Listening to Background Music While Studying - Emotional Drive or Cognitive Overload?

Thesis Report

by

Anna Tatiana Rödel

Submitted to the Faculty of Behavioural, Management, and Social sciences (BMS)

University of Twente

MSc Educational Science and Technology (EST)

June 2021

Supervisors

First supervisor: Prof. Dr. Bernard Veldkamp

Second supervisor: Enno Wigger

External supervisors: Prof. Dr. Anne C. Frenzel, Dr. Daniel Fiedler

External institution

Department of Psychology

University of Munich (LMU)

Table of Contents

Acknowledgement

This study project was only possible because of the openness and curiousness of my four supervisors: When I almost gave up on finding support from a faculty of behavioural and management sciences for a music-psychology-related thesis topic that interested me, Bernard Veldkamp agreed in taking over the role of the first supervisor. Without a lot of background knowledge about the topic itself, he was simply open to being infected by my enthusiasm and interest in the research question. He was joined by Anne Frenzel who agreed in accepting the role of the official external supervisor. In this role, she did not only allow me to fulfil the requirements for a double degree but also helped me to zoom out from problems that I had only observed in a narrow scope before. Enno Wigger joined in as the second supervisor and shared valuable tips that helped me, in particular, in limiting the scope of the project and in sticking to the red thread. And, last but not least, Daniel Fiedler, my de-facto supervisor, was open to extending his planned study for me. Thank you for this, and for your never-ending, continuous, and always available support, for the productive discussions, for the coffee breaks, and for sharing my frustrations when the Windows system in the testing computer suddenly decided to do extensive updates. In sum, I am very aware, grateful and proud of being mentored by such a competent, interdisciplinary, and above all fun team of excellent supervisors – this project would not be the same without any one of you!

Further support was given to me in form of detailed proofreading by Eva, Mikelis, and my father Dietmar Rödel – thanks for your patience and preciseness, you definitely earned your thank-you-dinner (with the one for Dietmar still to come)! Thanks to all of my gorgeous housemates for always asking me if they should make more coffee or if I would like to join them for a walk. And last but not least, thanks to everyone helping me in the past to gain the knowledge and experience in project management skills that allowed me to minimize the thesis stress and, thus, to really enjoy my thesis time by truly focusing on the content that I burn for.

PS: An additional thanks goes to the gorgeous instrumental music playlists from Spotify which accompanied me for most of this report’s writing time. They proved to me how much music can support writing and studying, at least on my very own personal level.

Abstract

Music is an omnipresent element in our daily life that is nowadays easier to access than ever. Since music is also used in the background while being in cognitively demanding situations, like studying, it is important to understand the effects and influencing factors of music on learning. Past research investigating the effects of background music shows controversial results and did not investigate individual musical factors of the learner. Independently from musical experience, higher musical perception abilities are supposed to result in a higher cognitive load through background music, resulting in a lower frequency of listening to music while studying (H1). Secondly, based on the arousal-mood hypothesis and the Yerkes-Dodson law, middle levels of emotional reactivity on music could increase listening frequency, while low and high values would result in no benefit or over-arousal (inverted u-shape, H2). Furthermore, this study explores the general usage of background music in studying situations to provide guidance and advice for future research. The study sample contained N = 129 participants (87 female, M_{Age} = 31.10, SD_{Age} = 12.94). Musical perception abilities, habits of listening to background music while doing cognitively demanding tasks, and general musical experience were assessed. To assess emotional reactivity to music, participants listened to musical stimuli before self-reporting their arousal and valence. Additionally, we measured physiological arousal data (HR, GSR) while listening to these music excerpts for a sub-sample (n = 66). A negative partial correlation between the background music frequency and the musical perception abilities could be confirmed, after controlling for musical experience values (r = -.31, p < .001, H1). Polynomial regression analysis did not show significant results for the relationship between emotional reactivity to music and the frequency of listening to background music (H2). The results indicate that cognitive overload through higher musical perception abilities is more likely than emotional drive through emotional reactivity, based on the habits of the learners. The study confirms the importance of the topic and argues that learners do and should differ in their habits of listening to background music while studying. Suggestions for future studies are provided to ensure the relevance of their results for learners listening to music.

Keywords: **Background Music, Learning, Cognitive Load, Musical Perception Abilities, Emotional Reactivity to Music**

List of Tables

List of Figures

Background Music While Studying - Emotional Drive or Cognitive Overload?

Music plays an important role in the daily life of most people. It is nowadays more popular than ever since music "is socially acceptable, healthy, inexpensive, and ubiquitously available" (Hu et al., 2021, p. 1). One of the strongest motives for listening to music in daily life is the emotions that are induced by it (Juslin & Laukka, 2004). For example, music can influence our own emotions or moods (e.g. Hallam & MacDonald, 2016), thus helping us to process our feelings, or to change our mood. While style, preferences of music, and situations in which we listen to music differ across cultures and demography, we all have the same musical biological bases that make us relate to music in some way (e.g. MacDonald et al., 2002; Trevarthen, 2002). Music allows us to express and perceive emotions, to communicate independently from social or cultural background, and from language (Elliott, 2012; Hargreaves et al., 2005; Pavlicevic & Ansdell, 2004).

Due to its accessibility and popularity, music is used to accompany us in all kinds of situations and activities. In 2019, people listened to music on average for 18 hours a week, which is more than 2.6 hours a day, with the global recorded music market still continuing to grow (IFPI, 2019). Especially the younger generation makes use of the accessibility and the emotional effects of music, resulting in frequent music listening (e.g. Hallam & MacDonald, 2016; Hu et al., 2014, 2021; Kotsopoulou & Hallam, 2010): Worldwide, the biggest group of online users that use music streaming service platforms such as Spotify or YouTube are between 16 and 24 years old (IFPI, 2019), covering the predominant age of higher education students. However, the older age group (35 - 64 years) shows constantly increasing interest in musical engagement as well (IFPI, 2019), suggesting that the interest in music grows for adults in general. The increasing usage of music in everyday life also includes situations of cognitively demanding tasks such as learning, which increasingly accelerates the scientific interest in the effect of music on learning.

Learners seem to differ in their habits of music listening while studying (i.e. Hu et al., 2020; Kotsopoulou & Hallam, 2010): While some people seem to use music actively in their background when learning, other people cannot learn with background music at all. There are a number of studies that investigated the effects of different music on different learning activities, but they show conflicting results (for a recent overview, see de la Mora Velasco & Hirumi, 2020). One reason for the controversial findings is the differences on individual level regarding if, how, and when learners listen to music (i.e. Kotsopoulou & Hallam, 2010). Thus, the effect of music on learning partly relies on the person who listens to the music while learning (i.e. Gonzalez & Aiello, 2019; Hallam & MacDonald, 2016). Some prior studies investigated individual differences when it comes to the effects of music on learning, such as personality (i.e. Cassidy & MacDonald, 2007; Dobbs et al., 2011) or character of the learner (Hallam & Price, 1998). To the author's best knowledge, individual differences in the musical perception and emotional reactions did not attract scientific attention yet - although it is likely that the ability to process musical information influences the music's effect on both cognitive and emotional level: On a cognitive level, differences in the ability of music perception could actually intervene to varying degrees with the learning process that also requires cognitive resources. On an emotional level, differences in how strongly a person reacts to emotions in music could either increase positive emotional effects or could result in over-arousal due to higher attention for (emotions in) music. Knowing more about the individual differences in musical perception and processing would allow recommendations for whom music might be more beneficial when learning.

A second possible reason for the controversial findings might be the rather unsystematic and inconclusive approaches of research in this area (Hallam & MacDonald, 2016). Prior findings often lack precise and clear research methods, including small sample sizes and approaches that are difficult to compare (i.e. de la Mora Velasco & Hirumi, 2020). For example, collected data often used self-reported measures that solely rely on conscious information (i.e. Scherer, 2005), while the basic physiological effects might actually give a clearer and less biased picture that is more sensitive to differences (as suggested i.e. by Lehmann & Seufert, 2017). This suggests using multiple methodological approaches in this study, instead of only relying on self-reported, and possibly biased data.

Not only factors on an individual level, but also the music played and the tasks worked on, generate an almost unlimited amount of parameters and factors that have to be taken into account when researching the relationship between music and learning (e.g. Hallam & MacDonald, 2016). For example, music can contain different instruments, languages, vocals, beats, rhythms, speed, volume, and emotional expressions. Cognitively demanding tasks also include a wide variety of different activities that require different cognitive abilities and domains (e.g. spatial tasks vs. reading comprehension). As a result of the extensive number of factors, existing studies often concentrated on only a small area of research on the complex interplay of musical and situational factors, limiting the generalisability and the applicability of the results. For example, most research in the past years provides specific music selected by the investigators (de la Mora Velasco & Hirumi, 2020), although, in common learning situations, the music is almost always selected by the listener. Furthermore, experimental designs only observed short-term effects instead of long-term effects. As an outcome, the results of most prior studies only apply for very limited effects on very specific, short-term circumstances, losing the link to real-life learning situations. To meaningfully guide research in this area, more knowledge is needed about the types of music and the situations that are actually of relevance because they are preferred by learners who listen to background music. Why is music perceived by so many people as helpful when studying, and why is it not wanted at all by others? In which situations is music used and which types of music are used most often? Information about music preferences, learning situations, and beliefs of the learner can help future research to direct its focus on factors that actually require further scientific investigation to provide useful advice for learners.

This study aims to address these research gaps by exploring the relevance of individual differences in cognitive and emotional processing of music, as well as the habits of background music while studying in everyday life: Firstly, this project investigates if and how differences in musical perception, both on a cognitive and emotional level, influence the frequency of listening to background music while learning - and if a cognitive overload or emotional drive through music is more likely. To provide a multidimensional picture of these effects that do not rely solely on self-reported data, multiple methods such as questionnaires, music tests and physiological arousal data are included in the study design. Secondly, this research study investigates in an explorative way the habits of background music listening, namely how often learners listen to music and which situational factors and musical parameters they prefer when doing so. Asking also for the learner’s beliefs of the effects of music on learning could provide information of underlying mechanisms which could be used to extend explanatory theoretical frames in the future.

This report introduces the reader to the theoretical background of the topic and provides an overview of prior research. Studies that give insights about the usage and the importance of background music while learning and about the known effects of music on learning are presented. The theoretical introduction continues with elaborating on musical perception abilities, emotional reactivity to music, and how individual differences in both of them could possibly influence the usage of background music while learning. Based on these theoretical assumptions, the research focus is defined with two hypotheses and an explorative research question. The study methods will be explained, namely the sample characteristics, the research design and procedure, the used materials, and the conducted statistical analysis. Results with descriptive statistics, findings regarding the hypotheses and the research question, and additional findings are presented. These results will be discussed with regards to the presented theory, including alternative explanations, and study limitations. Advice for learners and researchers is provided in a short, summarizing implications section. A conclusion will sum up the study project and its importance for future investigations.

1.1. Usage of Background Music While Studying

Most of the studies that investigated the influence of background music on learning in the past followed a small-scope, detailed, experimental approach that allows them to focus on single factors while controlling for possible side effects (see de la Mora Velasco & Hirumi, 2020 for a recent overview). Only recently, some studies followed a more general approach to find out about the habits of listening to background music while learning, providing first insights into why research in this area is of relevance, and which directions should be further investigated. For instance, Hu et al. (2020) investigated the use of music for learning and well-being by interviewing 40 Chinese university students. They found that university students perceived music as beneficial for their learning and for other areas in their daily life, partly because of increased well-being and positive emotions.

A broader study was conducted a bit earlier by Kotsopoulou and Hallam (2010) who investigated differences in the habits of music listening when learning for the age and culture of 600 students between 12 and 21 years from four different countries. They developed a questionnaire that is also partly used in this study. Not only did they find a number of significant effects of both age and culture, but most importantly, they also asked for the learning tasks in which background music is played, reasons for listening to background music while learning, and common types of background music when learning. Results showed that students do not play music often when doing extensive studying or highly cognitive learning activities such as memorising or revising content. Instead, they use background music mostly to relax, alleviate their boredom or increase their concentration when thinking or writing. A happy or bored mood functioned as a deciding factor to switch on the music. The most common music that was played in this age group was pop, the least common one was classical music, but the variety of music played seemed to increase with higher age.

These first research approaches that explored the habits of listening to background music while learning show that music is actively used for learning because it is perceived as beneficial in specific learning situations. Further, there seem to be two main types of effects of music on learning: a cognitive one, which is shown by learners deciding based on the task complexity, and an emotional one since music was played for positive emotions, or based on the current mood (Hu et al., 2021, Kotsopoulou & Hallam, 2010). The usage and the habits of using background music while studying vary a lot (Kotsopoulou & Hallam, 2010), hinting towards high inter-individual differences. This arouses the need to elaborate on how and why background music influences a cognitively demanding activity such as learning.

1.2. Background Music Influences Cognitive Performance

Studies that investigated the effects of background music on learning and cognitive performance differ widely in approaches, methods, and results. Some studies found no effect of background music, while others report negative or positive effects on learning variables (for systematic overviews see i.e. de la Mora Velasco & Hirumi, 2020; Hallam & MacDonald, 2016).

The most recent systematic literature review on this topic was conducted by De la Mora Velasco and Hirumi (2020) which contained 30 studies from 2008 to 2018 that investigated the effects of background music on learning in general. They report about 11 studies with positive, 10 studies with neutral, and nine studies with negative effects of background music on learning, concluding that the current research on this topic is incoherent and inconclusive. Studies with smaller sample sizes often reported more negative effects than studies with larger samples. Additionally, the used interventions in the studies differed a lot in approaches and methods, which makes them difficult to compare. De la Mora Velasco and Hirumi (2020) suggested that the field requires more rigid research methods to further investigate the effects of background music on learning.

While higher standards in research methods might help in receiving more comparable results in this field of research, another important reason for widely varying effects when looking at the influence of background music on learning is the almost unlimited amount of intervening factors. In their review, de la Mora Velasco and Hirumi (2020) used a framework that is based on another systematic review by Hallam and MacDonald (2016). This framework by Hallam and

MacDonald (2016) isolates potential factors possibly influencing the effect between music and learning based on research. Factors named in this framework can be sorted into three categories: 1) musical parameters, 2) situational factors such as the environment and the learning task, and 3) individual factors of the learner. All three of these factor categories showed to influence the effects of music on cognitive performance (i.e. Gonzalez & Aiello, 2019) and will be briefly elaborated upon in the following. An extensive overview of intervening factors in those three categories that have been invested by prior research can be found in a table in Appendix A.

1.2.1. Musical Parameters

Musical parameters such as tempo (e.g. Peretz, 2010, Kämpfe et al., 2010), volume (e.g. Wolfe, 1983), complexity (Kang & Williamson, 2014), emotionality (e.g. Hallam et al., 2002), and if the music is vocal or instrumental (e.g. Donlan, 1976; Martin et al., 1988; Perham & Currie, 2014; Pool et al., 2003) influence the musical effect on learning. For example, Thompson et al. (2011) looked into the interaction effects of tempo and volume intensity and only found positive effects for soft fast music on learning, while the other three combinations hindered learning. Especially, the tempo of the music seems to be of relevance, as it seems to influence the tempo of activities across multiple studies (see Kämpfe et al., 2010). Therefore, the effects of tempo resulting in faster performance could also apply for activities in learning, and also the differences in the volume of the music could be of specific interest.

The different effects of music with and without vocal information has been frequently investigated, with vocal music showing a greater negative effect (i.g. Perham & Currie, 2014), especially on literacy activities (i.g. Martin et al., 1988). It is also in line with the fact that music from the so-called classical genre, which is often non-vocal, showed the most positive effects across recent studies, although classical music was also investigated the most often in research (De la Mora Velasco & Hirumi, 2020). Vocals in music might compete against any other literacy information that is processed (Pool et al., 2003), highlighting the relevance of the existence of vocals in music for its effect on different learning tasks.

Every musical piece and its artistic interpretation is individual (e.g. Juslin, 2019), resulting in an unlimited number of possible parameters. In a self-report approach, it is only possible to assess those musical parameters that are well-defined and easy to understand: While volume, speed, and a vocal vs. instrumental character of the music are easy to report, the genre, the complexity, or the emotional expression is not that objectively clear. Volume, speed, and the existence of vocal information have all shown to influence the effects of music on learning in prior research (i.e. Kämpfe et al., 2010; Perham & Currie, 2014; Wolfe, 1983). Also, these three musical parameters undeniably change the intensity of auditory information in music, with faster music, louder music, or music with vocals increasing the information intensity for the listener.

1.2.2. Situational Factors

Situational factors describe non-musical elements of a learning situation with background music, such as the type of task that is worked on and the environment of the learner. Especially the type of tasks has proven to be of importance: Several authors found different results regarding the effect of background music for the domain of memory tasks alone (see Hallam et al., 2002 for an overview). The cognitive channel might be of relevance in this regard (Martin et al., 1988), as an effect for varied task difficulty has been found: music that was loud and fast showed higher intervening effects on more complex cognitive activities such as reading comprehension (Anderson & Fuller, 2010; Thompson et al., 2011). Similarly, faster overarousal and sub-optimal performance through music appear when the task is more difficult (Konecni & Sargent-Pollock, 1976).

Besides the nature of the task, environmental factors such as the familiarity of the environment and if the learner is alone or in company might be of relevance (Hallam & MacDonald, 2016). Waterhouse (2006) suggests that the time the music is playing in the background might be another situational factor that influences learning. Due to longer playing music, an effect of habituation might appear.

Based on these findings, information about the type of situations in which learners listen to music could support or counter-argue the negative cognitive effect of music shown through task difficulty manipulations. Furthermore, the type of situations and the beliefs about the effects of music on learning could provide first insights into the environmental factors that are taken into account by the learner: If people think that music helps them to focus on learning or to alleviate their boredom (i.e. Kotsopoulou & Hallam, 2010), this could indicate possible reasons for positive effects of music on learning.

1.2.3. Individual Factors

Research has shown differences in the relationship between music and learning due to inter-individual differences, such as working memory capacity, personality traits or personal preferences (i.e. Hallam & MacDonald, 2016). Individual factors of the learner such as age

(Kotsopoulou & Hallam, 2010), gender (Anderson & Fuller, 2010), introverted or extroverted personality (Cassidy & MacDonald, 2007; Dobbs et al., 2011) or a more sensitive character (e.g. Hallam & Price, 1998) can play a significant role. The familiarity of the music (Hilliard & Tolin, 1979), how much the music is liked by the listener (Iwanaga & Moroki, 1999), and if it is self-selected (Schwartz et al., 2017) are also of relevance.

Furthermore, the frequency of the use of background music, namely the extent to which one is used to playing background music while doing cognitive tasks, can have an effect: The individual habituation to background music seems to improve the studying performance (Etaugh & Michals, 1975). However, Anderson and Fuller (2010) found that text comprehension is worse for young learners who said that they liked listening to music while learning, although this correlational effect of personal preference for background music and lower text comprehension performance might not be causal.

The findings regarding individual factors show that differences on the individual level are of importance and that the first approaches towards investigating inter-individual differences that might influence the effect of music on learning have been taken in research. Hallam and MacDonald (2016) suggest that individual differences in musical factors, such as in musical experience, could also be of importance (see also Wallace, 1994). However, past studies did not investigate individual effects that are related to music and to the perception of and reaction to music, neither on an emotional nor on a cognitive level. How could individual factors of musical understanding and reactivity to music-induced emotions influence the effect of music on learning?

1.3. Musical Understanding and Musical Expertise

The German word "Musikalität", which can be translated as musicality, is used in German-speaking countries to describe naturally given musical abilities and musical auditive understanding. However, in the English language, both in daily life and in scientific research, the phrase *musicality* often refers to skills that only depend on how intense an instrument has been studied and played in the past. Instead, for describing how well a person understands music, international research refers to musical perceptual or perception abilities (i.e. Müllensiefen et al., 2014; Schaal et al., 2014).

Which structures underlie musical abilities are still unknown up to this day (e.g. Müllensiefen & Hemming, 2017). Recently, different ways of defining musical experience and skills in a multidimensional approach have been investigated to avoid a merely uni-dimensional approach to musical skills. For example, Chick and Richards (2012) created the MUSE, the Musical USE questionnaire, that measures musical engagement by assessing different musical habits. Instead of one outcome variable, the survey assesses different indices, for instance, the index of music listening (IML), the index of music instrument playing (IMIP), and the index of music training (IMT). However, these indices only look at how often a person interacts with music in different ways, ignoring other musical parameters that differ on an individual level, such as specific musical perception abilities and emotional understanding of music.

Müllensiefen et al. (2014) addressed this gap by defining the term *Musical Sophistication* as a construct of musical expertise that is not only measured by musical training but includes other ways of actively engaging with and experiencing music in all its facets. Musical sophistication is, thus, mainly independent from how specific musical expertise has been acquired, or from specific learning processes. Müllensiefen and colleagues (2014) developed a self-report instrument, the Goldsmith Musical Sophistication Index v. 1.0 (Gold-MSI). The Gold-MSI measures an overall score of musical sophistication, as well as five factors included in this overall construct: Active Musical Engagement, Perceptual Abilities, Musical Training, Singing abilities, and Sophisticated Emotional Engagement. With an impressively big sample size (N ~ 150.000), the reliability and validity of this instrument for non-musicians in the English language were demonstrated (Müllensiefen et al., 2014), which could be repeated in a translated German version as well (Schaal et al., 2014).

