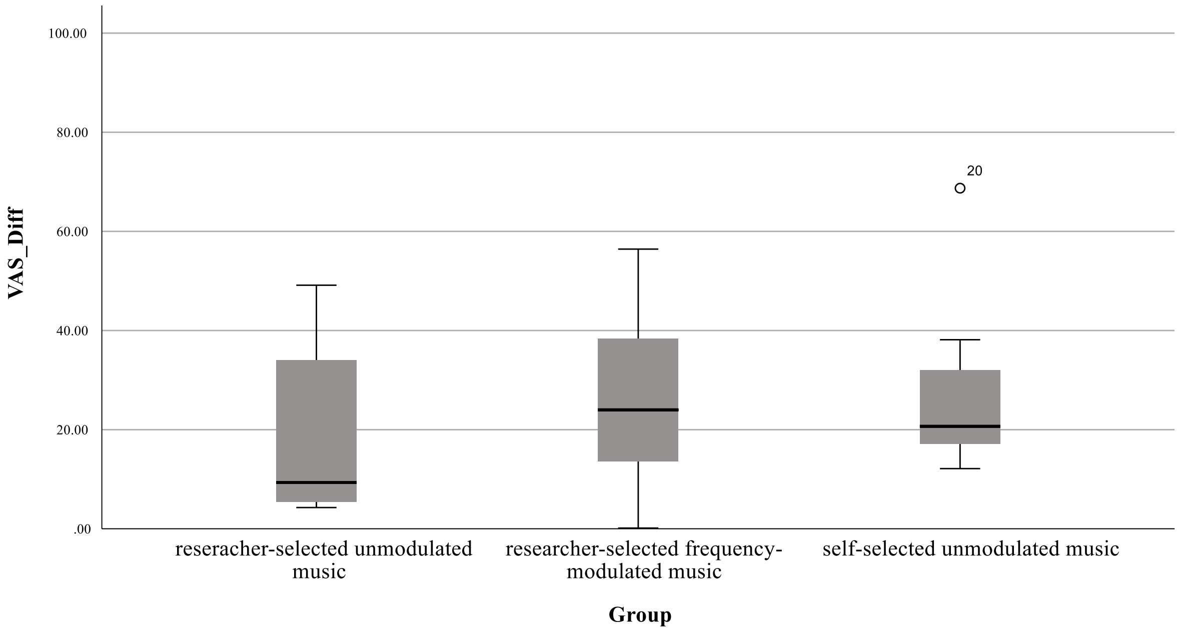



*Note.* Average means are provided in mm. Own work.

Then, one final Kruskal-Wallis-Test for k independent samples was run to see whether these results statistically differ between the three groups, using the newly calculated variable VAS_Diff as the dependent variable to answer H2. Figure 3 shows the average differences between VAS 3 & 4 per group, to emphasize the similarity in dispersions. Table 5 shows results were non-significant at each of the timepoints, meaning no differences between the groups could be shown in the current samples. Once again, means and standard deviations across the whole sample are provided, so as to emphasize variation irrespective of group. Chi-squared, degrees of freedom and asymptotic significance values show results for the group comparisons.

**Figure 3**

*Dispersion of VAS_Diff averages per group*




*Note.* Own work.

**Table 5**

*Descriptives and Kruskal-Wallis-Test regarding Pain Intensity (H2)*

| | Baseline | M1 | M3 | M6 | M10 | Post | Follow-up |
|---|---|---|---|---|---|---|---|
| Mean ($\bar{x}$) | 26.875 | 24.140 | 27.083 | 22.083 | 20.680 | 22.840 | 22.900 |
| SD | 22.415 | 19.659 | 21.641 | 17.131 | 15.558 | 21.751 | 22.114 |
| Chi-sq. ($\chi^2$) | 2.376 | 2.218 | 1.791 | 2.111 | 3.286 | 3.179 | 0.273 |
| df | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| p | .305 | .330 | .408 | .348 | .193 | .204 | .872 |

*Note.* SD = Standard Deviation. df = degrees of freedom. Means provided in mm. P-values are asymptotic significance values. Own work.