1.3.1. Musical Perception Abilities

One sub-construct of the *Musical Sophistication* definition by Müllensiefen and colleagues (2014) is *Musical Perceptual Abilities* (i.e. rhythm, pitch, timbre) which is of interest regarding the relationship of music and learning. In the Gold-MSI, musical perceptual abilities were found as one factor of the construct of Musical Sophistication that was shown to correlate with the other sub-scales for musical sophistication (Müllensiefen et al., 2014; Pausch et al., in review; Schaal et al., 2014). Musical abilities can be developed, but their basis is assumed to be a natural musical giftedness or musical potential describing the aptitudes that are naturally given (i.e. Gagné & McPherson, 2016). This being said, a high musical perception ability can occur even without much prior training or knowledge in the musical field. Instead, musical perception abilities can be assumed to be naturally given to a person, even though it can be improved through developmental processes such as exercising and informal learning (see also Gagne's Developmental Model for Natural Abilities, Gagné, 2015).

While Müllensiefen et al. (2014) assessed musical perception abilities with self-report items, there have been multiple different attempts to measure "naturally given" musical understanding with specific auditive tests. Already over one century ago, the first standardized tests to measure musical abilities were developed, starting with Seashore's (1919, as cited in Müllensiefen et al., 2014) test for musical talents. It defined six sub-tests that were assumed to be independent (Müllensiefen & Hemming, 2017). At the end of the 20th century, the idea of "talent" had changed rather into a skill of understanding music. Further instruments to measure this musical competence that is independent of musical training or experience have been developed. For example, the PROMS (Profile of Music Perception Skills, Law & Zentner, 2012) focused mainly on auditive tests within different musical areas and was a basis for developing the Musical Perceptual Abilities self-report items from Müllensiefen et al. (2014). In one of their studies (Study 4), Müllensiefen and colleagues validated these self-report items with the auditory perception of specific auditive tests for musical parameters (melody memory, musical beat). These auditive tests have been further developed in following studies, providing tests for different aspects of musical perception, such as mistuning perception (Larrouy-Maestri et al., 2019), beat perception (Harrison & Müllensiefen, 2018), and melodic discrimination (Gelding et al., 2020; Harrison et al., 2017). These music tests have been developed in a computerized adaptive way using a high number of items with different difficulties. They are language-independent and completely independent of specialized musical knowledge such as music theory or sheet reading abilities.

Recently, Pausch et al. (in review) proved that this test battery is a valid instrument for measuring musical perception abilities: they found a general underlying factor, a so-called g-factor, for musical perception abilities that can be built by the scores from the music tests in the test battery, namely beat perception, melodic discrimination, mistuning perception, and emotional discrimination (based on the Musical Emotion Discrimination Test, MEDT, MacGregor & Müllensiefen, 2019). This proves that musical perception abilities can be defined by one single underlying general construct, similar to the g-factor of intelligence (Spearman, 1904), rather than multiple independent musical parameters as for example assumed by Seashore (1919, as cited in Müllensiefen et al., 2014).

Based on the research from Müllensiefen et al. (2014), Schaal et al. (2014), and Pausch et al. (in review), *Musical Perception Abilities* can be defined as one general construct of musical understanding that can be measured by assessing the perception abilities for different musical parameters (e.g. beat, pitch, and mistuning perception). This construct is independent of any specific musical knowledge. Musical perception abilities differ among individuals, and can, thus, also result in influencing the effects of music on learning in different ways.

1.3.2. Effects of Differences in Perception Ability Through Cognition

When concentrating on music, cognitive effort is required (Berlyne, 1973) to process this auditive information we perceive. Perception, from a cognitive perspective, can be seen as a way of processing information we recognize with our senses (i.e. Marr, 1982). Higher perception abilities, thus, allows more information to be processed. In the domain of music, this means that the perception abilities define the amount of musical information that can be processed: Higher musical perception abilities would result in more musical information being processed, and, consequently, in an increased demand for cognitive resources. As such, differences in the individual musical perception abilities could influence our cognition and our cognitive resources when it comes to listening to music while studying. Different theories describe cognitive information processing and allow us to assume the effects of changes in musical perception abilities on the relationship between music and learning.

A theory that aims to provide guidelines in the applied field of learning while multiple channels are used is the *multimedia design theory*, which is based on Mayers (1997) cognitive theory of multimedia learning. The multimedia design theory postulates that information not essential for learning, such as music playing in the background, can intervene with the learning process by decreasing intention and the transfer of knowledge (Mayer, 2014). While the multimedia design theory concluded with a lot of general practical implications for multimedia learning (e.g. Mayer & Moreno, 1998), De la Mora Velasco and Hirumi (2020) found that there is a lack of studies that focus on the influence of music on learning in multimedia settings specifically. This shows that the implications of the multimedia design theory, at least when it comes to the influence of background music in learning settings, is, for now, only theoretical advice that still needs to be confirmed in practice.

The multimedia design theory builds its argumentation on the fact that background music is information that is not related to the actual learning tasks but still attracts attention, which can also be described as a seductive detail (Rey, 2012). Listening to music while studying would generally result in a *seductive detail effect* influencing the learning task negatively (Lehmann & Seufert, 2017). Kämpfe et al. (2010) supported this assumption by showing an overall negative effect of background music on learning in their meta-analysis.

The reason for this negative impact of background music on attention and on the learning outcome itself can be explained with theories about cognitive processing in the working memory. Up to today, the most accepted theory for how new information is cognitively processed is the *working memory model* from Baddeley and Hitch (1974). Based on the previous model about short term memory that is separated from long term memory (Atkinson & Shiffrin, 1968), Baddeley and Hitch suggested a working memory that is limited in its memory capacity as well as in its processing capacity. It contains three components that are connected with each other: The visuospatial sketchpad, the phonological loop, and the central executive. The working memory consists of the phonological loop which holds new auditive-verbal information and the visuospatial sketchpad which holds visual-spatial information. The central executive connects and guides both the visual and the verbal-auditory information processing channel, allowing the connection of visual and auditory information and transmitting it into the long term memory (Baddeley, 2000).

The memory capacity of the visuospatial sketchpad and phonological loop, as well as the processing capacity of the central executive, are limited (Baddeley & Hitch, 1974): Since the nineteen-eighties, the *cognitive load theory* has been one of the most famous assumptions regarding cognitive processing in working memory. The cognitive load theory assumes that a limitation for cognitive processing, or cognitive load, exists (Sweller, 1988). If a current cognitive task does not require the maximum cognitive load capacity, a part of the cognitive load can be used for other cognitive processes such as listening to music. However, if the task is more complex and requires the maximum cognitive load, additional (musical) information cannot be processed and would result in cognitive overload.

Salamè and Baddeley (1989) argue that it is not possible to hinder the processing of auditory information and that auditory information is always processed first. This negative effect of auditive information happened both for instrumental and for vocal music, with stronger disruption by the latter. Any kind of verbal-auditory information, even if it does not contain known language or language at all, can and will access the phonological loop and can intervene with the processing of other target information (Salemé & Baddeley, 1989). This means that background music would - always and with priority - create a cognitive load that would occupy a part of the working memory capacity, leaving less capacity for the actual learning activity and resulting in a likely lower learning outcome, especially for cognitively demanding learning tasks. As music, which contains auditory information, is processed in the phonological loop, it could intervene particularly with learning activities that require verbal processing in the phonological loop, such as reading comprehension. This assumption is supported, among others, by the meta-study from Kämpfe et al. (2010) which shows that background music impacts memory performance negatively for reading tasks.

Differences in the amount of information contained in music can have a similar negative effect on cognition. For example, music that includes lyrics can increase the negative cognitive effect of music processing because it increases the load for the phonological loop, resulting in a higher negative effect on learning in general (i.e. Perham & Currie, 2014; Salamé & Baddeley, 1989) and for literacy tasks in particular (i.e. Martin et al., 1988). It can be assumed that also other parameters that influence the amount of information contained in music (e.g. more instruments, more complex musical patterns, faster or louder music) increases the cognitive load of music. If a higher information intensity in music generally occupies a higher amount of the working memory capacity due to increased cognitive load, this leaves less cognitive capacity for the learning task, possibly resulting in lower learning outcomes. Thus, the information intensity of music can also contribute to the overall cognitive load induced by music.

Another important factor that defines the cognitive load is the learner's individual cognitive capacity. The *working memory capacity* that is available differs among learners (e.g. Lehmann & Seufert, 2017). Based on Cowan (2016), the working memory capacity describes the number of separate information units that can be processed simultaneously. A higher working memory capacity also benefits more effective learning, because more chunks can be processed at the same time (e.g. Alloway & Alloway, 2010; Daneman & Carpenter, 1983). The working memory capacity of the learner, therefore, defines the individual's cognitive load of a task and the amount of cognitive capacity that is left for other processes, such as listening to music. For example, Christopher and Shelton (2017) found a moderating effect of working memory capacity on the effect of music on student performance, with higher working memory capacity reducing a generally found negative effect of music on reading comprehension.

Neither only the individual working memory capacity, nor the amount of musical information alone could define the cognitive load when doing a task whilst listening to music; differences in musical perception and music processing could also be contributing factors: Learners with higher musical perception abilities could experience an increased cognitive load due to more musical information they perceive and need to process since they cannot ignore this auditive information (Salemé & Baddeley, 1989). This would lead to a higher cognitive load and less cognitive capacity left for the actual learning task. Thus, learners with higher musical perception abilities could be more affected by listening to music while learning, which would ultimately reduce the frequency of how often they listen to music while studying. Furthermore, people with lower musical perception abilities could listen to relatively more music compared to those with a higher musical perception.

Possibly, a higher musical information density (music with lyrics, faster, more energetic, more complex, louder music) could mediate the cognitive effects: If musical perception abilities are low, less information from music would be processed. Music with a high information intensity would not intervene this strongly and could be used more often as background music.

However, most people who like music would agree that they do not like to listen to music solely because they enjoy processing it on a cognitive level. Instead, music has an important emotional component, and how this emotional component is processed can also vary among listeners.

1.4. Emotions Through Music

Music can induce arousal and change the mood of a listener due to the emotions in music - this has been shown in a study by Thompson et al. (2001) who argued that the famous positive cognitive outcomes after listening to musical pieces of Mozart, the so-called *Mozart effect*, actually appears because of the high arousal and positive mood due to the emotions in Mozart's music. This positive effect of arousal and mood also seems to apply when listening to music while studying: Emotions are one of the strongest reasons for listening to music in daily life (Juslin & Laukka, 2004). Ter Bogt et al. (2011) found that relaxation and boredom reduction, which can be seen as emotional reactions to music, are among the most significant effects of listening to music while learning. Since both relaxing and non-boredom effects through music seem to be wanted by learners, it seems like music of both relaxing and energizing character have positive emotional effects on the learner.

Definitions of emotion are numerous and do vary widely across prior research. Some reasons for that are that emotions appear widely in every area of human behaviour and that they are difficult to measure (i.e. Sloboda & Juslin, 2001). Following the dimensional approach to emotions, Russel (1980) created a circumplex model that defines emotions on two dimensions: activation (or arousal, e.g. calm vs. aroused) and valence (e.g. sad vs. happy). These two dimensions of arousal and valence have also shown to be valuable for the domain of music as a source of emotions (i.e. Baumgarten, 1992; Eerola & Vuoskoski, 2011; Grekow, 2018; Merril et al., 2020).

The theoretical approach of two dimensions (arousal, valence) for emotional reactions on music has been used by Husain and colleagues (2002) to explain the Mozart effect with their *arousal-mood-hypothesis*: Arousal and mood are influenced through music. In particular, the tempo in music influences arousal, and the mode (valence) of music influences the mood of the listener. Husain et al. (2002) use the arousal-mood-hypothesis to explain other study results, such as the improved spatial task performance after listening to a Mozart sonata, compared to a short story as a stimulus (Nantais & Schellenberg, 1999). The arousal-mood-hypothesis can also be explained on a neurological level: emotionally arousing music influences dopamine regulation; this neurotransmitter can support motivation and processing in episodic and procedural memory (Salimpoor et al., 2011).

1.4.1. Emotional Reactivity to Music

How strongly someone reacts with changing arousal and mood due to emotions in music can differ individually based on one's emotional reactivity to music (e.g. Vuoskoski et al., 2012). Based on the dimensional approach of emotions induced by music and on the arousal-mood-hypothesis, a high individual emotional reactivity to music could be shown on both dimensions of emotions through music: by high values of arousal, as well as by high absolute valence values in both directions, since high values of arousal are related to highly positive or highly negative values of valence (i.e. Holz et al., 2021).

Measuring emotional reactivity to music is at least as difficult as measuring emotions in general. While only a small part of emotional reactions might be conscious to a person and, as such, can be assessed by self-report, another, probably bigger part happens unconsciously (Scherer, 2005). Thus, measuring emotional reactivity should not be based solely on self-assessment, but should also try to approach unconscious changes based on emotions, e.g. by measuring physiological changes (i.e. Eerola & Vuoskoski, 2011, Scherer, 2005). For example, Merrill et al. (2020) measured in a recent study both psychophysiological and body responses that also included skin conductance and heart rate. They found that the psychophysiological responses can actually differ for the same musical stimulus due to a different task, while physiological responses to music were shown independently from the task. Thus, physiological measures for assessing emotional reactivity induced by music seem to be more stable since they are independent of consciousness. Individual differences in those measures for reactivity of emotions through music could influence the effect of music on arousal and mood, and thus, also the effect that music has on learning.

1.4.2. Effects of Differences in Emotional Reactivity

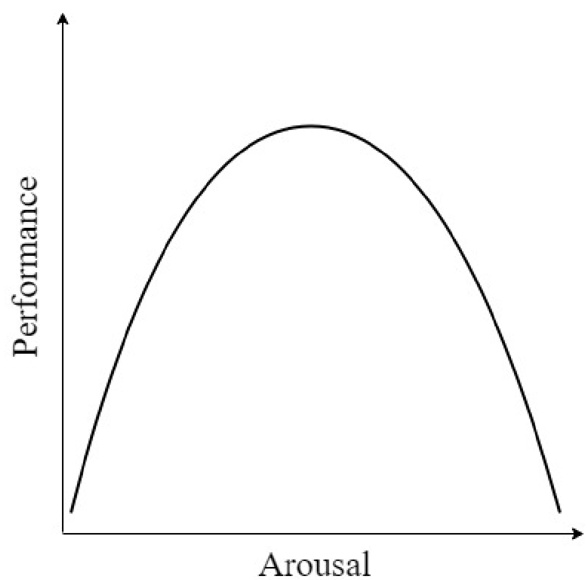
Spoken from a cognitive point of view, music can never benefit cognitive performance directly, as it is always perceived as additional information that needs to be processed, increases the cognitive load and decreases the cognitive capacity for the primary task of a learner. This explains why some learners do not want to listen to music at all. Nevertheless, music is still actively used by a lot of learners in different situations, for example, to relax, alleviate boredom, support concentration (e.g. Kotsopoulou & Hallam, 2010), or affect attention positively in the workplace (Shih et al., 2012).

Thus, music seems to have a (perceived) beneficial effect on the learner that influences the learning situation in another way than directly via cognition. The arousal-mood-hypothesis from Husain et al. (2002) argues that listening to background music affects cognitive abilities and performance indirectly via arousal and mood as mediators: Music is supposed to influence arousal and mood, which then influences the learning outcome and the cognitive performance required for this learning outcome. Therefore, not the music itself, but instead, its effect on the learner could influence the overall learning outcome through improved emotions, mood and arousal (Lehmann & Seufert, 2017). This can be true especially if the working memory capacity of the learner is not completely required for the current learning task so that the positive emotional effects might outweigh the negative cognitive effects of music (Lehmann & Seufert, 2017). For example, the positive emotional effects of music on mood and arousal can also lead to increased motivation and retention when learning rather informally, which is visible in multimedia settings such as digital video games (e.g. Kang & Williamson, 2014; Linek et al., 2014; Richards et al., 2008). Based on these findings, de la Mora Velasco and Hirumi (2020) suggested integrating music into multimedia learning environments, as long as the music is not resulting in cognitive overload.

How does emotional reactivity influence performance in learning? This question can be answered on a more general level with the Yerkes-Dodson law which describes the relationship between arousal and performance in an inverted u-shape as depicted in Figure 1: Increased arousal improves performance up to a high point, after which too much arousal leads to overarousal and performance decreases again (i.e. Hallam & MacDonald, 2009). Transferred to the situation investigated in this study, music listening can be seen as the factor that induces arousal, and learning can be seen as the outcome variable that shows performance. Following the Yerkes-Dodson law, learning outcomes would be best for middle levels of emotional arousal.

Figure 1

Relationship Between Performance and Arousal Based on the Yerkes-Dodson Law



The high point of the Yerkes-Dodson law differs due to individual differences. For example, the high point of the u-shape after which over-arousal and sub-optimal performance appear shifts towards lower arousal levels when the task is more difficult (Konecni & Sargent-Pollock, 1976) or when the working memory capacity is low (Lehmann & Seufert, 2017). Since arousal through the same musical stimulus is supposed to differ for people as well based on individual emotional reactivity to music, this factor could also change the curve of the Yerkes-Dodson law. Learners with middle values for emotional reactivity to music would more likely end up in the beneficial middle part of the curve with middle arousal levels through music. Thus, learners with middle values for emotional reactivity are more likely to profit from emotional arousal through music. Learners with low or with high levels of emotional reactivity would either not react with enough arousal to the music to increase their learning performance, or they would rather tend towards overarousal when listening to music. Based on this assumption, people with middle levels of emotional reactivity to music could listen more often to music because arousal through music is most beneficial for them, compared to high or low emotional reactivity.

1.5. Research Focus

Prior research showed widely controversial findings regarding the impact of background music on learning. Both possible negative and positive effects can be explained using different theoretical approaches. However, it is very likely that many individual factors additionally influence the relationship between background music and learning.

While some cognitive individual factors, such as the working memory capacity or existing pre-knowledge, have already been investigated in prior research, individual differences in the processing of music received less attention in the past. Neither individual differences in musicality or musical perception abilities, nor in emotional reactivity when listening to music have been investigated in this context so far. People who are gifted with higher musical perception abilities could process music differently when listening to it while studying, compared to people with lower musical abilities. Since personality levels might influence the levels of arousal (Eysenck, 1967), the emotional reactivity of a person could also influence the arousal and mood this person reacts with when listening to music in the same way. Thus, the individual factors of musical perception abilities and musical emotional reactivity could influence the assumed u-shaped relationship between musical arousal and cognitive performance, as described by the Yerkes-Dodson law (see Figure 2). Investigating their influences can help to formulate concrete, individual advice to learners about when and why they might benefit from background music in their learning outcome. Additionally, by exploring the habits of background music listening, this study aims to provide directions for relevant scientific research in the future.

1.5.1. Cognitive Approach: Influence of Musical Perception Abilities (H1)

From a cognitive aspect, the cognitive load theory with a limited working memory capacity (Sweller, 1988), and the seductive detail effect (Rey, 2012) suggest that additional information such as music will always occupy cognitive processing capacities, especially since auditive information cannot be ignored and is always processed first (Salamé & Baddeley, 1989).

This could be especially true if the overall learning situation requests all available cognitive resources, either because of high task difficulty (i.e. Lehmann & Seufert, 2017) or - possibly - because of the amount of musical information processed in parallel.

Musical perception abilities differ for individuals (i.e. Müllensiefen et al., 2014). The same music could lead to an increased amount of information that is processed when the individual musical perception abilities are high, resulting in a higher cognitive load through music and lower cognitive resources for the learning activity. This would lead to less frequent music listening while learning. If this effect exists based on cognition, a higher general affinity of music due to higher musical experience and engagement values (e.g. general music listening frequency or prior engagement in musical training and instrument playing) should not be related to a change in the frequency of background music listening while learning. Based on these theoretical assumptions, we predict the following hypothesis (first graph in Figure 2):

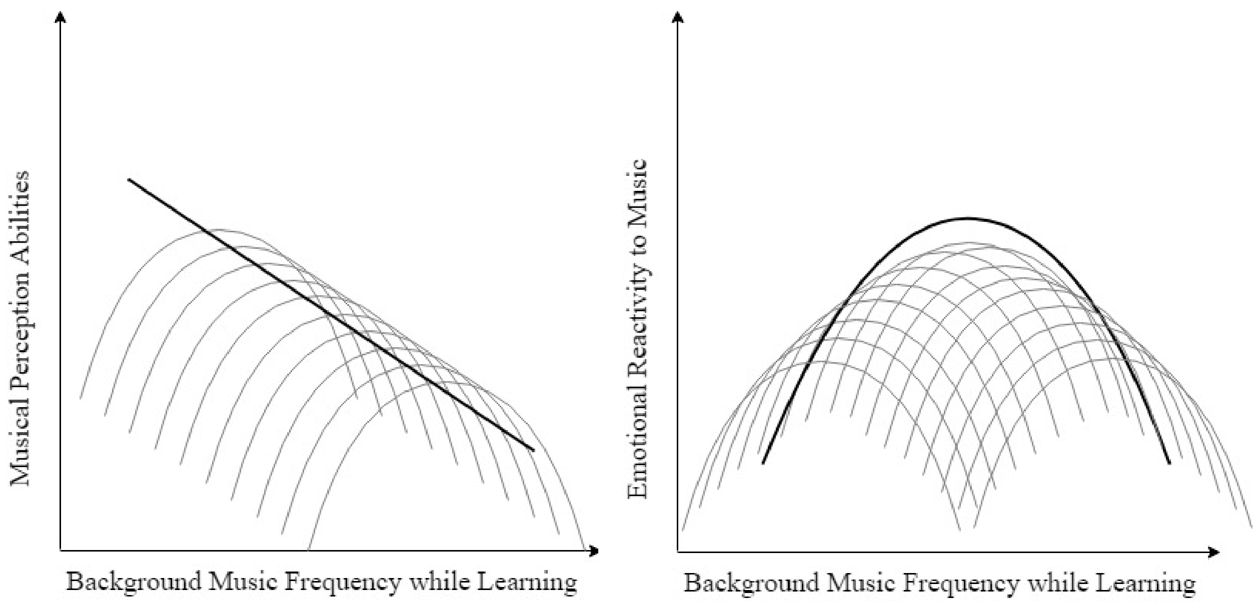
H1: The frequency of listening to background music while studying and the individual musical perception abilities are negatively correlated, after controlling for general musical experience values and musical engagement habits.

1.5.2. Emotional Approach: Influence of Emotional Reactivity to Music (H2)

The amount of needed cognitive load is smaller if the task is simple (i.e. Konecni & Sargent-Pollock, 1976) or when the learner has a high working memory capacity (i.e. Alloway & Alloway, 2010; Daneman & Carpenter, 1983; Lehmann & Seufert, 2017). This could result in boredom - one of the reasons why young people play background music in order to improve their motivation and focus on the task (Kotsopoulou & Hallam, 2010) which they perceive as too easy for activating all their cognitive resources (see also Gonzalez & Aiello, 2019). From an emotional perspective, arousal-mood-hypothesis (Husain et al., 2002) supports a positive effect of background music on learning by improving mood and motivation via emotional arousal. However, too much arousal could reduce the positive effect in learning performance, as stated by the Yerkes-Dodson law (i.e. Hallam & MacDonald, 2016). At which point too much arousal results in overarousal is also defined by different individual parameters, for example, the individual working memory capacity of the learner (Lehmann & Seifert, 2017) or the complexity of the task (Konecni & Sargent-Pollock, 1976).

Figure 2

Assumed Changes of the U-shaped Relationship Through Musical Factors



Note. These graphs show the assumed schematic changes of the generally applying Yerkes-Dodson curve between musical arousal and learning performance (in grey). Due to the individual factors of musical perception abilities (first graph) and emotional reactivity to music (second graph), the frequency of background music listening while studying is supposed to change (in black).

How much learners react emotionally to music could also influence their arousal levels. Thus, individual emotional reactivity to music could influence the relationship described by the Yerkes-Dodson law, while its general structure of an inverted u-shape would still apply. Middle levels of emotional reactivity to music could lead to rather beneficial levels of arousal when listening to music. Respectively, people with middle levels of emotional reactivity to music might listen more often to music while studying. People with low or high emotional reactivity values would listen less often to music while studying, either because they would not be aroused enough or because they would rather be over-aroused through music. We assume the following relationship of emotional reactivity to music with the frequency of listening to music while studying in hypothesis 2 (second graph in Figure 2):

H2: The frequency of listening to background music relates to individual musical reactivity on music following an inverted u-shape: The frequency is high for middle levels *of emotional reactivity, while low-frequency levels appear both for high and low emotional reactivity. This applies to both (a) physiological data (heart rate, skin conductivity) and (b) self-reported values (arousal, absolute valence) of emotional reactivity.*

1.5.3. Explorative Approach: Relevant Habits of Background Music Listening (RQ)

Most of the studies which researched the topic of music and learning approached the effect of a specific type or factor of background music on a specific learning outcome variable. They followed an experimental approach of manipulating an independent variable to see their specific effects. While some of these studies tried to integrate some of the other possible co-variables into their study design, it seems to be nearly impossible to take all the factors collected by Hallam and MacDonald (2016) into account in an experimental study format. This problem goes in line with the heterogeneous study results and their methodological issues, also already mentioned by De la Mora Velasco and Hirumi (2020). To solve the issue of managing the huge amount of intervening factors, a structured approach that uses experimental studies examining factor by factor while controlling for all other factors would be a never-ending task. Instead, this research area should focus on the essential question that it tries to investigate: The effects of background music on learning *when it is actually relevant*. Instead of looking at a single factor at a time, we should first find out which factors actually play an important role in daily life, based on the habits of the learners: How often do people listen to music when learning, or when doing similar cognitively demanding tasks? Which type of tasks are they mainly doing while listening to background music, and it is useful to investigate the effects of background music on these specific tasks? Which is the musical type and mode that people prefer to listen to most of the time when learning? Answers to these questions can guide future research by showing which specific factors are actually worth investigating in a systematic approach that helps to state concrete advice for everyday learning.

Following the first efforts in exploring the existing habits when it comes to music and learning (i.e. Hu et al., 2021; Kotsopoulou & Hallam, 2010), this study wants to further investigate actual habits and parameters of music listening while studying in the following research question:

RQ: Which habits regarding music listening while learning exist based on the frequency, the musical parameters, learning situations, and learner's beliefs?

Concretely, this research question will explore the following sub-questions to provide guidance for future research:

a) *How frequently do learners listen to music while studying?*
b) *In which learning situations do people frequently listen to music?*
c) *Which musical parameters are preferred when listening to music while studying?*
d) *What do learners believe and perceive when learning with background music?*

2. Methods

2.1. Sample

The study sample consisted of N = 129 participants (87 female, M_{Age}= 31.10, SD_{Age}= 12.94). The main part of the sample (n = 66, 52 female, M_{Age}= 25.80, SD_{Age}= 7.52) participated at a computer in the video-lab FEEL ("Forschung zum Emotionalen Erleben im Lehr-Lern-Kontext", research for emotional experience in the teaching-learning-context) in the Department of Psychology at the LMU (Ludwig-Maximilians-Universität München, Germany). Measures of physiological arousal for emotional reactivity were assessed while participants listened to specific musical excerpts. By assessing these physiological data, we followed a suggestion for future research that recommended not only relying on potentially biased self-reported data (e.g. Hallam & MacDonald, 2016; Scherer, 2005). Based on qualitative as well as quantitative data analysis, the physiological measures of five datasets showed bad signal quality for the skin conductance measurement, such as many bumps on the measurement curve indicating irregularities, and an unrealistically high or low number of detected peaks. Thus, the skin conductance data (GSR, galvanic skin response) of these five participants were removed from further analysis, leaving a data set of n = 61 participants for these variables. Additionally, two of these removed data sets for skin conductance values also showed bad values for the heart rate measurement (no clear heartbeat curve) and were removed for the HR variables as well (n = 64).

Additionally, we extended the sample by test persons that participated fully online (n = 63, 35 female, M_{Age}= 36.81, SD_{Age}= 14.95). This additional online data collection allowed a more representative sample since the online study was location-independently and time-independently accessible. It was, thus, also completed by participants living not in Munich and people not related to the university context. Also, this additional online study access assured that data collection could continue independently from potential restrictions due to the ongoing COVID-19 pandemic that could have completely prevented in-person data collection. Besides the absence of the collection of physiological arousal data, the study design and methodology did not differ for online participation, compared to the participation in the FEEL lab since the participation in the lab also completely took place with a computer.

As prerequisites for participation, participants had to be at least 18 years old and understand the German language. The maximum age for participating in the lab study version was limited to 50 years to avoid high age differences and control for side effects related to high age, especially regarding the physiological data.

No major hearing issues for participants were named by participants, but three participants specified that they sometimes have Tinnitus. One participant specified that ignoring loud noises is difficult for her due to autism spectrum disorder. 119 participants were German, 122 spoke German as a native language. 71 participants were students, 45 were employed. Table 1 shows the educational degrees of the sample: 113 participants finished at least the German Abitur (equivalent to a college AA degree) that allows university access.

Table 1

Overview of Education of the Study Sample

Educational degree	Elementary or secondary school	GED or high school (Real-schulabschluss)	College: AA (Abitur)	Higher education (BA, MA, PhD)
n from *N* = 129	3	12	69	45

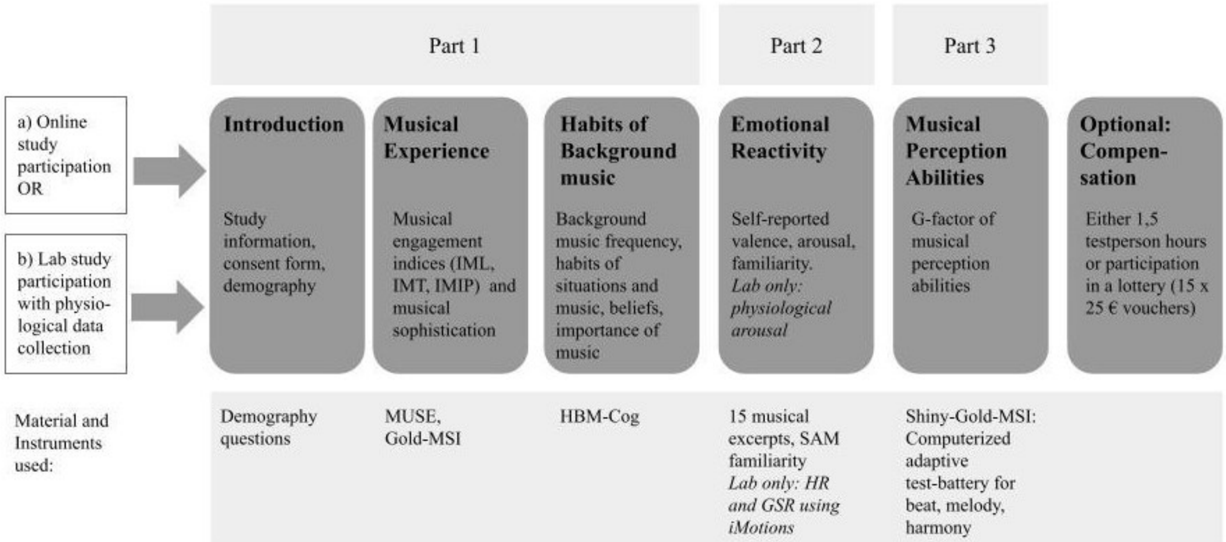
2.2. Research Design and Procedure

Since it was the goal of this study to investigate existing relationships between musical factors and the habits of listening to background music in daily life, the study design does not contain any independent variables. Instead, we measured the dependent variables of musical perception abilities, musical emotional reactivity, and the habits of listening to background music while doing cognitively demanding tasks. As controlling covariates, we measured different values for musical experience and engagement: a global factor of musical sophistication, and indices for music listening, musical instrument playing, and musical training.

Figure 3 shows the study design with all used questionnaires and collected variables. We conducted the study in German. The study contained an introduction and three parts: the assessment of musical experiences and habits as well as demographic variables, the musical emotional reactivity assessment, and the musical perception abilities assessment.

Figure 3

Study Design and Procedure



Note. Online participation and participation in the lab only differed in terms of additionally measured physiological arousal measures in part 2, as indicated with the italic font style.

The introduction included information about the study, a consent form for data collection, and demography questions. The first part of the study assessed the musical experience using both the MUSE indices (Music USE, Chin & Rickard, 2012) for musical engagement and the Gold-MSI (Goldsmiths Musical Sophistication Index, Müllensiefen et al., 2014) for musical sophistication. The habits of listening to background music while doing cognitively demanding tasks was assessed using a survey adapted and extended on the basis of Kotsopoulou and Hallam (2010) and Hu et al. (2020).

In the second part of the study, the emotional reactivity to music was assessed. Participants listened to 15 emotionally arousing music excerpts of movie music (based on data from Merril et al., 2020), which each lasted around 30 seconds. If the participation took place in the FEEL lab, a PPG (photoplethysmography) device from Biopac Systems Inc. was attached to the fourth finger of the left hand to measure the heart rate. EDA-electrodes (electrodermal activity electrodes) from Biopac Systems Inc that were attached to the hand palm measured the skin conductance (GSR). Participants were asked to lay down their prepared hand on a soft block and to avoid movements with their left hand on which the measurement equipment was attached.

Additionally, before listening to the first and after listening to the last music excerpt, we assessed one-minute-long physiological baseline values without music or a task for the participants.

In the third part of the study, the participants completed a computerized adaptive test battery to assess musical perception abilities based on three adaptive sub-tests: the Mistuning Perception Test (Larrouy-Maestri et al., 2019), the Beat Perception Test (Harrison & Müllensiefen, 2018), and the Melody Discrimination Test (Harrison et al., 2017). After completing the study, participants could sign up for a compensation option, either receiving a test-person hour or participating in a lottery for one out of 15 restaurant-vouchers of 25 €. Participants could also sign up for receiving the study results.

2.3. Material

We measured musical engagement and sophistication, musical emotional reactivity, and musical perception abilities with existing questionnaires. For measuring the habits of listening to background music while doing cognitively demanding tasks, a new survey was created based on existing instruments.

2.3.1. Measuring Musical Experience

The musical experience was assessed as a control variable with instruments for measuring musical engagement and musical sophistication. For assessing musical engagement, we used the MUSE (Music USE Questionnaire, Chin & Rickard, 2012). This instrument contains items to measure different indices that assess musical engagement in different contexts: the Index of Music Listening (IML), the Index of Music Instrument Playing (IMIP), and the Index of Music Training (IMT). Additionally, we assessed musical sophistication by using the overall scale of the Gold-MSI (Goldsmiths Musical Sophistication Index, Müllensiefen et al., 2014) that contains the following sub-constructs: Active Musical Engagement, Perceptual Abilities, Musical Training, Singing Abilities, and Sophisticated Emotional Engagement. This instrument for measuring the general musical sophistication score has been validated both for the English-speaking (Müllensiefen et al., 2014) and German-speaking version (Schaal et al.2014). Figure 4 shows example items for the used musical engagement indices and musical sophistication score.

Figure 4

Example Items for Assessing Musical Experience

Index/Scale	**Question**	**Answer options**
IML (MUSE item 1)	On average, how often do you listen to music in a week?	o Less than once a week o 1 - 2 times a week o 3 - 4 times a week o 5 - 6 times a week o More than 6 times a week
IMIP (MUSE item 5)	How long since you last regularly played a music instrument (includes singing, practice, and performance)?	o Less than a week ago o Less than a month ago o Less than 1 year ago o Between 1 and 5 years ago o Between 5 and 10 years ago o More than 10 years ago
IMT (MUSE item 6)	What is the highest level of formal music training you have received?	o None o Primary (Elementary) school music classes o Secondary (High) school lessons o Tertiary (University) undergraduate training o Conservatory of music or master classes o Postgraduate training, or advanced overseas training
Musical Sophistication Scale (Gold-MSI Item 23)	When I sing, I have no idea whether I'm in tune or not.	o Completely Disagree o Strongly Disagree o Disagree o Neither Agree nor Disagree o Agree o Strongly Agree o Completely Agree

Note. All example items are from the MUSE questionnaire from Chin and Rickard (2012), or from the Gold-MSI from Müllensiefen et al. (2014). Abbreviations are Index of Music Listening (IML), Index of Music Instrument Playing (IMIP), and Index of Music Training (IMT). All items were assessed in the German version.

2.3.2. Measuring Musical Perception Abilities

Musical perception abilities as a latent construct cannot be measured directly, but they can be operationalized using different musical tests (e.g. Werner et al., 2016). Individual differences in the cognitive processing and decoding of music exist (Schaal et al., 2014) and are assumed to be visible in different test scores in the Gold-MSI test battery (i.e. Müllensiefen et al., 2014; Pausch et al., in review; Schaal et al., 2014). Furthermore, the scores of the Gold-MSI test battery can be used to calculate one general factor for musical perception abilities (Pausch et al., in review).

Each participant listened to 15 test stimuli for beat and mistuning test, and to 18 for melodic discrimination, from a data set of 10.000 items per test. The music tests all contained examples and a training phase at the beginning of each test. The used stimuli and test items could be replayed unlimited times if wanted.

We used three of the four tests in the Shiny Gold-MSI test battery to calculate an overall score for musical perception abilities, namely the Mistuning Perception Test (Larrouy-Maestri et al., 2019), the Beat Perception Test (Harrison & Müllensiefen, 2018), and the Melodic Discrimination Test (Harrison et al., 2017, Gelding et al., 2020). Mistuning perception describes the ability to define if a voice is too high or too low in relation to the background music (Larrouy-Maestri et al., 2019). In the respective music test, participants had to choose between a correctly tuned and a mistuned version of the same musical excerpt in a two-alternative forced-choice task. Beat perception is the ability to recognize a basic beat within music (i.e. Harrison & Müllensiefen, 2014). In the Beat Perception Test, participants had to decide in a two-alternative forced-choice task which of two versions contained a beep-tone that was on the beat, compared to an off-beat version. In the Melodic Discrimination Task, the ability to differentiating between different melodies was assessed (Harrison et al., 2017). Participants had to choose one out of three melody versions that contained one different tone, compared to the other two versions. All three music tests are adaptive, meaning that they adapt to the initial performance of the test taker and select the item difficulty of following items based on this performance. Computerized adaptive testing allows more precise results with fewer items (e.g. Wainer et al., 2000), resulting in a test score that is relative to the test difficulty. As such, the three computerized adaptive tests are a reliable assessment instrument for measuring the construct of musical perception abilities.

While Pausch and colleagues (in review) used all four music tests of the test battery, we did not include the fourth test of the Gold-MSI test battery, the Musical Emotion Discrimination Test (MEDT, MacGregor & Müllensiefen, 2019), for calculating the general score of musical perception abilities. The MEDT measures the ability of a person to recognize an intended emotional interpretation of the artist and the music (MacGregor & Müllensiefen, 2019). As such, it focuses on the emotional perception only, not relating to the cognitive aspects of musical understanding measured by the other tests in the battery. Another reason for excluding the MEDT was that this test is, in contrast to the other three tests, not adaptive and uses the same items for all participants. Due to this limited amount of items, of item variability and the non-adaptive character, the EDT is not as precise as the other adaptive tests: Results showed a lack of difficulty for this statistical test, with many participants reaching the highest possible norm score (27 of 129 participants, 20.93 %), while the highest possible norm score was not reached by anyone for the other three perception tests (0 of 129 participants, 0.00 %). Thus, the EDT was excluded from calculations for a general score of musical perception abilities.

2.3.3. Measuring Emotional Reactivity to Music

As proxy-variables for emotional reactivity to music (Scherer, 2005), we used self-reported emotional arousal and valence values, as well as physiological measurements (in case of participation in the lab): After each music excerpt, the participants reported valence and arousal using the SAM (Self-Assessment Manikin, Bradley & Lang, 1994) as well as the familiarity of the specific music excerpt. High arousal or high absolute valence values (that resulted from recorded highly negative or highly positive valence values) were used for self-reported emotional reactivity to music since these values are related (Holz et al., 2021).

If the study was conducted in the lab, physiological measures of arousal were assessed while the participant listened to the music excerpts: With measurement equipment from Biopac Systems Inc and software from iMotions (2021), we assessed and measured heart rate (HR) and skin conductance (GSR). For GSR, two EDA-electrodes with Ag/AgCI contact from Biopac Systems Inc were attached to the ball of the left-hand palm after the introduction. Palmar sites have good electrodermal activity and electrodes can be fixed easily there (Boucsein, 2012). These electrodes were only used in the second part of the study, but ohm values (impedance) seem to improve for a more precise measurement of skin conductivity if the electrodes were attached earlier, which is why they were already attached after the introduction. Ohm-values for the skin conductance were measured manually to control for a correct attachment of electrodes, but nevertheless, high differences for these manually measured impedances appeared. Participants were asked to not move their hand with the measurement devices attached to minimize error noise through movement.

The used music was specifically selected for this study based on data from Merril et al. (2020; see also Eerola & Vuoskoski, 2011), after conducting an exploratory factor analysis to identify the 15 music excerpts with the highest physical emotional reactivity: Eerola and Vuoskoski (2011) showed high internal reliability for GSR ($M_{\text{GSR-}\alpha}$ = .86) and for HR ($M_{\text{HR-}\alpha}$ = .98) data. Each musical excerpt lasted approximately 30 seconds. Additionally, two one-minute baselines were recorded before the first and after the last excerpt, in which participants only looked at a black screen in front of them without music playing.

For the collected physiological variables, we calculated means per participant and for all 15 music excerpts for all six GSR and HR variables. After calculating reliability for all six variables across all musical excerpts, we summarized those means to one single physiological value for each variable per participant, across all 15 stimuli. This preparation allowed us to calculate with one overall mean score for each of the used physiological emotional reactivity values per person: Average GSR peaks per minute, average epoch GSR, epoch GSR RMSSD (root mean square standard deviation), average HR, average HR R-R-interval (interval between heartbeats), average HR RMSSD. Reliabilities for all used variables were confirmed using Cronbach’s Alpha and McDonald’s Omega (McDonald, 1999), as shown in Table 2. McDonald’s Omega is more robust against homogeneous factor loadings (i.e. Dunn et al., 2014), which makes it a suitable second measure of internal consistency next to Cronbach's Alpha. Means for Raw Alpha and Omega values for the single physiological GSR and HR variables were calculated across all 15 musical excerpts used. We used the GSR and HR variables in the further analysis separately to cover different aspects of physiological arousal. However, mean baseline values and mean music values did not significantly differ across participants for any of these physiological variables.

Table 2

Reliability of Variables Measuring Physiological Emotional Reactivity

Construct	Physiological emotional reactivity on music					
Variable	Average peaks per minute	Average epoch GSR	Epoch GSR RMSSD	Average HR mean	Average HR RR interval (reversed)	Average HR RMSSD (reversed)
Raw Alpha	.97	1	.97	.98	.86	.81
Omega	.98	1	.98	.98	.96	.94

Note. Average epoch GSR consistency values are exceptionally high because the applied poch algorithm already uses internal reliability values and adapts the output according to them.