**Further Analyses**

Some exploratory analyses were run with further variables. First, a one-way ANOVA with repeated measures was calculated, using once again the newly created variable VAS_Diff, while including the variable city (in which city participants were tested) into the equation as an independent variable. Normal distribution was shown through a Kolmogorov-

Smirnov-Test concerning the variable VAS_Diff, which is why a parametrical procedure was chosen here. Wilks-Lambda showed that the city was almost significant (F = 2.524, df = 7, p = .067). A partial Eta-Square value of $\eta^2_p$ = .558 was found, meaning 55.8% of the variance would have been explained by the variable city. Though the result was not significant, it warranted a second look at the data. Average CPT Temperatures were $\bar{x}$ = 3.06 °C (SD = 0.629) in Marburg and $\bar{x}$ = 1.07°C (SD = 0.124) in Vienna. To see whether the temperatures significantly differed, a Mann-Whitney-U-Test was calculated for the two cities. Temperatures significantly differed at each of the assessments (Baseline, M1-M10, Post, Follow-up), with p-values of $p < .001$ for each time point, except M10 ($p_{M10}$ = .00124).

Then, Spearman correlations were calculated between the VAS_Diff per timepoint and their respective VAS 4 item-rating regarding the painfulness of the CPT. Spearman correlations were chosen, since it is a size using rank order which is unbiased by outliers. Correlations for each of the time points were significant, with values ranging from $r_s$ = .447 – .779, meaning if participants' judgment of painfulness of CPT was high, the respective markings on the VAS for pain intensity were also high (see Table 6 for correlation coefficients per time point). When calculating these correlations for the groups individually, the results slightly differ. While correlations in the self-selected unmodulated condition and the researcher-selected frequency-modulated conditions are still significant, the researcher-selected unmodulated condition shows no significant correlations between the pain intensity ratings and perceived painfulness of the test.

**Table 6**

*Correlation Coefficients between VAS_Diff and Painfulness per Time Point*

| | VAS_Diff BL | M1[a] | M3 [a] | M6 [a] | M10 [a] | Post [a] | Follow-up [a] |
|---|---|---|---|---|---|---|---|
| Painfulness BL | .779** | | | | | | |
| Painfulness M1 | | .629** | | | | | |
| Painfulness M3 | | | .689** | | | | |
| Painfulness M6 | | | | .689** | | | |

| | | | | |
|---|---|---|---|---|
| Painfulness M10 | | .447* | | |
| Painfulness Post | | | .560** | |
| Painfulness Follow-up | | | | .494* |

*Note.* * = Significant correlation p < 0.05. ** = Significant interaction p < 0.01. Own work.
[a] = VAS_Diff for each of the provided timepoints.

Lastly, Spearman correlations were also calculated between pain intensity (VAS_Diff values) per time point and their respective pain tolerance values (in seconds). Here, across the whole sample and for the individual groups, no correlations were found to be significant, meaning that pain intensity and pain tolerance are statistically not significantly associated.

## Discussion

Statistical analyses in the current sample could not replicate the results seen in similar studies. While almost all of the analyses show non-significant values, some results merit discussion and descriptive comparisons.

Pain tolerance could not be shown to be significantly different between the three groups at any of the time points. Yet, due to the small sample size, descriptive comparisons between the groups offer some insight into the possible effects. While H1 assumed self-selected music to produce better results than either of the researcher-selected music conditions, mean ranks show a different tendency. At almost all the time points (except M3 and M10) mean ranks for the self-selected unmodulated group are indeed higher than those of the researcher-selected unmodulated group. This tendency is in line with literature postulating an increased pain tolerance for participants in self-selected conditions (Basiński et al., 2018; Howlin & Rooney, 2021). Interestingly though, the researcher-selected frequency-modulated group shows the longest times of immersion at each of the time points, providing a first hint of evidence for the mechanism of frequency modulation. Since this mechanism for music-induced analgesia has rarely been investigated, no real assumptions can be made here. Yet, as descriptive values hint at stronger effects for frequency-modulation compared to choice over music, a comparison of these two mechanisms seems promising for a deeper understanding of music-induced analgesia.