2.3.4. Developing an Instrument for Habits of Background Music

While the previously elaborated instruments were tested and validated multiple times in research (e.g. Bradley & Lang, 1994; Müllensiefen et al., 2014; Pausch et al., in review; Schaal et al., 2014), no instrument that assesses the habits of listening to background music while learning, or while doing any cognitively demanding tasks, existed up to today. Existing questionnaires about the usage of background music mainly focus on daily tasks, not necessarily taking the cognitive demand into account: For example, Juslin and Laukka (2004) created a survey about the role of music in daily life including many non-cognitive activities such as listening to music “while waking up”, “while doing a workout”, or “while eating”. A rather unknown “Daily Living Questionnaire” from Rosenblum et al. (2017) used items that describe household tasks, activities involving language, communication or participation situations, and complex tasks which are not necessarily highly cognitive though (e.g. “paying bills” or “fixing/repairing things”). Some other approaches that were of interest for this studies approach rather focus on measuring the frequency of doing cognitive tasks (e.g. the Florida Cognitive Activities Scale that focuses on the elderly generation, Schinka et al., 2005) or the mere cognitive load while doing specific tasks in the laboratory setting (e.g. Leppink et al., 2013). These did not include habits of music listening, which made them not useful for this study.

Since there did not exist a useful instrument for measuring the frequency and habits of music listening while studying, we created a new survey for *habits of listening to background* *music while doing cognitively demanding tasks* (HBM-cog). Two studies provided material that showed to be useful for our direction of research: A survey from Kotsopoulou and Hallam (2010) and an interview script from Hu et al., (2021).

Kotsopoulou and Hallam (2010) looked at the perceived impact of playing music while studying and created a 5-point rating scale survey with a frequency from "never" to "always". With this survey, they explored the music listening habits of young people while learning for different ages and nationalities, as well as if they are aware of the impact that music has for them while studying. Their questionnaire was validated using interviews with young people of their target population. The survey included the presentation of different studying situations (e.g. "I listen to music while:"... "studying" / "memorising texts" / "doing course work" / "studying my least favourite subject"). Furthermore, it presented statements for beliefs of the influences of music (e.g. "I believe that music:"... "Helps me concentrate" / "Alleviates my boredom" / "Interferes because it makes me too aroused") and for situations, reasons and habits (e.g. "I listen to music when studying when I am happy", "I turn the music off when I dislike the subject", "Listening to music depends on the subject"). Some items are only applicable in the institutional learning context such as school or university.

We used the items focusing on habits of background music (situations, beliefs) from the Kotsopoulou and Hallam survey (2010): We selected and adapted the sub-items to make them suitable for a broader population instead of being applicable only in the school and university learning context. We also used their 5-point rating for agreement as an answer scale.

Secondly, Hu et al. (2021) recently conducted a qualitative study with 40 in-depth interviews of Chinese university students to investigate university student's use of music for learning and well-being. In their interview script, they used questions like "what kind(s) of music do you like listening to?", "In what kind(s) of situations do you frequently listen to music? Why?", "Based on your own experience, what do you think about the possible effects of music listening on learning?", and "On a scale of 1 (not important at all) to 10 (extremely important), rate the importance of music in your life. Why?". These questions show some content-wise overlaps with the survey from Kotsopoulou and Hallam (2010) in regards to the learning situations of music listening and the beliefs about the effects of music on learning.

From Hu et al. (2021), we used the content of the questions asking for types of music listened to ("What kind(s) of music do you like listening to?",) and the general importance of music in one's life ("Rate the importance of music in your life."). For the types of music, we added the context of studying, as well as some quantitative structure by asking specifically for the frequency (on the same 5-point rating scale from Kotsopoulou and Hallam from "never" to "always"). We decided to ask a general question about the frequency of listening to background music while doing cognitively demanding tasks, and to also ask specifically for the types of music in additional items: Instead of an open-answer-format for the kind(s) of music from Hu et al. (2021), four sub-items for the types of music were defined based on the musical parameters that have proven to influence the effect of background music on learning (e.g. de la Mora Velasco & Hirumi, 2020; Hallam & MacDonald, 2016, see also Appendix A). These parameters are also easy to self-assess for participants (e.g. asking for the genre or the complexity of the music is much more difficult to answer). The sub-items for the type of music are the vocalization (instrumental vs. vocal music), speed of music (slow vs. fast), the volume of music (quiet vs. loud), and the energy (calm vs. energetic music). Evidence for the relevance of these musical parameters was given in the literature review in chapter 1.2; an extended analysis can also be found in Appendix A. The items about musical parameters preferred as background music can also be answered on a 5-point scale for frequency, ranging from one pole to the other (e.g. "only instrumental music", "more instrumental than vocal music", "both instrumental and vocal music", "more vocal than instrumental music", "only vocal music"). Lastly, we transformed the "music relevance" item from Hu et al. (2021) into a quantitative answer format on a 10-point Likert scale: "On a scale from 1 to 10, how important is music in your life?".

We conducted five cognitive interviews in English and in German in order to ensure an easy understanding of this adapted, but not yet validated instrument HBM-cog for assessing musical habits when doing cognitively demanding tasks. Based on these cognitive interviews, we extended the introduction text: We defined "cognitively demanding tasks" with "activities that require concentration, such as reading, writing, calculating, or learning". Furthermore, we excluded items that are not relevant if the participants answered "never" in the general frequency of listening to background music while doing cognitively demanding tasks (the situations and the type of music used when studying). After these improvements, the HBM-cog was easy to understand and to answer, based on the cognitive interviews that we conducted.

The final version of the HBM-cog can be found in Appendix B and contains five questions that assess:

a) The frequency of music listening (HBM-frequency) while doing cognitively demanding tasks on a 5-point scale from “never” to “always”.
b) The type of learning situation in which background music is used, containing 7 situations independent from the institutional context that can be confirmed or denied, as well as an additional open-answer option (adapted from Kotsopoulou & Hallam, 2010).
c) The preferences of listening to specific types of music, with a 5-point scale from *only A* to *only B*, containing four musical parameters with poles from instrumental-vocal, slow-fast, quiet-loud, and relaxed-energetic (adapted from Hu et al., 2021, musical parameters selected based on the literature review).
d) The beliefs of effects of music on learning (based on Kotsopoulou & Hallam, 2010).
e) The general importance of music in one’s life on a scale from one to 10 (adapted from Hu et al., 2021).

Appendix B shows the complete HBM-cog survey used in this study. Overall reliabilities for the numeric scale values (excluding the situation-items with Boolean format) were acceptable with Cronbach’s Alpha of .81 and McDonald’s Omega of .87. For the numeric items included in the question for preferred musical types, Cronbach’s Alpha was .80 and McDonald’s Omega was .88. The beliefs items also showed acceptable reliability with Cronbach’s Alpha of .74 and McDonald’s Omega of .81.

2.4. Statistical Analysis and Data Preparation

Data was collected and analysed in iMotions (2021). For statistical analyses, both the analysing algorithms of iMotions (2021) for emotional physiological data, as well as the statistics software R was used. From iMotions, the Peak Detection Algorithm from © iMotions (as available in iMotions 9.0.5, 2021) calculated the GSR peaks per minute. The GSR epoch algorithm from the R-Notebooks “GSR Peak Detection” from © iMotions (as available in iMotions 9.0.5, 2021) calculated average GSR values, as well as average RMSSD (root mean square standard deviation) values. This epoch algorithm uses a lowpass filter (Empirical Iterative Algorithm) with cut-off frequency to remove powerline noise for GSR signal pre-processing. By applying the “Fixed Duration” option, the original signal was reduced to an equally sized time-epoch signal that represents the average GSR signal for a stimulus over a specific time frame (for a more detailed explanation, see Gautam et al., 2018). Data points for all three used GSR variables were provided by the R Notebooks export in average values per 1000 ms time frames (original data contained data points for every two milliseconds). Besides to these pre-processed GSR values, we used HR average, HR-R-R-interval (interval between heartbeats) average, and HR RMSSD (root mean square standard deviation) average calculated per 1000 ms by the R Notebooks from © iMotions (as available from iMotions 9.0.5, 2021).

The test battery for musical perception abilities (containing tests for mistuning perception, beat perception, melody discrimination) also contained a system-integrated calculation of standardized means for each test. The three tests in the test battery for the musical perception are adaptive; the scores for each test provide standardized normally distributed ability estimates based on item response theory.

Further calculation of physiological data, test battery mean scores per subtest and of the survey data was done in R Studio (R Core Team, 2013, version 4.0.3). We used the "dplyr" package (v1.0.2; Wickham et al., 2020) for data restructuring and the "psych" package (v2.0.12; Revelle, 2020) for calculating reliabilities. With the "lavaan" package (Rosseel, 2012), we calculated exploratory and confirmatory factor analyses to create weighted general scores. The package "ppcor" (v1.1; Kim, 2015) was used to calculate correlations and partial correlations. Polynomial regression was calculated with the "stats" package (R Core Team, 2013, version 4.0.3). Graphs were refined with the help of the "PerformanceAnalytics" package (v2.0.4; Peterson & Carl, 2020). For cluster analysis, "cluster" (v2.1.0; Maechler et al., 2019), and "fpc" (v2.2-9; Hennig, 2020) were used.

For the analysis, we created a general music perception abilities score and a general music information intensity score. Following Pausch et al. (in review, see also Müllensiefen et al., 2014), we created one overall score of musical perception using the sums of weighted values of the three used subtests from confirmatory factor analysis. We also created a general "information intensity" score for the four items asking for the frequency of learners listening to specific musical parameters (volume, speed, relaxed-energetic, instrumental-vocal) based on exploratory factor analysis. We assume that increased volume or speed, as well as more energetic music or music with vocals inevitably intensify the amount of auditory information in music so that creating an overall factor score based on these items seems logical.

Based on the beliefs items, we calculated two underlying factor scores: The 10 items (e.g. "I believe that listening to music while learning helps me concentrate") showed two underlying factors in the minimal average partial procedure (Velicer, 1976). An exploratory factor analysis revealed good loadings for most of the items (.47 - .94) and three items with low loadings (below .4). After excluding the three items with loadings lower than .4 (reversed item: "I believe that music interferes because it makes me too aroused.", reversed item: "I believe that music interferes because I sing along.", "I believe that music keeps me company."), we conducted a confirmatory factor analysis for a model that predicted the two underlying factors we found, which were named "concentration beliefs" (cognitive approach) and "atmosphere beliefs" (emotional approach). The respective item loadings are shown in Table 3. The fit for this model was acceptable based on the cut-off values recommended by Hu and Bentler (1999), with a robust Comparative Fit Index (CFI) of .96 (CFI > .95), a robust Root Mean Square Error of Approximation (RMSEA) of .07 (RMSEA < .08), and a Standardized Root Mean Square Residual (SRMR) of .05 (SRMR < .06). Thus, we created two general factor scores for *concentration beliefs* and *atmosphere beliefs* based on the predicted estimates using the loadings of the CFA.

We used partial correlation for investigating the relationship between the general score for musical perception and the frequency of listening to background music while learning, controlling for musical engagement indices and musical sophistication. For investigating the possible u-shape of correlations, we used polynomial regression with the different factors for emotional reactivity to music (self-reported arousal, self-reported absolute valence, HR-values, GSR-values) as predictors and the frequency of listening to background music as the dependent variable. For further exploratory analyses of habits of background music, we used descriptive data and correlation analyses for the relationships between frequency and the different habits regarding music, situation, and beliefs. Additionally, we used hierarchical agglomerative clustering based on Ward (Ward Jr, 1963) to explore possible clusters, especially with regards to the selected learning situations.

Table 3

Factor Loadings for Beliefs

Belief item	**Item number**	**Loadings Factor 1**	**Loadings Factor 2**	**Communality *h2***
Concentration	8	0.91		0.82
No concentration (reversed)	9	0.74		0.52
Faster learning	10	0.72		0.53
Focus	5	0.67		0.56
Too aroused (reversed)	7	0.39		0.14
Singalong (reversed)	6	0.22		0.05
Relaxation	3		0.94	0.89
Mood	4		0.72	0.52
No boredom	2		0.47	0.21
Company	1		0.31	0.09

Note. Items with loadings lower than .4 were excluded for confirmatory factor analysis and for calculating two factor scores based on this analysis. The two factors were named “concentration beliefs” (factor 1) and “atmosphere beliefs” (factor 2).

3. Results

3.1. Descriptive Statistics

The descriptive statistics of the sample provide first insights into the frequency of listening to music, the musical perception abilities and emotional reactivity, the musical experience, and the habits of listening to background music based on the HBM-cog survey.

Most participants listen “rarely” to music while studying on the 5-point Likert scale (median = 2, n = 36), with an average score of M = 2.57 (SD = 1.19). 30 participants answered that they “never” listen to music, while 99 listen at least sometimes to music (36 “rarely”, 26 “sometimes”, 33 “frequently”, and four “always”). The sample showed high overall importance for music (M = 8.37 on a scale from 1 to 10) and was rather sophisticated in music (M = 4.51 on a scale from 1 to 7). Table 4 shows descriptive data for all measured and analysed variables, providing an overview of the data with minimum (Min) and maximum (Max) values, means (M), and standard deviations (SD) for the measured variables.

Descriptive analysis of the HBM-cog items, in particular, contains indications for the specific situations, the type of music, and the beliefs of the learners about listening to music while studying. Table 5 shows the frequencies of listening to music in specific learning situations across the sample, showing that participants listen most often to music while generating ideas (52.71%) and the least often while memorizing content (13.18%). Seven participants added other situations in the open answer response input field (“Doing tasks”, “Painting”, “Diverse tasks on the desk”, “Daily work”, “Car driving”, “Planning”, “Translating texts”).

Learners differed in the frequency of choosing different musical parameters (speed, volume, relaxing-energetic, instrumental-vocal) for their learning situation (see Table 6). But there is no item that shows specifically high means (all means are between M = 2.13 and M = 2.57, on a scale from 1 to 5). The general information intensity factor that was built based on values from an exploratory factor analysis shows a mean of M = 7.08 (on a range from 2.90 to 14.50).

Table 4

Factors with Descriptive Data and Their Correlations with HBM-frequency

Factors						HBM-frequency	
	n	Min	Max	*M*	*SD*	*r*	*CI*
Age	129	18.00	74.00	31.18	12.94	-.22*	-.38, -.05
Musical perception	129	-2.46	1.24	0.00	0.67	-.31***	-.46, -.15
HBM Frequency	129	1	5	2.57	1.19	1.00***	1, 1
Amount of Situations	129	0.00	8.00	2.44	2.00	.80***	.73, .85
Music intensity	99	2.90	13.01	7.08	1.89	.21*	.02, .40
Concentration beliefs	129	-1.96	2.31	0.00	1.03	.76***	.68, .83
Atmosphere beliefs	129	-4.02	1.48	0.00	0.96	.25**	.08, .40
Importance of music	129	1.00	10.00	8.37	1.52	.14	-.03, .31
Musical sophistication	129	1.29	6.75	4.51	1.25	-.15.	-.32, .02
IML	129	1.00	25.00	8.61	4.64	.31***	.14, .46
IMT	129	1.00	10.00	5.24	2.42	.00	-.17, 0.17
IMIP	112	0.03	300.00	18.49	42.34	-.07	-.24, .12
Arousal	129	2.27	6.88	4.72	0.93	.05	-.12, .22
Valence	129	0.40	3.00	1.62	0.47	.12	-.05, .29
GSR peaks per minute	61	0.00	12.65	3.78	1.62	-.04	-.28, .20
GSR epoch (ms)	61	0.51	6.05	2.45	1.29	-.01	-.25, .23
GSR epoch RMSSD	61	0.00001	0.00038	0.00010	0.00007	.02	-.22, .26
HR average	64	56.19	114.28	76.18	11.02	-.02	-.26, .23
HR R-R-interval (ms)	64	528.70	1108.20	844.20	141.37	-.05	-.29, .19
HR average RMSSD	64	31.57	453.42	206.34	115.43	-.11	-.34, .14

Note: Factors are grouped by demography, musical perception abilities, background music habits, musical experience, self-reported, and physiological emotional reactivity (lab data set). Significance values are indicated: "." for < .1, "*" for < .05, "**" for < .01, and "***" for < .001.

Table 5

Agreement for Different Learning Situations

Learning Situation	"True" from $N = 129$	Percentage of agreement
Studying	48	37.21 %
Reading	60	46.51 %
Writing	41	31.78 %
Calculating	34	26.36 %
Memorising	17	13.18 %
Problem Solving	40	31.01 %
Idea Generation	68	52.71 %
Other (open answer)	7	5.43 %

Table 6

Music Parameters and Their Correlations with the HBM-frequency

Musical parameters					HBM-frequency	
	Min	Max	*M*	*SD*	*r*	*CI*
Instrumental- Vocal	1	5	2.40	1.10	.24*	.04, .42
Speed: Slow - fast	1	4	2.57	0.72	.17.	-.03, .35
Volume: Quiet - Loud	1	4	2.13	0.74	.18.	-.01, .37
Relaxing - Energetic	1	5	2.57	0.74	.11	-.09, .30
Information intensity score	2.90	13.01	7.08	1.89	.21*	.02, .40

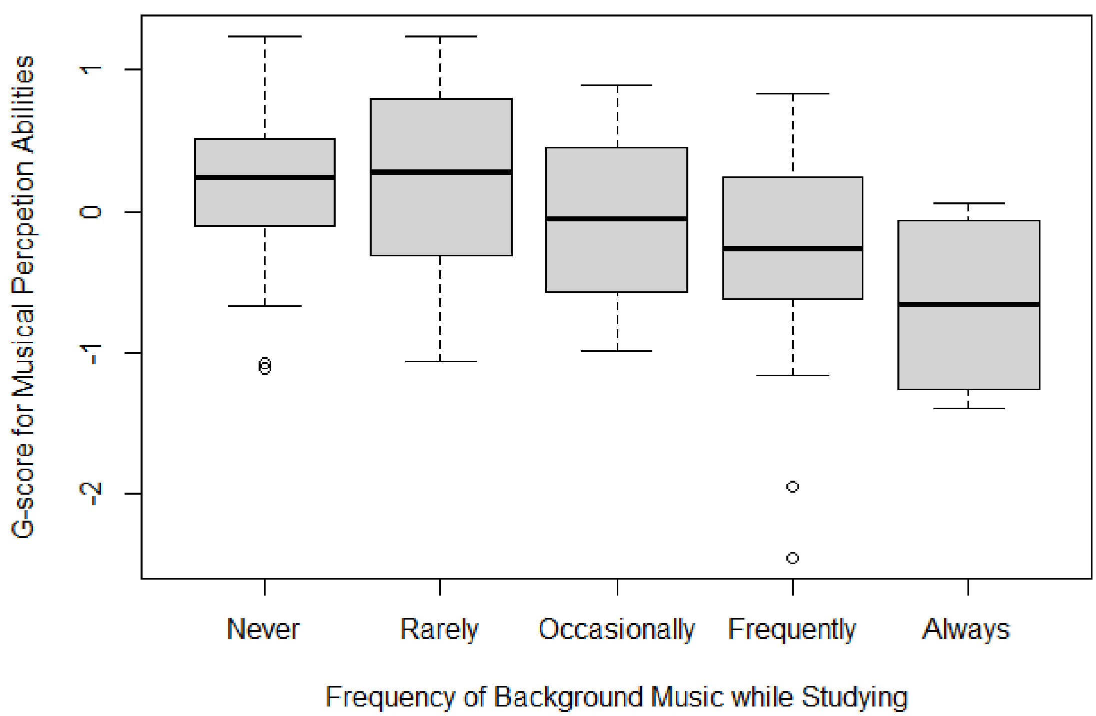
Note. The values are based on $n = 99$ participants, excluding $n = 30$ participants who reported that they never listen to background music while studying. Significance values are indicated: "." for < .1, "*" for < .05, "**" for < .01, and "***" for < .001.

3.2. Relationship of Background Music Frequency and Perception Abilities (H1)

Figure 5 shows the relationship between the frequency of listening to background music while doing cognitively demanding tasks and the general factor of musical perception abilities. The data showed a weak but highly significant negative relationship that is independent of general musical engagement and sophistication: Partial correlations for frequency and perception abilities are significant after controlling for the general index of music listening (IML, r = -.33, p < .001). The partial correlation between frequency and musical perception also holds true after controlling for other measured factors of musical experience, which are the index of music training (IMT, r = -.32, p < .001), the index of music instrument playing (IMIP, r = -.29, p = .002), and the musical sophistication score (r = -.28, p = .001). Thus, hypothesis 1 can be confirmed.

Figure 5

Relationship Between HBM-frequency and Musical Perception Abilities



Only four participants selected the "always" (5) option for the frequency of background music. Since the boxplot in Figure 5 shows the lowest perception ability for this level of frequency, the negative relationship should be confirmed without the small number of answers for this "always" option. After downrating the four "always" answers to the more conservative answer of “frequently” (4), the correlation between frequency and perception abilities still holds true, with only a slightly reduced correlation coefficient and a constantly high significance value ($r = -.30$, $p < .001$).

3.3. Relationship of Background Music Frequency and Emotional Reactivity (H2)

The possibility of an inverted U-shape between emotional reactivity on music and the background music frequency was inspected using the emotional reactivity variables as predictors in a linear as well as a second-degree polynomial regression model. Simple correlation analysis already showed non-significant relationships, visible in Table 4. Linear regression of the frequency on all variables of emotional reactivity could not be confirmed due to non-significant regression results for all variables of emotional reactivity to music. Adding a quadratic predictor x^2 to the regression model did not improve the fit significantly and also only showed non-significant results. Figure 6 and Figure 7 show slightly inverted u-shapes in the graphs of the fit for a quadratic polynomial regression for self-reported arousal and valence with the HBM-frequency. Further graphs showing the quadratic polynomial regression model fit for the frequency and the physiological HR- and GSR-data can be found in Appendix C. No significant linear or negative quadratic relationship between the background music frequency and the emotional reactivity values was found. Thus, no inverted u-shape between these factors was found and hypothesis 2 was rejected.

However, further investigating the relationship between emotional reactivity variables and the frequency of background music, a significant difference was found for participants who never listen to background music while studying (score of 1, $n = 30$) and participants who listen at least sometimes to music while studying (score of 2 to 5, $n = 99$): The self-reported absolute valence values for listening to music are significantly higher for participants that listen to background music at least sometimes, compared to those never listening to background music while learning ($t = 2.08$, $p < .05$).

Figure 6

Quadratic Polynomial Regression Fit for Frequency and Self-reported Arousal

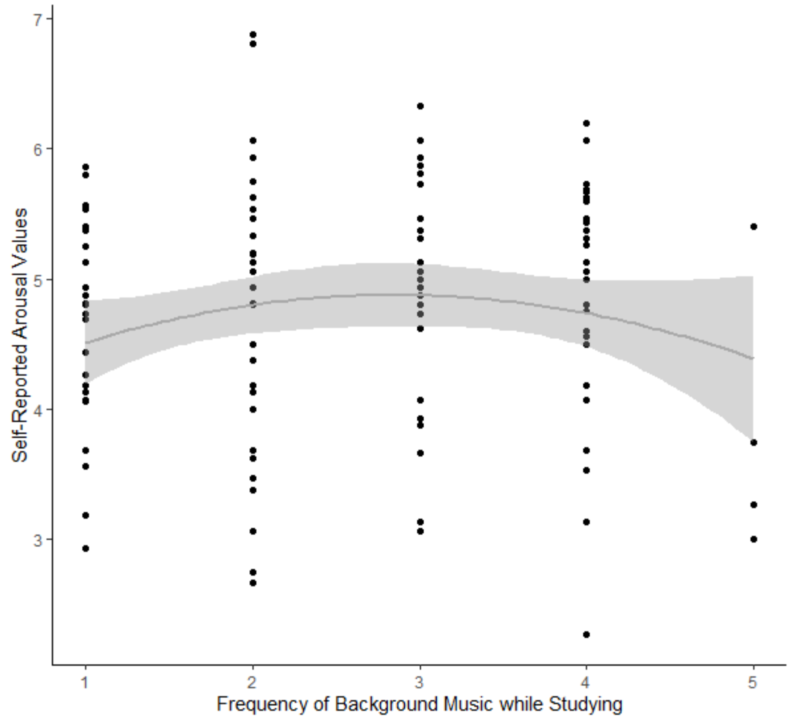
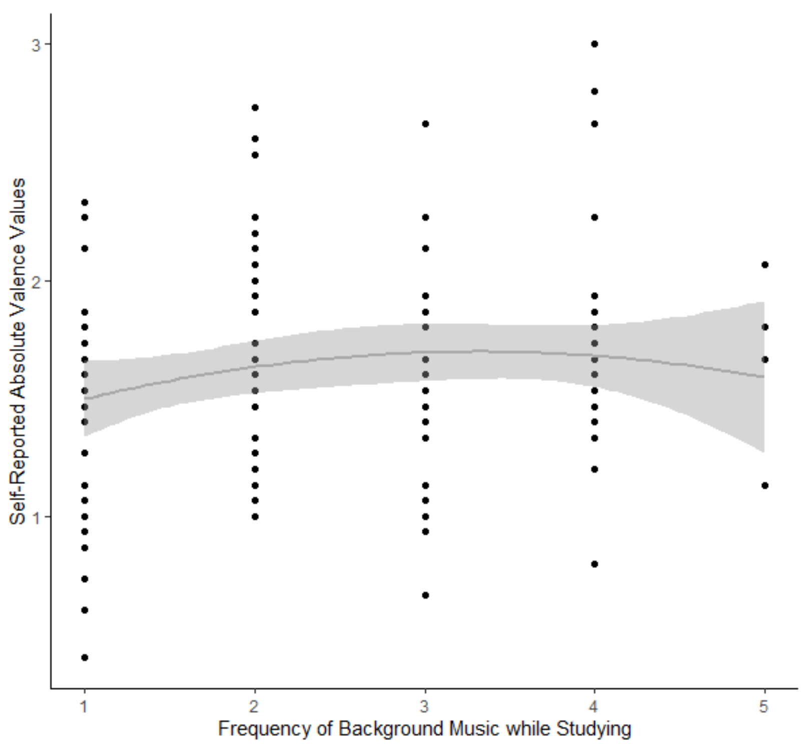


Figure 7

Quadratic Polynomial Regression Fit for Frequency and Self-reported Valence



3.4. Exploratory Analyses of Additional Influencing Factors (RQ)

In an exploratory research question, habits for specific musical, situational, and conviction factors were investigated. Relations towards individual musical factors (background music frequency, emotional reactivity to music, musical perception abilities, sophistication, IML, IMT, IMIP) were also explored. Correlations with all assessed variables and the frequency of listening to background music while studying (HBM-frequency) are also shown in Table 4.

The cognitively demanding situations in which participants listen or do not listen to music (studying, writing, reading, calculating, memorizing, problem-solving, idea generation) were answered in a Boolean format. A strong positive correlation between the item score for the frequency of background music (HBM-frequency) and for the amount of studying situations selected (r = .80, p < .001) was found. The general background music frequency while studying also differed significantly between agreeing and disagreeing groups in almost all specific situations (t-values between t = 1.99 and t = 4.64, significance values between p < .05 and p < .001, after excluding participants that "never" listen to music since they could not select any answers for the situation items): higher frequency values were found for the group that agreed to listen to background music in the single situations. Solely for the "Idea generation" situation, we found only a tendency but no significance towards the same effect (t = 1.79, p = .078). The patterns of the Boolean answer variables for the presented situations of cognitively demanding situations were inspected with cluster analysis. Hierarchical agglomerative clustering following Ward (Ward Jr, 1963) did not show more than one significant group indicating that there are no existing subgroups that would build specific clusters.

The general information intensity factor for preferred music correlated weakly positively with the background music frequency (r = .21, p = .033) and with the index of musical training (IMT, r = .22, p = .029). When looking at the single underlying items, the background music frequency correlates significantly with the frequency of listening to instrumental or vocal music (r = .24, p = 017.). No further significant correlations between the types of music and the frequency of background music were found, although tendencies for a positive correlation are shown for speed and volume of the music with the HBM-frequency (see Table 4).

As elaborated earlier, the beliefs of effects of background music on studying were merged into one concentration beliefs factor and one atmosphere beliefs factor based on loadings from confirmatory factor analysis. Both beliefs factors correlate weakly with each other (r = .31, p <

.001). A strong and highly significant positive correlation between the background music frequency and the concentration beliefs was found ($r = .74$, $p < .001$), while the correlation of background music frequency and the atmosphere beliefs factor was only weak but also highly significant ($r = .24$, $p < .001$). At the same time, weak positive correlations between both beliefs factors existed with the Index of Music Listening (IML, concentration beliefs: $r = .30$, $p < .001$, atmosphere beliefs: $r = .23$, $p = .008$). The concentration beliefs factor also showed a weak negative correlation with the general factor for musical perception abilities ($r = -.17$, $p = .048$).

The last item of the HBM-cog survey investigated the general importance of music in the participant's life. This factor showed a moderate positive correlation with the atmosphere beliefs ($r = .39$, $p < .001$) and a weak positive correlation with self-reported valence ($r = .26$, $p = .003$). It did not show any significant correlation towards the background music frequency, but a moderate one towards the general music listening habits (IML, $r = .48$, $p < .001$).

3.5. Additional Findings

3.5.1. Musical Experience, HBM-frequency, and Perception Ability

As the relationship between background music frequency and perception abilities is supposed to be independent of musical experience, we also gathered insights about the relationships of these factors controlled for. The background music frequency was weakly positively related to the general index of music listening (IML, $r = .31$, $p < .001$). The background music frequency does not show any considerable correlations with other indices of musical engagement (IMT, IMIP), but a weak negative correlation tendency with musical sophistication ($r = -.15$, $p = .088$, see also Table 4).

As for the musical perception abilities, no correlation with the index of music listening (IML) has been found. However, there is a tendency towards a positive correlation with the index of music training (IMT, $r = .15$, $p = .082$) and a weak significant positive correlation with the index of music instrument playing (IMIP, $r = .24$, $p = .001$). A moderate positive correlation has been found between musical perception abilities and the musical sophistication score ($r = .56$, $p < .001$).

3.5.2. Relationship of Self-reported and Physiological Emotional Reactivity Data

All physiological variables across all musical excerpts did not differ significantly from average baseline values that were assessed before and after listening to all musical stimuli. For further insights into the measurement of self-reported and physiological arousal data when listening to music, we investigated the relationship between self-reported and physiologically measured values of arousal. Table 8 shows the correlation between all variables assessing emotional reactivity to music with indications of significance. GSR values correlated strongly among each other ($r = .67$ to $.88$, $p < .001$). Moderate to strong negative relationships applied for HR-means with the HR deviation scores R-R interval and RMSSD ($r = -0.93$ and $r = -0.41$, $p < .001$), indicating lower deviation when the HR-mean is higher. A tendency for a negative correlation between GSR peaks per minute and HR deviation values (R-R interval, RMSSD) appears, but is not significant (between $r = -0.19$ and $r = -0.13$, $p > .05$). Self-reported arousal and valence are weakly correlated ($r = .24$, $p = .006$). No significant correlations between self-reported values and GSR values were found. Self-reported values and HR values are correlated negatively, with higher self-reported arousal and valence values relating to lower HR-means (arousal: $r = - 0.35$, $p = .004$, valence: $r = -.25$, $p = .043$) and self-reported arousal relating to higher HR deviation values (HR-R-R intervals with $r = .34$, $p < .007$, HR RMSSD with $r = .31$, $p < .013$).

3.5.3. Age Effects

We found weak age effects shown in a negative correlation with the general music listening index (IML, $r = -.28$, $p = .001$), as well as with the specific background music frequency ($r = -.22$, $p = .012$). Furthermore, a weak negative correlation between age and the general score for musical perception abilities was found ($r = -.27$, $p = .002$).

3.5.3. Location of Participation

The data sets collected in the FEEL lab compared to the online assessment only differed regarding additionally measured physiological data, with both versions having exactly the same study procedure and content besides that. However, the different locations of participation should be investigated to exclude possible co-variables due to different assessment modes.

The group of participants that participated in the lab differed significantly from the test persons who participated online in age, the general music listening habits (IML), and the musical training (IMT): Participants in the lab were younger ($t = -5.24$, $p < .001$), listened more often to music in general (IML, $t = 3.28$, $p = .001$), and had a lower music training index (IMT, $t = -4.39$, $p < .001$). There also was a tendency towards a lower factor score for the concentration beliefs for the lab participants ($t = -1.74$, $p = .085$). No other significant group differences were found.

Table 7

Correlation of Self-reported and Physiological Emotional Reactivity to Music

	1	2	3	4	5	6	7	8
1. Arousal	**1.00**	**0.24****	-0.07	-0.18	-0.03	**-0.35****	**0.34****	**0.31***
2. Valence		**1.00**	0.13	0.06	0.08	**-0.25***	0.20	0.08
3. GSR Peaks			**1.00**	**0.67*****	**0.88**	0.14	-0.19	-0.13
4. GSR mean				**1.00**	**0.67*****	0.02	0.00	0.18
5. GSR RMSSD					**1.00**	0.02	-0.09	-0.06
6. HR mean						**1.00**	**-0.93*****	**-0.41*****
7. HR R-R							**1.00**	**0.64*****
8. HR RMSSD								**1.00**

Note. Calculations were done with the complete data sets from the lab participation, with $n = 61$ for GSR variables and $n = 64$ for HR variables. Significance values are indicated: "." for < .1, "*" for < .05, "**" for < .01, and "***" for < .001.

4. Discussion

Nowadays, music is an omnipresent and always accessible option in everyday life, especially, since it can influence our emotions and moods (i.e. Hallam & MacDonald, 2016). Thus, music is also used in cognitively demanding situations like learning. However, individuals differ subsequently in their habits of listening to background music while studying (e.g. Kotsopoulou & Hallam, 2010). Most prior studies that investigated the effect of music on learning focused mainly on narrow relationships including different influencing factors (musical, situational, and individual differences) and found controversial results (e.g. de la Mora Velasco & Hirumi, 2020; Hallam & MacDonald, 2016). Inter-individual differences in musical perception and processing have not been investigated in this area of interest but could provide an explaining approach to the controversial findings. They could also provide approaches and advice to when and for whom music could be beneficial while studying. Further, information about actual habits of listening to background music while learning is rather rare. The current study approaches these research gaps by investigating the effects of inter-individual differences in music processing on both the cognitive and the emotional level, as well as by exploring how background music is used while studying. In sum, our results showed that cognitive overload due to individual differences in musical perception seems to be more likely than emotional drive through emotional reactivity to music. Furthermore, the explorative study results regarding the habits of background music listening provide a picture of how frequently and in which ways music is used while studying. The findings are elaborated and discussed in the following.

4.1. Musical Factors and Their Influences

4.1.1. Cognitive Overload Through Musical Perception Abilities (H1)

From a cognitive perspective, it has been argued that music as additional information will always require attention (seductive-detail-effect, Rey, 2012) and cognitive load (Sweller, 1988) that can only negatively influence learning by reducing the overall cognitive capacity of the learner. Since auditory information cannot be ignored and is always processed with priority (Salamé & Baddeley, 1989) in the working memory (Baddeley & Hitch, 1974), an increased musical understanding through higher perception abilities would lead to more cognitive load and would reduce the working memory capacity for the learner (cognitive load theory, Sweller, 1988). Based on these theoretical assumptions, the first hypothesis of this study assumed a negative correlation between individual musical perception abilities and the frequency of listening to music while studying that is independent of general musical experience values.

The first hypothesis could be confirmed: Higher individual perception abilities of music relate to a lower frequency of listening to background music while studying and this relationship is not simply created by general musical engagement or experience. This finding allows the discussion of different arguments, which are presented in this section: First and foremost, the results indicate that music creates a higher cognitive load for learners with high musical perception abilities. Secondly, this cognitive argumentation is supported by the fact that the result is independent of musical experience values such as general music listening or musical sophistication: The effect does not appear merely because people with higher musical perception abilities listen to more music in everyday life in general, or because they engage more often with music, but it appears specifically for the context of learning. Thirdly, the results also show that learners seem to realize the possible disadvantages of music for themselves specifically and adapt their learning habits accordingly to the cognitive effort that background music induces in them. Lastly, this section will discuss if a causal relationship of musical perception abilities influencing the frequency of background music while learning, or vice versa, can be assumed.

Why are musical perception abilities and the frequency of music listening while learning related to each other? Musical perception abilities seem to influence cognitive load: When learners with high musical perception abilities process background music, the music creates more cognitive load for them compared to people with lower musical perception. The music as auditory information cannot be ignored and is always processed with priority (Salamé & Baddeley, 1989). Therefore, listening to it requires cognitive effort (i.e. Berlyne, 1973) because perception requires information processing (i.e. Marr, 1982). This increased cognitive load reduces the limited cognitive capacity that is needed for the learning task, based on the cognitive load theory (Sweller, 1988). Thus, music is more likely to generate cognitive overload when musical perception abilities are high, which results in music being more likely to intervene in the cognitive learning process. Due to higher probabilities of intervention by music, learners with high perception abilities listen less often to background music while learning, compared to learners with lower abilities of musical perception.

This cognitive argumentation is supported by the fact that the effect is independent of general musical habits and experiences: The finding does not depend on general musical engagement, such as music listening, musical training and instrument playing indices (Chin & Rickard, 2012), and general musical sophistication as defined by Müllensiefen et al. (2014). This is specifically interesting for the general listening habits that are measured with the index of music listening (IML), as they have shown to correlate positively with the music listening frequency specifically in learning situations: People who listen more often to background music while studying also listen more often to music in general, while, on the other hand, they also have lower musical perception abilities. However, by partialling out the general music listening index, the negative effect between musical perception and background frequency was shown to be independent of the correlation between general music listening and specific music listening while learning. Instead, general music listening also showed to be unrelated to perception abilities, which means that people who listen in general more often to music do not have higher or lower perception abilities. These additional findings further support the assumed and argued cognitive effect for individual perception abilities on music listeners: Musical perception abilities only seem to be of relevance when it comes to a cognitively demanding situation such as learning, but they do not concern the general music listening habits.

The musical sophistication factor (Müllensiefen et al., 2014) does correlate moderately positively with the musical perception abilities, which confirms the findings from previous studies (Müllensiefen et al., 2014, Schaal et al., 2014, Pausch et al., in review): Musical perceptual abilities are one of five sub-constructs that build the musical sophistication score (Müllensiefen et al., 2014), and as such, the musical perception abilities test score loads moderately on this higher-order sophistication factor (i.e. Pausch et al., in review). At the same time, the musical sophistication factor shows a tendency for a weak negative relation with the background music frequency assessed in this study that could appear only due to the perception ability factor included in the sophistication construct.

The results of the first hypothesis also highlight the reliability of self-assessed habits of music listening while learning. Our study results allow us to argue that these self-assessed habits can be used to measure real underlying effects of music on learning: By only using self-reported information about habits differences in the effect of music on learning could be shown on a cognitive level. Kotsopoulou and Hallam (2010) already showed in their study that learners seem to be able to decide on a metacognitive level when background music is beneficial for their learning and when it intervenes too much with their learning process (see also Hu et al., 2021).

This study confirms those initial findings: learners seem to be quite aware of the effect that music has on them and individually adapt their learning habits accordingly. While music might be perceived as beneficial for those learners who do not perceive that much musical information, learners who are more negatively affected by background music seem to know about this rather negative effect: They listen less often to music while studying.

Can the correlation be interpreted as a causal relationship? Based on Gagné (2015), musical perception abilities are traits that are rather stable and based on talent, and as such, they can only be trained to a limited amount. This allows the interpretation of an influence of individual perception abilities on the background music frequency: Prior existing high musical perception abilities can lead later to a lower frequency of background music listening while doing cognitively demanding tasks. On the other hand, Gagne's (2015) model also contains a development element that allows training through specific catalysers. Müllensiefen et al. (2014) suggested the construct of musicality in a multi-dimensional approach because musical sophistication can develop through different ways and channels. Thus, it could also be argued that, by listening to music even while learning, musical perception abilities are trained, which helps them develop. Further investigations, for example with a longitudinal study format, are needed to investigate the direction of a possible causal relationship.

4.1.2. Emotional Drive Through Emotional Reactivity to Music (H2)

Emotional reactivity to music differs between individuals (Vuoskoski et al., 2012). Positive effects of music are supposed to appear through emotions induced by the music, constituting one of the strongest motives for listening to music (Juslin & Laukka, 2004). Applying the approaches of the arousal-mood-hypothesis (Husain et al., 2002) and the Yerkes-Dodson law to the relationship of music and learning (Hallam & MacDonald, 2009), individual emotional reactivity could also influence the effect of music on the overall learning performance. The second hypothesis suggested a relationship of emotional reactivity to music with background music frequency that follows an inverted u-shape, with the highest levels of listening frequency for middle levels of emotional reactivity. However, we did not find such a quadratic relationship between the background music frequency and any variables of emotional reactivity of music, which resulted in declining the second hypothesis.

Although the graphs that are shown in Figure 6 and 7 indicate a tendency of the proposed relationship in an inverted u-shape, this study could not confirm that emotional drive through music, and, respectively, the background music listening frequency, is influenced through individual emotional reactivity. This means that, based on our results, people with middle levels of emotional reactivity to music do not benefit more from music than people with rather low or rather high levels of emotional reactivity. The effect of the arousal-mood-hypothesis (Husain et al., 2002) seems not to be influenced by inter-individual differences in emotional reactivity to music. Prior findings suggested that inter-individual differences in emotions are of relevance if it comes to musical effects (Vuoskoski et al., 2012). These differences in emotions through music cannot be further explained by individual differences in emotional perception and reactions. Furthermore, we could not show that the Yerkes-Dodson law that describes the relationship between performance and arousal in an inverted u-shape (Hallam & MacDonald, 2009) can be influenced through differences in individual reactivity to music.

Our results indicate that individual differences in musical processing rather lead to cognitive overload than to emotional drive through music while learning. Since the inspected context (studying) also has a cognitive character, an emotional drive through music might be more important when it comes to less cognitive situations, for example, workout, housework, or driving. Nevertheless, this study also proved that a lot of people use background music actively in one or multiple learning situations, with only around one out of four people never listening to music while studying. Since the effects of music are not explained through cognitive advantages, other reasons for the perceived benefits through music, such as emotional drive, are still likely. If individual differences in emotions through music while learning exists, this would mean that this study was, unfortunately, not able to measure them.

There are several reasons which might explain the non-significant result for emotional reactivity to music, such as a high measurement error, non-representative stimuli or methodological gaps. Firstly, we could not find any significant differences between baseline averages and music averages for all physiological data measured in the FEEL lab (in fact, for some participants the baseline means were higher than the music means). A reason for that could be that the physiological measures used in this study (HR, GSR) are not valid or sensible enough to assess differences based on the rather weak stimulation by music. Manually measured ohm values (impedance) for GSR differed a lot between participants which could result in a high standard error for these measures, including a low detection of GSR peaks. HR values seem to be a bit more stable, but might also be not that sensitive to small changes in emotional arousal.