Pain intensity ratings also did not significantly differ between the three investigated groups. Yet, while no significant differences could be found between the groups regarding either VAS 3 or VAS 4 pain intensity ratings, descriptive differences do exist. Contrary to H2, mean ranks for the researcher-selected unmodulated condition are lowest at almost all of the time points, meaning participants' pain intensity ratings were lowest in this condition. Participants in the frequency-modulated and the self-selected conditions seem to have rated subjective pain intensity higher. Comparing VAS 3 and VAS 4 values produced significant results with the VAS 4 ratings being significantly higher than VAS 3 in each of the groups at each of the time points. This, on one hand, speaks to a successful experimental pain induction through the CPT. On the other hand, looking at the respective p-values per group, it becomes clear that the differences between VAS 3 and VAS 4 (VAS_Diff) are lowest in the researcher-selected unmodulated condition. This corresponds with results from the additional item on VAS 4 (painfulness of the CPT). While no statistically significant differences in the perception of painfulness were found, participants in the researcher-selected unmodulated group seem to have perceived the experimental pain induction as less painful than the other groups. This could further be shown by the correlations between painfulness of the CPT and VAS_Diff. Results for the researcher-selected unmodulated condition are not significant, meaning there is no relevant association between the perceived painfulness of the CPT and the perceived pain intensity. Yet, the other groups produced significant results, meaning painfulness and pain intensity were indeed correlated. Since, to the author's knowledge, no studies have shown experimental pain induction to work differently depending on music condition, the most plausible explanation for these results lies in individual differences within the current samples. It is possible that participants in the researcher-selected unmodulated condition simply have a lower subjective perception of pain intensity in daily life, therefore results could mirror this tendency.

Though none of the relevant analyses yielded significant results, descriptive tendencies regarding pain tolerance were shown to be in line with the postulated effects. Pain intensity ratings on the other hand, descriptively oppose the postulated hypothesis. While this is most likely due to within-subject differences and sample size, a similar result has been found before. Mitchell et al. (2006) investigated three conditions, one of which was preferred music. They found significant increases in pain tolerance compared with the mental arithmetic condition. Against the authors' expectations, ratings of subjective pain intensity (VAS) did not differ between the groups. The authors aimed at comparing preferred music with two distracting conditions, giving way to an alternative explanation for the results of this thesis. It is possible, that while choice/ perceived control is the most effective mechanism concerning pain tolerance outcomes, distraction might be the most valid explanation for lower perceived pain intensity. As the authors of the study pointed to a relatively small sample size (N = 42; Mitchell et al., 2006), further investigations comparing pain tolerance with pain intensity outcomes are needed to further differentiate between mechanisms and their respective outcomes.

Putting aside the above-mentioned descriptive differences and tendencies, all three conditions still produced relatively similar results. This is most likely due to the small sample size, yet a further possibility is that participants had a high preference for/ enjoyment of the researcher-selected music. Warmbrodt et al. (2022) showed in their study that effects of selection of music lose significance, once participants' enjoyment is included into and controlled for in analyses. It is possible, that effects of choice and preference overlapped in the current sample. One of the researcher-chosen mixes uses music by The Beatles, which are music pieces often heard and encountered in everyday life. When exposed to a stimulus (i.e., a song) often, the mere-exposure-effect may cause individuals to rate specific stimuli with higher preference ratings (Bornstein & Craver-Lemley, 2022). Therefore, it is possible that participants had high subjective preference for the music the researchers chose, confounding effects of choice over the music. Some of the other music mixes provided by the research team could also be perceived as relaxing (violine and guitar mixes). As relaxing music tends to show improved pain management outcomes (Finlay & Anil, 2016), this may also have confounded effects of choice and offers a further valid explanation of the results at hand.

Another result warranting discussion is the fact that where participants were investigated (Marburg or Vienna) seems to have influenced the pain intensity ratings. Looking at the data, it becomes apparent that CPT water temperatures were higher for the participants in Marburg, compared to those in Vienna. Mitchell et al. (2004) found that a difference of 2°C in water temperature leads to a significant difference in pain intensity ratings (VAS). Since a difference of 2°C is given in the current samples, it's possible that the water temperature had an influence on pain ratings. There is no documentation of why participants in Marburg were exposed to warmer CPT trials than those in Vienna, yet it carries an implication for future research. Studies using CPT as experimental pain induction should either settle on one temperature and adhere to it throughout the whole investigation, so as not to bias results, or make use of different temperatures and strategically compare them against one another.

**Limitations**

Certain limitations to this study and thesis warrant consideration. Some pertain to the thesis at hand, some to the design of the MINTREP study.

First, one needs to consider the current sample. With only N = 25 participants in total, the sample was presumably too small to show postulated effects. Similar investigations have been able to show relevant effects in samples of about N = 45 – 50 participants (Choi et al., 2018; Garza Villarreal et al., 2012; Mitchell et al., 2006). Therefore, results may differ when investigating more participants. Secondly, all of the participants included in analyses were students, possibly contorting results.

Thirdly, it is worth mentioning that most of the research concerning MIA has been carried out through self-report measures of pain and analgesia, with some authors calling for studies using physiological data and biomarkers (Finlay et al., 2016). While the study underlying this thesis does include physiological and biological data (see Feneberg et al., 2020), none of it was used in analyses in the thesis for reasons of feasibility. Analyzing heart rate variability data or hair cortisol levels lies outside of the author's abilities, therefore a research question excluding said measures was chosen a priori. In order to further the current state of research, said data would need to be included and analyzed.

The fourth limitation pertaining to the thesis at hand is the handling of missing values. Most of the missing data was assumed to be Missing At Random (MAR) and therefore not imputed, yet the data could also have been Missing Not At Random (MNAR). Had this been the case, the data would be missing due to a factor not included in the design, potentially leading to a bias. Yet, since most of the relevant data was available and, to the author's knowledge, no potentially biasing variables were missing in the design, this limitation was assumed to be negligible.

As for the MINTREP study design, there is one limitation concerning the sample population. The current sample contained only participants from Germany and Austria, two high-income western countries. There is sufficient evidence that health care and subsequent health outcomes differ vastly between white, educated and wealthy patients compared to patients from marginalized groups (e.g.: Hammett et al., 2024), with some authors' publications calling to action and demanding structural changes for various sectors (research, practice, education, policy, etc.; Baker et al., 2023). Under this notion, research would need to broaden concerning study populations and settings. A more diverse sample could potentially lead to varying outcomes.

Another limitation can be found in the operationalization of pain. Since the participants do not stem from a pain population, pain was experimentally induced through a CPT. While this pain induction is widely used in research, the response to it may differ between subjects and normative values regarding sex and age are still needed (Lamotte et al., 2021). Mitchell et al. (2004) revealed a lack of standardization regarding equipment, as well as methodology, stating that "variation in [pain] tolerance might in fact relate to differences in methodology rather than the experimental conditions under investigation" (p. 234). Further, one pain component the CPT is not known to induce is the emotional component – while it's possible that participants feel emotional distress during the CPT, these mechanisms have not yet been studied in detail. Therefore, ratings of pain may differ when using different pain inductions or actively including emotional components of pain. As explained above, pain intensity ratings also differ according to CPT temperature (Mitchell et al., 2004), therefore temperatures should be controlled for in future studies.

Lastly, it needs to be mentioned that the music-listening sessions were held before the CPT pain induction and pain ratings. It is possible that MIA effects are bigger when pain induction and music intervention are administered simultaneously. As the MINTREP project is one of the first to investigate frequency-modulated music-interventions concerning pain and stress outcomes in a healthy sample, with a strict and randomized study design, no assumptions about mechanisms are to be made here. Further research is needed to address the above-mentioned limitations.

**Conclusion**

Chronic pain is a widespread problem affecting many individuals' health and their psychological well-being. Further, it burdens the health care systems with treatment costs and economic systems due to loss of productivity. Treatment is usually multimodal, depending on the specific condition and patient preferences. Multimodal management commonly involves medications, lifestyle modifications, pain psychology, behavioral interventions, exercise and alternative medicine with the goals of pain alleviation and an improved quality of life (Dey & Vrooman, 2023). As the thesis at hand provides some first hints of evidence regarding frequency-modulation, this sort of music-intervention warrants further investigation. The MINTREP study, once completed, will provide more insight into frequency-modulation and its role in MIA. Should the AVWF method of frequency-modulation prove fruitful, it will then need to be researched in tandem with pharmaceutical approaches to ideally merge this approach into existing treatment plans. The frequency-modulation provided by the AVWF method is not yet commercially available, therefore accessibility for patients is unclear. Should the MINTREP study confirm descriptive tendencies shown here (i.e., self-selection leading to better pain tolerance than researcher-selection), a comparison between self-selection and frequency-modulation should be made. If results are somewhat similar, self-selected music may still be a more feasible approach to treatment of chronic pain, due to its low costs and easy accessibility. A further possibility would be to let patients choose their own music and provide this music according to the AVWF method. This would probably have to be done through some kind of clinical institution though, once again meaning increased costs for health care systems.