Another reason for the lack of differences between stimuli and baseline values might have appeared because the baseline values are not a valid representation for a baseline. While assessing the baselines, participants looked for a minute on a black screen in a laboratory without windows, and with measurement instruments attached to their hand, which might result in much higher arousal values than intended.

Secondly, emotional reactivity values might show no significant results because the stimuli were not strong enough. We used stimuli based on a study from Merril et al. (2020). However, Merril and colleagues used additional physiological measures (facial electromyography and respiration). Furthermore, they used other measurement approaches to assess physiological arousal (they attached the skin conductance electrodes to the index and the middle finger instead of having both electrodes on the ball of the hand), as well as other procedures than the iMotions algorithms to prepare the data. Epoch algorithms for GSR data and the HR means used in this study might lead to smaller results for reactivity, or the statistical and methodological methods in the study by Merril and colleagues (2020) might be more sensitive towards changes based on stimuli. Also, Merril et al. (2020) did not assess additional self-reported values for arousal and valence.

Thirdly, stimuli for emotional reactivity might not be realistic enough for the subject inspected, namely the background music frequency while studying. We used instrumental film music excerpts only, but the HBM-cog survey results showed that learners do not listen only to instrumental music. Instead, they vary widely in the type and musical parameters preferred. For example, the used stimuli were mostly melodic rather than rhythmical. Possibly, the used stimuli did not induce the "same" arousal as the music that is used while learning. Thus, the used stimuli could have failed in driving the performance with the right amount of arousal, based on the Yerkes-Dodson law. We assumed that emotional reactivity can be seen in high values of arousal and high or low values of valence due to the two-dimensional approach of emotions (e.g. Eerola & Vuoskoski, 2011) and the findings from Holz et al. (2021). However, not many studies investigated the construct of emotional reactivity in the domain of music listening yet. How strongly people react emotionally to music could rather depend on different (musical) factors. Thus, the used stimuli may not induce the same emotional reactions as music used for learning.

Besides the stimuli and measurement features mentioned above, the methodological approach for assessing background music frequency might be another possible reason for not finding significant results that are related to the individual emotional reactivity: We only used a 5-point Likert scale to assess the HBM-frequency. While this measurement seemed to be valid as it showed a very high correlation with the number of learning situations in which participants listen to music, it might not be sensitive enough to register changes of slopes since it is not a continuous variable. Instead, a percentage item (e.g. asking for the percentage of learning time that is spent with background music), might provide more detailed differences in learner's music listening habits.

Interestingly, a post hoc analysis revealed a positive effect of music listening while learning with the self-reported absolute valence data: People who at least sometimes listen to music while studying showed significantly higher emotional reactivity to music (based on absolute valence values), compared to people who never listen to music. This additional finding can be explained through the positive effects suggested by the arousal-mood-hypothesis (Husain et al., 2002): People with higher emotional reactivity through music shown by more extreme valence values benefit more from the emotions induced by music, which helps them to get into a mood that is beneficial for them when learning. However, this finding contradicts the proposed result that was theoretically built on the Yerkes-Dodson law. Further, this effect was only found for valence values, but not for arousal values which were also assessed via self-report. Additionally, group sizes for this finding differed a lot. Thus, this argumentation lacks a more profound theoretical and methodological basis and needs to be invested in more detail before providing clear statements.

Nevertheless, this small effect could be a hint towards possible (positive) effects of emotional inter-individual differences influencing the effect of music on learning. One could argue now that this effect of a high listening frequency emerges only due to *perceived* advantages of music, although, in reality, music can only have negative cognitive effects. However, the significant result of this study found in the first hypothesis also showed that the cognitive effect was visible by only assessing self-reported habits. This speaks for a profound meta-cognition of adult learners: They seem to know when music is beneficial for their learning and when it is not. Thus, it is likely that the *perceived* positive effect of music, which is most likely the reason for listening to music while learning, is built on a *real* underlying positive effect of music. Even though a positive effect could not be confirmed within the assumptions made in this study, the study results do indirectly argue for the existence of a positive effect that should be further investigated in the future.

4.1.3. Exploring Habits: Situational, Musical, and Beliefs Factors (RQ)

In a research question, the study additionally investigated actual habits of music listening while doing cognitively demanding tasks regarding background music listening frequency, preferences in musical parameters, selected learning situations, and beliefs about effects. The results of the research question showed interesting insights into the habits of learners regarding their use of background music that can be used to provide advice on, and approaches for, future research in this area. The research question inspected the frequency of background music while studying, the specific learning situations, the types of music that are used, the beliefs, and the general importance of music.

Most importantly, the results showed the existence of a high general frequency of music listening while studying: More than three out of four adult learners listen at least sometimes to music. Further, there seems to be an increasing trend towards more music listening in studying situations since age effects showed a higher frequency for younger participants. This high overall frequency, with higher values especially for younger generations, confirms the relevance of the research topic, also for the future.

Preferences for specific learning situations can provide hints for future research towards those situations that are more relevant than others because music is played more often with them. A strong positive correlation between the background music frequency and the amount of studying situations selected indicates that the items for the different situations of learning, which are mainly taken from Kotsopoulou and Hallam (2010), are good representations for learning situations. Learners listen most often to music while they generate ideas, and least often while they try to memorize content. This replicates the findings from Kotsopoulou and Hallam (2010), who also showed that music was less often used for memorising or revising, but more often for thinking or writing. Memorizing content requires a lot of working memory capacity, especially if the content is verbal. Music might interfere more severely with the phonological loop of the working memory because this part is used to decode auditive knowledge (Salamé & Baddeley, 1989). On the other side, music might not intervene that strongly when ideas are produced; rather, it might help the learner in generating a creative, relaxed atmosphere on an emotional level. This also goes in line with a study by He et al. (2017) who found mediating effects of emotional arousal through music (both with positive and with negative music) on the effect of listening to music on creative thinking. Based on these findings, future research could differentiate between those learning activities that require all cognitive capacities, such as memorizing content and those who do not need all cognitive capacities but rather require creative inspiration, such as creative thinking or creative writing.

Learners differ regarding their preferred music and its parameters, but in general, people who listen more often to music also seem to prefer music with higher informational intensity (tendentially louder, faster, more energetic music that more often has vocals). This finding highlights again the importance of inter-individual differences regarding music and learning, especially, if it comes to music preferences. Further, it supports the cognitive load effect of music while studying that was found earlier for the first hypothesis: People who listen less often to music also prefer music with less information if they listen to music since this intervenes less with their cognitive learning process. In fact, the relationship between frequency and musical information intensity holds true especially for instrumental vs. vocal music: This could be explained with the phonological loop that can be more occupied by music if vocals are included (Salamé & Baddeley, 1989), increasing the distraction for the learner and leading to a lower frequency of music listening.

The individual working memory capacity can also play a role when it comes to the intervention of cognitive resources through music: Higher working memory capacity increases the amount of optimal arousal for the highest performance value in the curve of the Yerkes-Dodson law (Lehmann & Seifert, 2017). Since individual working memory capacity was not assessed in this study, the positive relationship between frequency and vocal music (as well as generally increased information intensity in music) could, thus, be simply a result of a higher working memory capacity of some participants. Future studies could investigate this relationship by assessing working memory capacity and the habits (as well as the preferences) of listening to music while studying.

Kämpfe et al. (2010) suggested that we need more testable theories that explain the effect of music on learning on different levels. Asking learners about their beliefs of the effect of music on learning can provide an approach for shaping such theories. The two identified factors for beliefs, one for increased concentration, one for improved atmosphere through music, both relate to overall music listening habits (IML) and to the frequency of listening to music specifically while learning: People who listen more often to music while studying also believe that music helps them concentrate and that it improves the atmosphere for them, resulting in a better mood and being more relaxed. Importantly, this relationship is much stronger for the concentration beliefs than for the atmosphere beliefs. This indicates that the main reason why people like to listen to music while studying is the perceived improved concentration. Interestingly, this perceived effect of improved concentration through music indicates a positive cognitive effect that is stronger than the atmosphere beliefs on an emotional level, contradicting the negative cognitive effect of music found earlier.

Lehman and Seufert (2017) already argued that the positive effects of music might outweigh the negative ones especially if the working memory capacity of the learner is not completely required. Recently, Gonzalez and Aiello (2019) provided an explanation that is related to perceived boredom while doing a task: They showed that music is beneficial for simple tasks, especially if external stimulation due to higher boredom proneness is preferred by the learner. Thus, people might perceive an improvement in their concentration through listening to music while studying, because they would be bored by only doing the (simple) task without the additional cognitive stimulation through music. Research could use this information to further investigate why people listen to music in cognitively demanding situations, and which positive effects influence this preference. This information could then be actively used to improve learning situations with stimulation through background music – at least if the situational, musical, and individual parameters allow it. Therefore, further investigation, especially regarding the (perceived) positive effects of music on learning, are worth the efforts for future research.

4.2. Study Limitations

This study investigated inter-individual differences regarding musical perception and reaction factors and also investigated the status quo of music listening habits while learning. The discussion of the results above already provides some aspects towards this study's limitations and respective ideas for future research. Some more limitations of this study are discussed in the following and should be taken into account for generating valid implications provided by this research project.

We assessed and analysed physiological data of arousal to measure individual emotional reactivity to music that does not only rely on self-report. However, both the measurement and the data itself confronted us with methodological challenges: While the physiological data was measured in the same laboratory room with the same devices and software, participants showed to differ widely regarding base values, especially for skin conductance. The manually assessed ohm values (impedance values) differed largely which indicated high differences in the preciseness of measured data. The assessed baseline values for both heart rate and skin conductance did not differ significantly from the values that were assessed with music, indicating that either the baseline scores did not demonstrate good values of comparison, or that the heart rate and skin conductance scores assessed with music were not valid. The used software for assessment and analysis, iMotions, does contain research-proven data-preparation algorithms, but those algorithms were not scientifically validated in terms of emotional reactions to music. Furthermore, iMotions does not contain any algorithms yet that control the data sets themselves for their validity and measurement correctness, resulting in applying a merely qualitative data set revision. These possible limitations might have prevented us from finding significant results for emotional reactivity to music in the physiological measurements and should be accounted for in future studies.

Secondly, the HBM-cog survey that was developed specifically for this study relies on two existing scientific instruments and showed good reliability scores, but it has not been validated in a bigger scope yet. Especially having only one item with a 5-point Likert scale answer for assessing music listening frequency while learning might not be sufficient for assessing smaller differences in the frequency of listening to music while learning. We also found a lack of instruments that can be used to assess the cognitive load for different learning activities, preventing that the learning situations used in the HBM-cog can be rated based on their average cognitive demand or task difficulty.

The framework from Hallam and MacDonald (2016) that was used to define the important factors that should be assessed by the HBM-cog also suggest some other influencing factors that were not taken into account in this rather short survey to limit the scope of the testing time (for an extensive overview and argumentation, see Appendix A). For example, the familiarity on different levels (familiarity of music, situational familiarity of listening to background music while studying) was highlighted by this framework but has not been taken into account in this first version of the HBM-cog. By extending and validating the HBM-cog or similar instruments in the future, more effects could be detected.

Thirdly, this study assessed data in two modes: people could either participate in the FEEL lab or they could participate online. While having an online version allowed to conduct the study with a larger and more heterogeneous sample, the different settings could include unnoticed factors: The lab setting was the same for every participant but could have increased average arousal due to excitement. Online participation was a lot more casual and relaxed for participants but varied most probably more regarding different environments, different devices, and different audio speakers or headphones. These possible intervening factors could not be controlled for the online sample.

Lastly, the sample might not have been representative. Most participants had high levels of education, with the majority at least attending or attended university. However, variables directly related to cognitive performance have not been assessed in this study, but the educational level might still influence the general musical sophistication, e.g. through socio-economic status. More importantly, high mean scores for sophistication and an extremely high average score for the importance of music in one's life indicate that the study topic attracted especially people who were interested or at least fond of music and music listening. Due to that, the number of people with lower perception abilities, lower emotional reactivity to music, lower musical experience values, and lower musical interest might have been rather small. With having a sample that has fewer people with low musical interest, experience, and abilities, effects might not have become visible that are only accessible with more (musically) heterogeneous samples.

5. Implications for Learners and Researchers

Which implications can be deducted from this study and its results for learners and researchers? For the common learner, this study can help to explain why some people prefer listening to music while learning and others do not, especially when doing specific learning activities. Based on our results, learners with lower musical perception abilities might profit more often from music while studying because the music does not intervene that strongly for them; however, other factors are also affecting this effect. More importantly, our findings suggest that every learner should accept that their habits and preferences for listening to background music while learning can (and should) differ from the habits of other people such as peers or parents. Furthermore, anyone that is concerned about a possible negative effect of music on a studying activity of learners, such as teachers, instructors, or parents, should know about the existence of important inter-individual differences. Our results indicate that they can trust the (adult) learners' capabilities to self-define if listening to music is still beneficial for their overall learning outcome or not.

For the research in this area of interest, multiple implications can be made. Firstly, the presented results can be an approach to explain the controversial results of studies by inter-individual differences in musical perception. Musical perception abilities have not been addressed in any past studies that researched the effects of music on learning. It could be an important co-variable that might have influenced these studies and contributed to their controversial outcomes. Prior research already defined a lot of important factors that influence the relationship between music and learning, and that concern the musical parameters, the situation and individual factors (Hallam & MacDonald, 2016). Based on the negative cognitive effect of background music on learning proven in the current study, musical perception abilities is another important individual factor that influences the (cognitive) effect of music on learning, besides already researched individual factors such as personality (e.g. Cassidy & MacDonald, 2007; Dobbs et al., 2011), or the individual working memory capacity (Lehmann & Seufert, 2017). Hallam and MacDonald (2016) already suggested a factor of musical experience that influences the effect of music and learning. In fact, based on our study's results, musical perception abilities seem to play an even bigger role than musical experience and should, thus, be included in frameworks and investigations of this topic in future research.

Musical perception abilities could be of specific relevance when learning requires all cognitive resources, and, accordingly, when studies investigate such situations of high cognitive demand. Based on prior studies, a high cognitive load can emerge due to a difficult learning task (Konecni & Sargent-Pollock, 1976) or due to a lower individual working memory capacity (i.e. Lehmann & Seufert, 2017). Musical perception abilities can be treated as a third factor that influences the cognitive load of a person in a learning situation with background music. Future studies that investigate the relationship of music and learning with concerns of the cognitive effects of music should, thus, take all three factors into account to assess the cognitive load for the learner. For example, it would be interesting to explore how these factors relate to each other and how strongly they contribute to the overall cognitive load of the learner in a studying situation.

Even though no positive influences of individual musical factors for the relationship between background music and learning were confirmed in this study, the results nevertheless indicate some positive effects by the mere level of frequency: 99 out of 129 people answered that they listen at least sometimes to music while doing cognitively demanding tasks, which is more than three out of four learners. This reveals that a majority of learners at least seem to perceive a positive impact by background music in learning situations. Since this study found negative cognitive effects only by self-assessing musical habits, it can be assumed that real effects underlies those habits not only regarding negative but also regarding beneficial influences of music. Despite the negative results that have been shown in this study and in other studies (for extensive overviews, see de la Mora Velasco & Hirumi, 2020; Hallam & MacDonald, 2016; Kämpfe et al., 2010), some perceived positive effects of background music must exist that outweigh the negative ones for *some* people in *some* learning situations with *some* types of music. Further, it can be said that the cut-off that defines when the perceived positive effects outweigh the perceived negative effects seem to differ widely across individuals. Individual factors are, thus, also for future studies an important aspect that has not been investigated a lot in the past and should be taken into account to further explore the wide differences in results when it comes to music and learning.

Not only the assumed inter-individual differences but also the research settings could be a reason for the controversial past findings that contradicts the high popularity of music listening demonstrated in this study. A lot of conducted studies measured the effect of background music on learning in an experimental lab setting. This includes systematically manipulated types of music, a rather short testing time, a rather artificial cognitive task, and a limited assessment of individual factors that often cover only the basic demography. However, learners seem to vary a lot regarding their musical (or non-musical) preferences. In real life, they can always select the preferred music for a situation, for example, because of their familiarity with the music that can induce emotions by associating specific music with specific life experiences (Juslin & Sloboda, 2013). The tasks that they do while listening to music usually take longer than a few testing minutes, which could lead to a positive overall effect for learning that only appears in the long term. For example, a learner could be less efficient in his or her learning process when learning with music compared to no music in the short term. But since music can increase motivation and retention (i.e. Kang & Williamson, 2014; Linek et al., 2014; Richards et al., 2008), a learner could stay motivated and more focused on the long term, which could result in an overall higher learning outcome, even though the needed time increased through music. Understanding these positive effects could enable us to actively use background music in a supportive manner for learning and educational settings, for example by improving instructional videos with background music and sound effects (de la Mora Velasco et al., 2021).

To ensure that future research can give scientific advice that is relevant for learners in practice, it is of utmost importance to take these variabilities in the real-life setting into account. This study can be seen as an approach to explore more about the tasks, situations, music, and individual factors that are relevant in daily life, following first studies by Kotsopoulou and Hallam (2010) and Hu et al. (2021). Future studies are advised to follow this direction and further investigate which elements in the relationship between music and learning are actually of importance. Only after conducting a profound basis about this, future research could adjust the dependent and independent variables, and their study designs accordingly. This allows future studies to investigate those factors in the systematic way that makes research so reliable, but while focusing on factors that matter for the common learner. By following this suggested order of research foci, future studies can generate valid results while making sure that the goal of a study is also applicable and useful for the typical learner.

6. Conclusion

Music is more and more omnipresent and accessible in every part of our daily lives, including situations of learning. However, research on this topic shows controversial results, no findings for the role of individual musical factors, and the tendency to focus on a small relationship of single factors in a big, multidimensional construct. This study investigated the influence of inter-individual differences in musical perception and emotional reactivity to music for the effect of music on learning to explain the high amount of differences in prior research and learners preferences. It further provides insights about the habits of background music listening while learning to provide future research with information about relevant aspects and factors.

Based on several cognitive theories and effects (Baddeley & Hitch, 1974; Rey, 2012; Salamé & Baddeley, 1989; Sweller, 1988), we assumed a negative effect of higher individual musical perception abilities with the frequency of listening to music while studying that is independent of musical experience. From an emotional perspective, we assumed a relationship following an inverted u-shape for emotional reactivity to music with the frequency of background music while learning, following the arousal-mood-hypothesis (Husain et al., 2002) and the Yerkes-Dodson law (based on i.e. Hallam & MacDonald, 2009). In a research question, we investigated the habits of music listening while doing cognitively demanding tasks.

A negative relationship between musical perception abilities and the frequency of listening to background music while studying confirmed an increased cognitive load through music when musical perception abilities are higher. Furthermore, this result showed that learners are proficient in adapting their music listening habits based on the actual underlying individual cognitive effects. No u-shaped relationship of the individual musical reactivity and the frequency of listening to background music while studying was found, but a post hoc analysis suggested a slightly positive effect of higher emotional reactivity to music that is related to a higher frequency of background music listening. Additional investigations regarding habits of background music while learning revealed that preferences regarding learning activity and music type vary a lot among learners. Music was used most often for creative learning activities, and less often for memorizing content. Reasons for listening to music seem to be a higher perceived concentration in the first place, but also improved atmosphere and relaxation seems to contribute. Generally, music is very important to learners and a high percentage of people like to listen to music while learning, which highlights the increasing relevance of the topic also for future research.

Future studies could address the limitations of the present study, especially by improving the assessment and analysis processes for physiological arousal data, extending the HBM-cog survey, and assessing a more representative sample that also contains more people that are less interested in music. Differences in individual musical perception should be added to the list of factors that influence the relationship between music and learning. Furthermore, future studies could investigate how and to which extent the overall cognitive load is increased by task difficulty, working memory capacity, and musical perception abilities in a learning situation with music. They should investigate why music is perceived as helpful, especially due to perceived improved concentration and in situations that do not require all cognitive but rather inspirational capacities, such as creative thinking. In any case, research should focus on further investigating the habits of learners in the first place and derive factors from these habits that are of relevance for the common learner, before investigating single factors on a systematic and narrow scientific scope.

This research project provided insights into why we differ that much if it comes to music listening preferences while studying. For learners and educators, the findings suggest accepting inter-individual differences for the effects of music on learning, and also being open for possible positive effects of music. If it comes to comparing possible cognitive overload versus emotional drive through music while learning, the study was able to provide an unambiguous answer: While both cognition and emotions seem to affect the relationship of music and learning, individual differences in musical processing seem to play a bigger role for cognitive overload than for emotional drive. However, this study can only be seen as a first approach to answering this question. The author of this report hopes that it will nevertheless be of useful guidance for future research that explores in more detail why music and learning can - sometimes - go so well together.