In conclusion, music-induced analgesia seems to be effective for chronic pain conditions. While some mechanisms are still to be researched and studied (i.e., frequency-modulation), it seems to be a valid adjunct to pain management. According to the literature, personal preference and choice over music have led to the biggest improvements in pain management, so these mechanisms call for closer inspection and application in pain patients' lives. Music interventions should then be included in and adapted to standardized treatment plans for various (chronic) pain conditions.

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## Appendix A

### Abstract – English

Pain is a subjectively unpleasant experience with high prevalence rates across most populations and high costs for health care systems. While effective treatments for pain conditions do exist, chronic pain patients often report an inefficacy of pharmaceutical approaches. Alternative treatments like music interventions have been well-researched. While music-induced analgesia (MIA) has been shown to be a safe, reliable and cost-effective treatment option, meta-analyses show a high variability in results and discussed mechanisms responsible for analgesic effects.

The aim of the current thesis was to examine the mechanism of choice over music in terms of analgesic effects, through a comparison of self-selected and researcher-selected music. In an experimental study, N = 25 participants (age: $\bar{x}$ = 24.2, SD = 3.628; N = 15 female, N = 10 male) were exposed to ten 60-minute music-listening sessions (3 groups: self-selected unmodulated music, researcher-selected unmodulated music, researcher-selected frequency-modulated music). A Cold-Pressor-Test (CPT) was used to experimentally induce pain, before and after which participants rated their subjective pain intensity through a Visual Analogue Scale (VAS). Pain tolerance was operationalized through the time of immersion (CPT). Self-selected music was postulated to produce better pain outcomes (higher pain tolerance, lower pain intensity) than researcher-selected music. None of the main analyses yielded significant results, yet descriptive tendencies show self-selected unmodulated music to be superior to researcher-selected unmodulated music. Interestingly, frequency-modulated music showed even better results, giving first hints of evidence for the mechanism of frequency-modulation. The results underline the importance of further studies differentiating mechanisms in MIA.

**Abstract – Deutsch**

Schmerz ist eine unangenehme, subjektive Erfahrung, die weltweit hohe Prävalenzen aufweist und Gesundheitssysteme finanziell stark belastet. Es existieren viele effektive Behandlungsansätze, (chronische) Schmerzpatient*innen berichten jedoch, dass pharmazeutische Ansätze ihre gewünschten analgetischen Effekte irgendwann nicht mehr aufweisen. Alternative Behandlungsansätze wurden bereits vielfach untersucht, wobei musik-induzierte Analgesie als wissenschaftlich belegte, sichere, reliable und kostengünstige Option im Schmerzmanagement gilt.

Die vorliegende Studie untersucht den Mechanismus der Musikauswahl, indem Proband*innen, die ihre Musik selbst gewählt haben mit jenen, die von Forschenden bereitgestellte Musik hörten, verglichen wurden. 25 Versuchspersonen (Alter: $\bar{x} = 24.2$, $SD = 3.628$; $N = 15$ Frauen, $N = 10$ Männer) nahmen an 10 Musikinterventionsterminen teil, zu denen sie je 60 Minuten Musik hörten (3 Gruppen: selbstgewählte unmodulierte Musik, fremdgewählte unmodulierte Musik und fremdgewählte frequenzmodulierte Musik). Mittels Kaltwassertest (CPT) wurde experimentell Schmerz induziert, der auf einer Visuellen Analogskala (VAS) bezüglich der Schmerzintensität bewertet wurde. Die Schmerztoleranz der Versuchspersonen wurde über die Dauer des CPT operationalisiert. Die Hypothesen vermuteten besseres Schmerzmanagement (höhere Schmerztoleranz, niedrigere Schmerzintensität) bei selbstgewählter im Vergleich zu fremdgewählter Musik. Obwohl keine der Hauptanalysen signifikante Ergebnisse produzierte, zeigen deskriptive Tendenzen bessere Ergebnisse für selbstgewählte Musik. Spannenderweise zeigten sich die besten Ergebnisse für die Proband*innen, die frequenzmodulierte Musik hörten. Weitere Untersuchungen sind nötig, um Wirkmechanismen genauer zu definieren, differenzieren und adäquate Behandlungspläne abzuleiten.

# Appendix B

## Study Flyer

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

**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

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

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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.**