References

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, *106*(1), 20–29. https://doi.org/10.1016/j.jecp.2009.11.003

Anderson, S. A., & Fuller, G. B. (2010). Effect of music on reading comprehension of junior high school students. *School Psychology Quarterly*, *25*(3), 178–187. https://doi.org/10.1037/a0021213

Atkinson, R. C., & Shiffrin, R. M. (1968). Human Memory: A Proposed System and its Control Processes. In K. W. Spence & J. T. Spence (Eds.), *Psychology of Learning and Motivation* (Vol. 2, pp. 89–195). Academic Press. https://doi.org/10.1016/S0079-7421(08)60422-3

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, *4*(11), 417–423. https://doi.org/10.1016/S1364-6613(00)01538-2

Baddeley, A. D., & Hitch, G. (1974). Working Memory. In G. H. Bower (Ed.), *Psychology of Learning and Motivation* (Vol. 8, pp. 47–89). Academic Press. https://doi.org/10.1016/S0079-7421(08)60452-1

Baumgarten, H. (1992). Aesthetica. see in Remembrance of things past: Music, autobiographical memory, andemotion. *Adv. Consum. Res*, *19*, 613–620.

Berlyne, D. E. (1973). Aesthetics and Psychobiology. *Journal of Aesthetics and Art Criticism*, *31*(4), 553–553. https://doi.org/10.2307/429334

Boucsein, W. (2012). *Electrodermal Activity*. Springer Science & Business Media.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, *25*(1), 49–59. https://doi.org/10.1016/0005-7916(94)90063-9

Cassidy, G., & MacDonald, R. A. R. (2007). The effect of background music and background noise on the task performance of introverts and extraverts. *Psychology of Music*, *35*(3), 517–537. https://doi.org/10.1177/0305735607076444

Chin, T., & Rickard, N. S. (2012). The Music USE (MUSE) Questionnaire: An Instrument to Measure Engagement in Music. *Music Perception*, *29*(4), 429–446. https://doi.org/10.1525/mp.2012.29.4.429

Christopher, E. A., & Shelton, J. T. (2017). Individual Differences in Working Memory Predict the Effect of Music on Student Performance. *Journal of Applied Research in Memory and Cognition*, *6*(2), 167–173. https://doi.org/10.1016/j.jarmac.2017.01.012

Cowan, N. (2016). *Working Memory Capacity: Classic Edition*. Psychology Press.

Daneman, M., & Carpenter, P. A. (1983). Individual differences in integrating information between and within sentences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *9*(4), 561–584. https://doi.org/10.1037/0278-7393.9.4.561

de la Mora Velasco, E., & Hirumi, A. (2020). The effects of background music on learning: A systematic review of literature to guide future research and practice. *Educational Technology Research and Development*, *68*, 2817–2837.

de la Mora Velasco, E., Hirumi, A., & Chen, B. (2021). Improving Instructional Videos with Background Music and Sound Effects: A Design-Based Research Approach. *Journal of Formative Design in Learning*. https://doi.org/10.1007/s41686-020-00052-4

Deutsch, D. (2012). *The Psychology of Music* (3. Edition). Academic Press.

Dobbs, S., Furnham, A., & McClelland, A. (2011). The effect of background music and noise on the cognitive test performance of introverts and extraverts. *Applied Cognitive Psychology*, *25*(2), 307–313. https://doi.org/10.1002/acp.1692

Donlan, D. (1976). The Effect of Four Types of Music on Spontaneous Writings of High School Students. *Research in the Teaching of English*, *10*(2), 116–126.

Dunn, T. J., Baguley, T., & Brunsden, V. (2014). From alpha to omega: A practical solution to the pervasive problem of internal consistency estimation. *British Journal of Psychology*, *105*(3), 399–412. https://doi.org/10.1111/bjop.12046

Eerola, T., & Vuoskoski, J. K. (2011). A comparison of the discrete and dimensional models of emotion in music. *Psychology of Music*, *39*(1), 18–49. https://doi.org/10.1177/0305735610362821

Elliott, D. J. (2012). Commentary: Music in the community. *The Oxford Handbook of Music Education*, *2*, 99–103.

Etaugh, C., & Michals, D. (1975). Effects on Reading Comprehension of Preferred Music and Frequency of Studying to Music. *Perceptual and Motor Skills*, *41*(2), 553–554. https://doi.org/10.2466/pms.1975.41.2.553

Eysenck, H. J. (1967). The biological basis of personality (Vol. 689). *Piscataway, NJ: Transaction*.

Gagné, F. (2015). Academic talent development programs: A best practices model. *Asia Pacific Education Review*, *16*(2), 281–295. https://doi.org/10.1007/s12564-015-9366-9

Gagné, F., & McPherson, G. E. (2016). Analyzing musical prodigiousness using Gagne's integrative model of talent development. *Musical Prodigies: Interpretations from Psychology, Education, Musicology, and Ethnomusicology*, *1*, 3–114.

Gautam, A., Simoes-Capela, N., Schiavone, G., Acharyya, A., De Raedt, W., & Van Hoof, C. (2018). A data driven empirical iterative algorithm for GSR signal pre-processing. *2018 26th European Signal Processing Conference (EUSIPCO)*, 1162–1166.

Gelding, R., Harrison, P. M. C., Silas, S., Johnson, B., Thompson, W., & Müllensiefen, D. (2020). An efficient and adaptive test of auditory mental imagery. *Psychological Research*. https://link.springer.com/article/10.1007%2Fs00426-020-01322-3#citeas

Gonzalez, M. F., & Aiello, J. R. (2019). More than meets the ear: Investigating how music affects cognitive task performance. *Journal of Experimental Psychology: Applied*, *25*(3), 431–444. https://doi.org/10.1037/xap0000202

Grekow, J. (2018). Music Emotion Maps in the Arousal-Valence Space. In J. Grekow (Ed.), *From Content-based Music Emotion Recognition to Emotion Maps of Musical Pieces* (pp. 95–106). Springer International Publishing. https://doi.org/10.1007/978-3-319-70609-2_9

Hallam, S., & MacDonald, R. (2009). The effects of music in community and educational settings. *The Oxford Handbook of Music Psychology*, 471–480.

Hallam, S., & MacDonald, R. (2016). The Effects of Music in Community and Educational Settings. In S. Hallam, I. Cross, & M. H. Thaut (Eds.), *The Oxford Handbook of Music Psychology* (pp. 775–788). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198722946.013.46

Hallam, S., & Price, J. (1998). Research Section: Can the use of background music improve the behaviour and academic performance of children with emotional and behavioural difficulties? *British Journal of Special Education*, *25*(2), 88–91. https://doi.org/10.1111/1467-8527.t01-1-00063

Hallam, S., Price, J., & Katsarou, G. (2002). The Effects of Background Music on Primary School Pupils' Task Performance. *Educational Studies*, *28*(2), 111–122. https://doi.org/10.1080/03055690220124551

Hargreaves, D. J., MacDonald, R., & Miell, D. (2005). How do people communicate using music. *Musical Communication*, *1*, 1–26.

Harrison, P. M. C., Collins, T., & Müllensiefen, D. (2017). Applying modern psychometric techniques to melodic discrimination testing: Item response theory, computerised adaptive testing, and automatic item generation. *Scientific Reports*, *7*(1), 3618. https://doi.org/10.1038/s41598-017-03586-z

Harrison, P. M. C., & Müllensiefen, D. (2018). Development and Validation of the Computerised Adaptive Beat Alignment Test (CA-BAT). *Scientific Reports*, *8*(1), 12395. https://doi.org/10.1038/s41598-018-30318-8

He, W.-J., Wong, W.-C., & Hui, A. N.-N. (2017). Emotional Reactions Mediate the Effect of Music Listening on Creative Thinking: Perspective of the Arousal-and-Mood Hypothesis. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.01680

Hennig, C. (2020). *Flexible Procedures for Clustering* (R package version 2.2-9) [Computer software]. https://CRAN.R-project.org/package=fpc

Hilliard, O. M., & Tolin, P. (1979). Effect of Familiarity with Background Music on Performance of Simple and Difficult Reading Comprehension Tasks. *Perceptual and Motor Skills*, *49*(3), 713–714. https://doi.org/10.2466/pms.1979.49.3.713

Holz, N., Larrouy-Maestri, P., & Poeppel, D. (2021). The paradoxical role of emotional intensity in the perception of vocal affect. *Scientific Reports*, *11*(1), 9663. https://doi.org/10.1038/s41598-021-88431-0

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1–55. https://doi.org/10.1080/10705519909540118

Hu, X., Chen, J., & Wang, Y. (2021). University students' use of music for learning and well-being: A qualitative study and design implications. *Information Processing & Management*, *58*, 102409. https://doi.org/10.1016/j.ipm.2020.102409

Hu, X., Lee, J. H., & Wong, L. K. Y. (2014). Music information behaviors and system preferences of university students in Hong Kong. In *Proceedings of Fifteenth International Society for Music Information Retrieval Conference*. ISMIR. The Conference proceedings' website is located at http://www.terasoft.com.tw/conf/ismir2014/Proceedings.html.

Husain, G., Thompson, W. F., & Schellenberg, E. G. (2002). Effects of musical tempo and mode on arousal, mood, and spatial abilities. *Music Perception*, *20*(2), 151–171.

IFPI. (2019). *Music Listening 2019: A look at how recorded music is enjoyed around the world*. https://www.ifpi.org/wp-content/uploads/2020/07/Music-Listening-2019-1.pdf

iMotions Biometric Research Platform (Version 8.1), iMotions A/S, Copenhagen, Denmark, 2021.

Juslin, P. N. (2019). *Musical emotions explained: Unlocking the secrets of musical affect*. Oxford University Press, USA.

Juslin, P. N., & Laukka, P. (2004). Expression, perception, and induction of musical emotions: A review and a questionnaire study of everyday listening. *Journal of New Music Research*, *33*(3), 217–238.

Juslin, P. N., & Sloboda, J. A. (2011). *Handbook of Music and Emotion: Theory, Research, Applications* (Reprint Edition). Oxford University Press.

Juslin, P. N., & Sloboda, J. A. (2013). Music and emotion. In *The psychology of music, 3rd ed* (pp. 583–645). Elsevier Academic Press. https://doi.org/10.1016/B978-0-12-381460-9.00015-8

Kämpfe, J., Sedlmeier, P., & Renkewitz, F. (2010). The impact of background music on adult listeners: A meta-analysis. *Psychology of Music*, *39*(4), 424–448. https://doi.org/10.1177/0305735610376261

Kang, H. J., & Williamson, V. J. (2014). Background music can aid second language learning. *Psychology of Music*, *42*(5), 728–747. https://doi.org/10.1177/0305735613485152

Kim, S. (2015). *ppcor: Partial and Semi-Partial (Part) Correlation* (R package version 1.1) [Computer software]. https://CRAN.R-project.org/package=ppcor

Konecni, V. J., & Sargent-Pollock, D. (1976). Choice between melodies differing in complexity under divided-attention conditions. *Journal of Experimental Psychology: Human Perception and Performance*, *2*(3), 347–356. https://doi.org/10.1037/0096-1523.2.3.347

Kotsopoulou, A., & Hallam, S. (2010). The perceived impact of playing music while studying: Age and cultural differences. *Educational Studies - EDUC STUD*, *36*, 431–440. https://doi.org/10.1080/03055690903424774

Larrouy-Maestri, P., Harrison, P. M. C., & Müllensiefen, D. (2019). The mistuning perception test: A new measurement instrument. *Behavior Research Methods*, *51*(2), 663–675. https://doi.org/10.3758/s13428-019-01225-1

Law, L. N. C., & Zentner, M. (2012). Assessing Musical Abilities Objectively: Construction and Validation of the Profile of Music Perception Skills. *PLOS ONE*, *7*(12), e52508. https://doi.org/10.1371/journal.pone.0052508

Lehmann, J. A. M., & Seufert, T. (2017). The Influence of Background Music on Learning in the Light of Different Theoretical Perspectives and the Role of Working Memory Capacity. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.01902

Leppink, J., Paas, F., Van der Vleuten, C. P. M., Van Gog, T., & Van Merriënboer, J. J. G. (2013). Development of an instrument for measuring different types of cognitive load. *Behavior Research Methods*, *45*(4), 1058–1072. https://doi.org/10.3758/s13428-013-0334-1

Linek, S. B., Marte, B., & Albert, D. (2011). Background music in educational games: Motivational appeal and cognitive impact. *International Journal of Game-Based Learning (IJGBL)*, *1*(3), 53-64.

MacDonald, R. A., Hargreaves, D. J., & Miell, D. (2002). *Musical identities*. OUP Oxford.

MacGregor, C., & Müllensiefen, D. (2019). The Musical Emotion Discrimination Task: A New Measure for Assessing the Ability to Discriminate Emotions in Music. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.01955

Maechler, M., Rousseeuw, P., Struyf, A., Hubert, M., & Hornik, K. (2019). *cluster: Cluster Analysis Basics and Extensions* (R package version 2.1.0) [Computer software].

Marr, D. (1982). Vision: A Computational Investigation into the Human Representation and Processing of Visual Information. *New York, NY: W.H. Freeman and Company*. http://papers.cumincad.org/cgi-bin/works/Show?fafa

Martin, R. C., Wogalter, M. S., & Forlano, J. G. (1988). Reading comprehension in the presence of unattended speech and music. *Journal of Memory and Language*, *27*(4), 382–398. https://doi.org/10.1016/0749-596X(88)90063-0

Mayer, R. E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist*, *32*(1), 1–19.

Mayer, R. E. (2014). Principles based on social cues in multimedia learning: Personalization, voice, image, and embodiment principles. *The Cambridge Handbook of Multimedia Learning*, *16*, 345–370.

Mayer, R. E., & Moreno, R. (1998). A cognitive theory of multimedia learning: Implications for design principles. *Journal of Educational Psychology*, *91*(2), 358–368.

McDonald, R. P. (1999). *Test theory: A unified approach*.

Merrill, J., Omigie, D., & Wald-Fuhrmann, M. (2020). Locus of emotion influences psychophysiological reactions to music. *PLOS ONE*, *15*(8), e0237641. https://doi.org/10.1371/journal.pone.0237641

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The Musicality of Non-Musicians: An Index for Assessing Musical Sophistication in the General Population. *PLOS ONE*, *9*(2), e89642. https://doi.org/10.1371/journal.pone.0089642

Müllensiefen, D., & Hemming, J. (2017). *Musikalische Fertigkeiten und ihre Messbarkeit* (A. C. Lehmann & R. Kopiez, Eds.). Hogrefe. http://research.gold.ac.uk/id/eprint/22525/

Nantais, K. M., & Schellenberg, E. G. (1999). The Mozart Effect: An Artifact of Preference. *Psychological Science*, *10*(4), 370–373. https://doi.org/10.1111/1467-9280.00170

Pausch, V., Kopiez, R., & Müllensiefen, D. (in review). Struktur und Leistungskennwerte musikalischer Fähigkeiten im Jugendalter: Erste Ergebnisse der Studie LongGold. (in review).

Pavlicevic, M., & Ansdell, G. (2004). *Community music therapy*. Jessica Kingsley Publishers.

Peretz, I. (2010). Towards a neurobiology of musical emotions. In *Handbook of music and emotion: Theory, research, applications* (pp. 99–126). Oxford University Press.

Perham, N., & Currie, H. (2014). *Does listening to preferred music improve reading comprehension performance?*

Peterson, B. G., & Carl, P. (2020). *PerformanceAnalytics: Econometric Tools for Performance and Risk Analysis* (R package version 2.0.4) [Computer software]. https://CRAN.R-project.org/package=PerformanceAnalytics

Pool, M. M., Koolstra, C. M., & Voort, T. H. A. van der. (2003). Distraction Effects of Background Soap Operas on Homework Performance: An experimental study enriched with observational data. *Educational Psychology*, *23*(4), 361–380. https://doi.org/10.1080/01443410303211

R Core Team. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. http://www.R-project.org/

Revelle, W. (2020). *psych: Procedures for Psychological, Psychometric, and Personality Research* (R package version 2.0.12) [Computer software]. Northwestern University. https://CRAN.R-project.org/package=psych

Rey, G. D. (2012). A review of research and a meta-analysis of the seductive detail effect. *Educational Research Review*, *7*(3), 216–237. https://doi.org/10.1016/j.edurev.2012.05.003

Richards, D., Fassbender, E., Bilgin, A., & Thompson, W. F. (2008). An investigation of the role of background music in IVWs for learning. *ALT-J*, *16*(3), 231–244. https://doi.org/10.1080/09687760802526715

Rosenblum, S., Josman, N., & Toglia, J. (2017). Development of the Daily Living Questionnaire (DLQ): A Factor Analysis Study. *The Open Journal of Occupational Therapy*, *5*(4). https://doi.org/10.15453/2168-6408.1326

Rosseel, Y. (2012). lavaan: An R Package for Structural Equation Modeling. *Journal of Statistical Software*, *48*(2), 1–36.

Russel, J. (1980). A circumplex model of emotions. *Journal of Personality and Social Psychology*, *39*, 1161–1178.

R-Notebook "GSR Peak Detection" as available in iMotions 9.0.5 (2021). iMotions A/S, Copenhagen

R-Notebook "GSR Epoch Algorithm" as available in iMotions 9.0.5 (2021). iMotions A/S, Copenhagen

Salamé, P., & Baddeley, A. (1989). Effects of Background Music on Phonological Short-Term Memory. *The Quarterly Journal of Experimental Psychology Section A*, *41*(1), 107–122. https://doi.org/10.1080/14640748908402355

Salimpoor, V. N., Benovoy, M., Larcher, K., Dagher, A., & Zatorre, R. J. (2011). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature Neuroscience*, *14*(2), 257–262. https://doi.org/10.1038/nn.2726

Schaal, N. K., Bauer, A.-K. R., & Müllensiefen, D. (2014). Der Gold-MSI: Replikation und Validierung eines Fragebogeninstrumentes zur Messung Musikalischer Erfahrenheit anhand einer deutschen Stichprobe. *Musicae Scientiae*, *18*(4), 423–447. https://doi.org/10.1177/1029864914541851

Scherer, K. R. (2005). Unconscious Processes in Emotion: The Bulk of the Iceberg. In *Emotion and consciousness* (pp. 312–334). The Guilford Press.

Schinka, J., McBride, A., Vanderploeg, R., Tennyson, K., Borenstein (Graves), A., & Mortimer, J. (2005). Florida Cognitive Activities Scale: Initial development and validation. *Journal of the International Neuropsychological Society : JINS*, *11*, 108–116. https://doi.org/10.1017/S1355617705050125

Schwartz, R. W., Ayres, K. M., & Douglas, K. H. (2017). Effects of music on task performance, engagement, and behavior: A literature review. *Psychology of Music*, *45*(5), 611–627. https://doi.org/10.1177/0305735617691118

Shih, Y.-N., Huang, R.-H., & Chiang, H.-Y. (2012). Background music: Effects on attention performance. *Work*, *42*(4), 573–578. https://doi.org/10.3233/WOR-2012-1410

Sloboda, J. A., & Juslin, P. N. (2001). Psychological perspectives on music and emotion. *Music and Emotion: Theory and Research*, 71–104.

Spearman, C. (1904). 'General intelligence,' objectively determined and measured. *The American Journal of Psychology*, *15*(2), 201–293. https://doi.org/10.2307/1412107

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285. https://doi.org/10.1016/0364-0213(88)90023-7

Ter Bogt, T. F. M., Mulder, J., Raaijmakers, Q. A. W., & Nic Gabhainn, S. (2011). Moved by music: A typology of music listeners. *Psychology of Music*, *39*(2), 147–163. https://doi.org/10.1177/0305735610370223

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2001). Arousal, Mood, and The Mozart Effect. *Psychological Science*, *12*(3), 248–251. https://doi.org/10.1111/1467-9280.00345

Thompson, W. F., Schellenberg, E. G., & Letnic, A. K. (2011). Fast and loud background music disrupts reading comprehension. *Psychology of Music*, *40*(6), 700–708. https://doi.org/10.1177/0305735611400173

Trevarthen, C. (2002). Origins of musical identity: Evidence from infancy for musical social awareness. *Musical Identities*, 21–38.

Velicer, W. F. (1976). Determining the number of components from the matrix of partial correlations. *Psychometrika*, *41*(3), 321–327.

Vuoskoski, J. K., Thompson, W. F., McIlwain, D., & Eerola, T. (2012). Who Enjoys Listening to Sad Music and Why? *Music Perception*, *29*(3), 311–317. https://doi.org/10.1525/mp.2012.29.3.311

Wainer, H., Dorans, N. J., Flaugher, R., Green, B. F., & Mislevy, R. J. (2000). *Computerized Adaptive Testing: A Primer*. Routledge.

Wallace, W. T. (1994). Memory for music: Effect of melody on recall of text. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(6), 1471–1485. https://doi.org/10.1037/0278-7393.20.6.1471

Ward Jr, J. H. (1963). Hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association*, *58*(301), 236–244.

Waterhouse, L. (2006). Multiple Intelligences, the Mozart Effect, and Emotional Intelligence: A Critical Review. *Educational Psychologist*, *41*(4), 207–225. https://doi.org/10.1207/s15326985ep4104_1

Werner, C., Schermelleh-Engel, K., Gerhard, C., & Gäde, J. C. (2016). Strukturgleichungsmodelle. In N. Döring & J. Bortz (Eds.), *Forschungsmethoden und Evaluation in den Sozial- und Humanwissenschaften* (pp. 945–973). Springer. https://doi.org/10.1007/978-3-642-41089-5_17

Wickham, H., François, R., Henry, L., & Müller, K. (2020). *dplyr: A Grammar of Data Manipulation* (R package version 1.0.2) [Computer software]. https://CRAN.R-project.org/package=dplyr

Wolfe, D. E. (1983). Effects of Music Loudness on Task Performance and Self-Report of College-Aged Students. *Journal of Research in Music Education*, *31*(3), 191–201. https://doi.org/10.2307/3345172

Appendix A: Factors that Influence the Relationship Between Music and Learning

Factors		Prior research		Implementation into the current study	
Cate-gory	**In the framework of Hallam and MacDonald (2016)**	**Studies in systematic reviews (de la Mora Velasco & Hirumi, 2020; Hallam & MacDonald, 2016)**	**Relevant study results/statements**	**Included in the present study?**	**Argumentation / Comment**
Music parameters	**Type (genre)**	Peretz (2010)	Tempo, among other factors, influences moods, emotions, and arousal.	Partly	Genre is not included because of its wide variation, but the frequently used types of music regarding speed, volume, vocal/instrumental, and relaxed/energetic characteristics is assessed in the HBM-cog
		Donlan (1976)	Whether the music is vocal or instrumental influences its effect.		
		Martin et al. (1988)	Verbal music has a greater negative impact on literacy tasks, such as reading comprehension		
		Pool et al. (2003)	Lyrical music and written text compete against each other		
		De la Mora Velasco and Hirumi (2020)	Based on a systematic review on different genres used in studies, classical music showed the most positive effects and pop music showed the most negative effects (but classical music was also investigated most often in the studies of this review).		
	Stimulating /relaxing	De la Mora Velasco and Hirumi (2020)	Relatively few studies investigate the effects of arousal and valence in music, although these factors	Yes	Included in the HBM-cog

		might influence the effect of music while learning.		
Complexity	Kang and Williamson (2014)	Certain music (with low complexity) can facilitate language learning for beginners on the long-term.	No	It is difficult to self-report the complexity of music one frequently listens to. Assessing this would go beyond the scope of this study, since an extended analysis of the music preferred would be needed.
Volume	Peretz (2010)	Volume, among other factors, influences moods, emotions, and arousal.	Yes	Included in the HBM-cog
	Moreno and Mayer (1998)	The volume of background music could influence learning in a multimedia setting.		
Familiarity	Hilliard and Tolin (1979)	The familiarity of specific music influences its effect.	Partly	The familiarity of music is not assessed in the HBM-cog, but it is included for assessing emotional reactivity to music.
	Anderson and Fuller (2010)	Text comprehension was worse for students who had a stronger preference for the used background music.		
Liked/disliked	Iwanaga and Moroki (1999)	Favourite music has the tendency to reduce subjective tension, without necessarily influencing physiological measures in the same way.	Partly	The music that the HBM-cog refers to, is always self-chosen, thus always liked. The music used for assessing emotional reactivity is selected by the researcher.
	Hurtes (2002), Tarrant (2002)	Young adults typically rather like to listen to music they perceive as socially accepted within their peers.		
Self-selected	Schwartz et al. (2017)	Based on a summary of existing studies, instrumental BM or self-selected BM shows the highest academic performance results for people with developmental disabilities.	Partly	The music that the HBM-cog refers to, is always self-chosen. The music used for assessing emotional reactivity is selected by the researcher.

	Associated with life events			Partly	The music's familiarity that would allow associations to experience is not assessed in the HBM-cog, but it is included for assessing emotional reactivity to music.
Situational factors	**Nature of the task**	Furnman (1978), Myers (1979), Salamé and Baddeley (1989), Hallam et al. (2002)	Results for memory tasks while listening to music differ, e.g. for aural information (Furman, 1978), for paired associate recall (Myers, 1979), for phonological short-term memory (Salamé & Baddeley, 1989), or for recalling written, visual sentences (Hallam et al., 2002)	Yes	This study always refers to cognitively demanding tasks. Within this field, the HBM-cog assesses the cognitive (learning) activities for which music is played.
		Martin et al. (1988)	Verbal music has a greater negative impact on literacy tasks, such as reading comprehension.		
	Difficulty of the task	Anderson and Fuller (2010), Thompson et al., (2012)	More complex tasks such as reading comprehension are intervened by loud and fast music.	Partly	The HBM-cog assesses the cognitive tasks for which music is played, a clear categorization of task difficulty for these activities does not exist up to today.
	Distractions in the environment	Richards et al. (2008)	Background music improved recall of facts in immersive virtual worlds.	Yes	The HBM-cog asks for reasons why one thinks that background music is helpful/not helpful, such as asking for perceived improved focus.
		De la Mora Velasco and Hirumi (2020)	If background music is compatible with the visual information of an environment, this could promote emotional engagement that supports learning in multimedia contents.		
		Greasley and Lamont (2011), Herbert (2011)	Loud background music in particular may have the effect to isolate other auditory noises that distract the individual.		

	Familiarity of the environ-ment	Waterhouse (2006)	They argue that the duration of background music is played might be a situational factor that influences learning.	No	The HBM-cog asks for general habits regarding background music listening, thus, we can assume an always familiar environment.
		De la Mora Velasco and Hirumi (2020)	Based on a systematic review of studies, significant effects might appear especially with longer interventions. More positive effects where found for longer intervention (more than 90 minutes), maybe because the influence of BM is less interruptive if participants have the possibility to get used to it.		
	alone/in company			Partly	The HBM-cog asks for reasons why one thinks that background music is helpful/not helpful, such as the perceived effect of company through music.
Individual factors	**Age & Gender**	Kotsopoulou and Hallam (2010)	Age influences actual and perceived impact of music on performance.	Yes	In demographic data.
		Anderson and Fuller (2010)	Female junior high school students had significantly worse comprehension performance when listening to vocal music and a higher preference of listening to music when studying, compared to male students. Girls could potentially be distracted more easily than boys.		
	Ability			Partly	Musical perception abilities are measured, but cognitive ability and working memory capacity is not measured due to the scope of the study.

	Personality	Cassidy and MacDonald (2007), Dobbs et al. (2011)	Introverts, compared to extroverts, have a higher base-line of arousal and are more sensitive to over-arousal, resulting in a lower task performance with background music.	No	This is not measured due to the scope of the study.
		Hallam and Price (1998); Savan (1998)	Calm music can reduce the stress and anxiety for children with emotional and behavioral difficulties.		
	Metacog-nitive strategies			No	This is not measured due to the scope of the study.
	Musical expertise	Hallam and MacDonald (2016)	They argue that the musical experience and training of participants may be an important factor that influences the relationship between background music and learning.	Yes	Included in the MUSE and the GOLD-MSI.
	Frequency of use of backgroun d music	Etaugh and Michals (1975)	Students who are used to listening to background while studying performed better with background music.	Yes	Included in the HBM-cog
		Waterhouse (2006)	How long/often background music is played might influence learning.		
		Anderson and Fuller (2010)	Text comprehension is worse for students who had a preference for listening to music while learning.		

Note. Overview of factors that influence the relationship between background music and learning, based on the framework from Hallam and MacDonald (2016), as well as if and how they are incorporated into the present study. Additionally, research publications that investigated the effect of music on learning, and their conclusions as reported by either Hallam and MacDonald (2016) or De la Mora Velasco and Hirumi (2020), are sorted for these factors.

Appendix B: HBM-cog survey

Please answer the following questions about your habits of listening to background music while doing cognitively demanding tasks. In this context, cognitively demanding tasks are activities that require your concentration, such as reading, writing, calculating, and learning.

Please choose the option that fits you the most.

1. I listen to music while doing cognitively demanding tasks, such as studying, writing, reading, or calculating.

   1 - never   2 - rarely   3 - occasionally   4- frequently   5 - always

2. Which cognitively demanding tasks do you do while listening to music? *(non-mandatory question)*
   a. Studying
   b. Writing
   c. Reading
   d. Calculating
   e. Memorising content
   f. Solving problems
   g. Developing ideas
   h. Other:

3. Which type of music do you rather listen to when doing cognitively demanding tasks? *(non-mandatory question)*

   While doing cognitively demanding tasks I listen....
   a. to instrumental music only. - more often to instrumental than to vocal music. - both to instrumental and to vocal music. - more often to vocal than to instrumental music. - to vocal music only.
   b. to slow music only. - more often to slow than fast music. - both to slow and to fast music. - more often to fast than to slow music. - to fast music only.
   c. to quiet music only. - more often to quiet than to loud music. - both to quiet and to loud music. - more often to loud than to quiet music. - to loud music only.

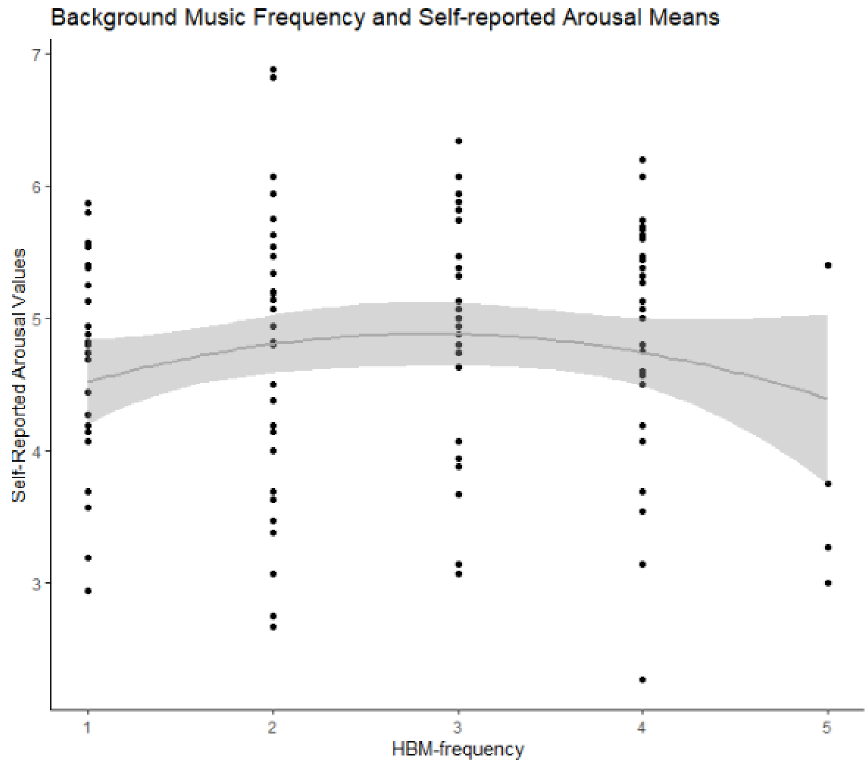
   d. to calm music only. - more often to calm than to energetic music. - both to calm and to energetic music. - more often to energetic than to calm music. - to energetic music only.

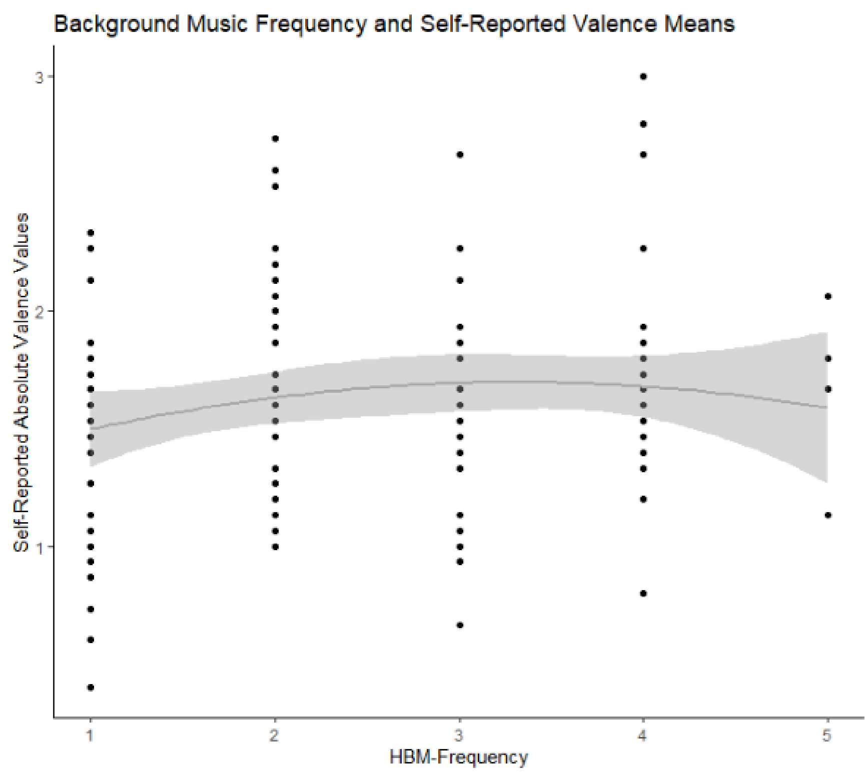
4. I believe that music *(5-point Likert scale for agreement with (1) strongly disagree, (2) somewhat disagree, (3) neither agree nor disagree, (4) somewhat agree, (5) strongly agree)*
   a. helps me concentrate (c)
   b. keeps me company (e)
   c. alleviates my boredom (e)
   d. relaxes me (e)
   e. improves my mood (e)
   f. improves my focus (c)
   g. helps me learn faster (c)
   h. interferes so I can’t concentrate (c - reversed)
   i. interferes because I sing along (c - reversed)
   j. interferes because it makes me too aroused (e - reversed)

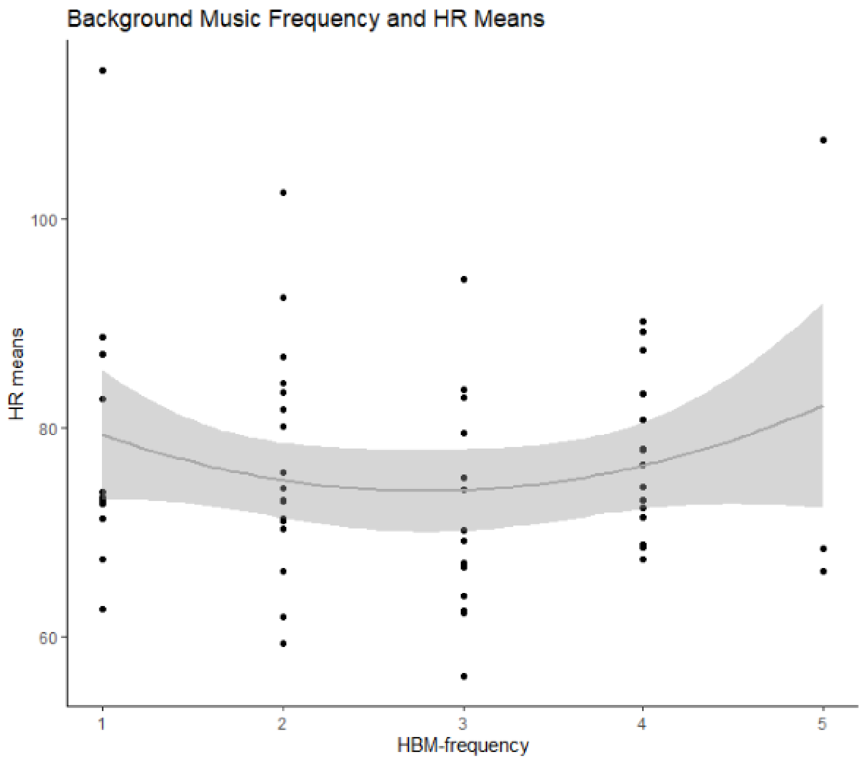
5. Finally, please rate the importance of music in your life, on a scale from “not important at all” (1) to “extremely important” (10).

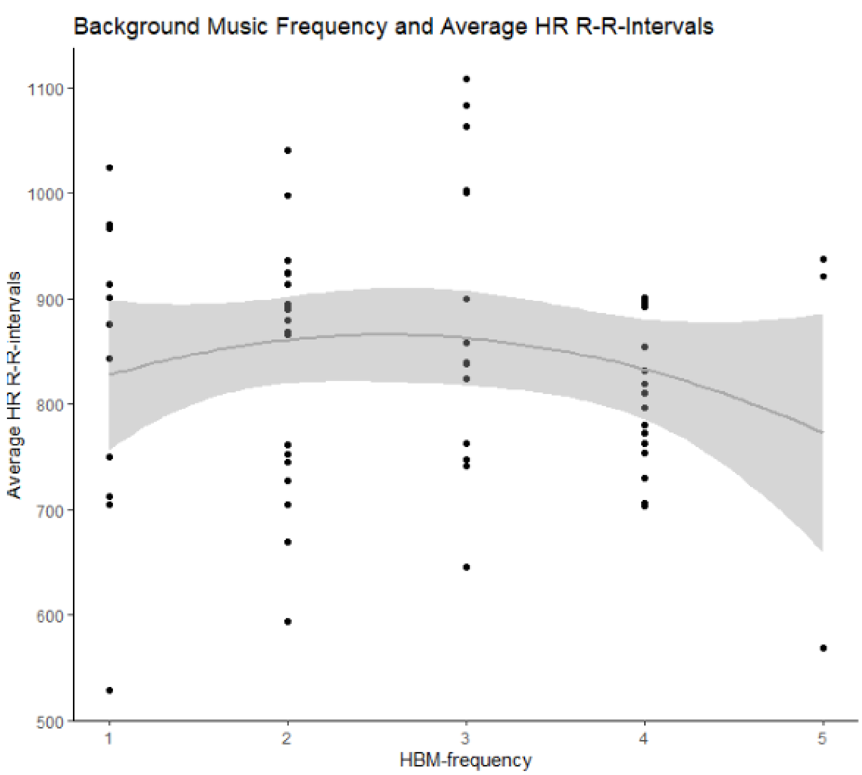
   1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10

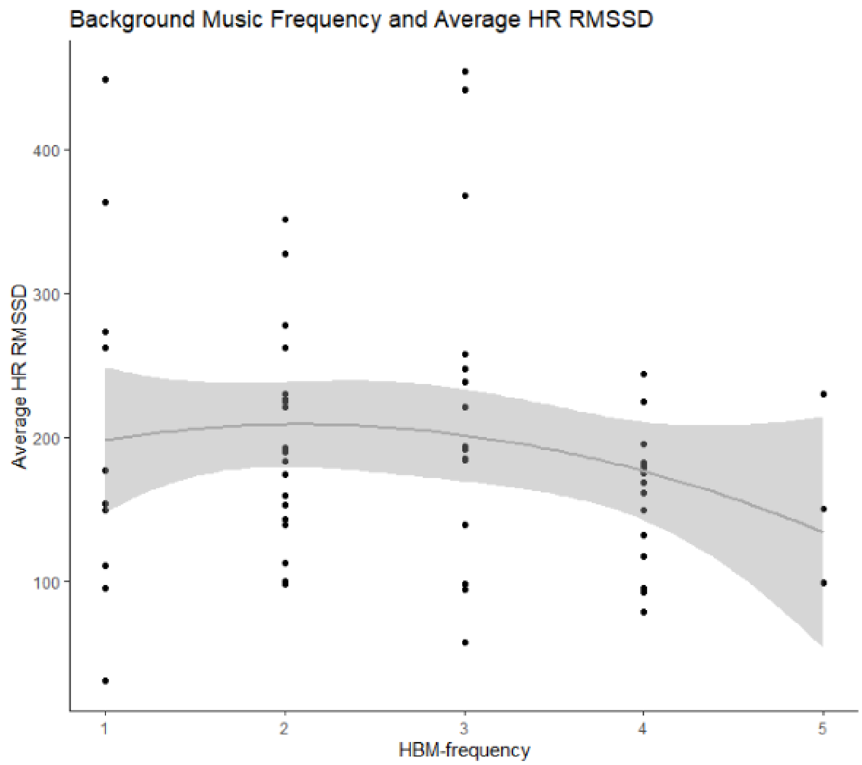
Appendix C: Polynomial Regression Fit Graphs for Emotional Reactivity Variables

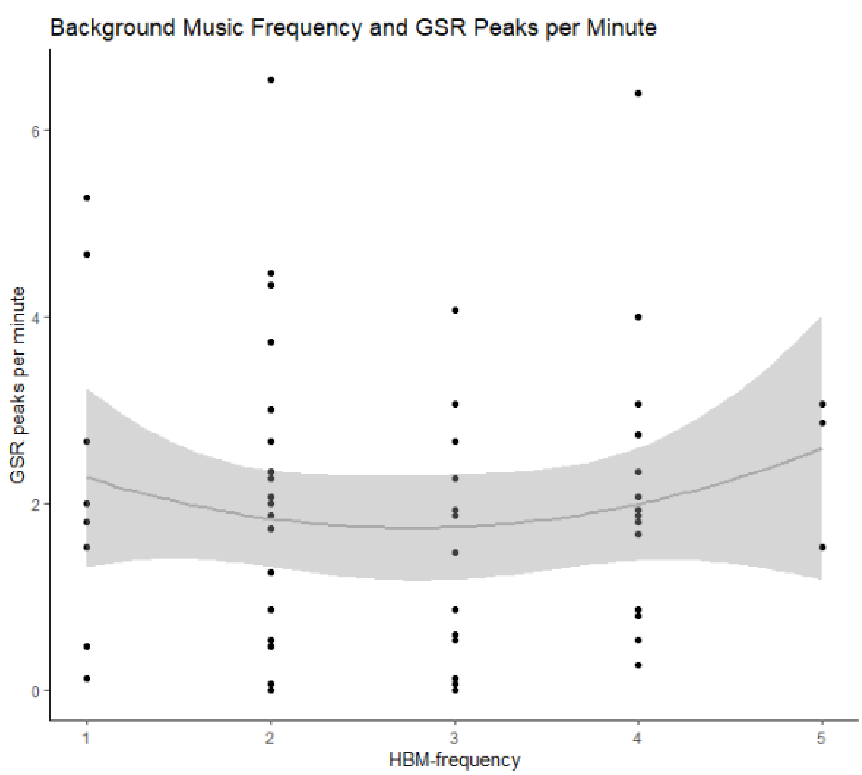


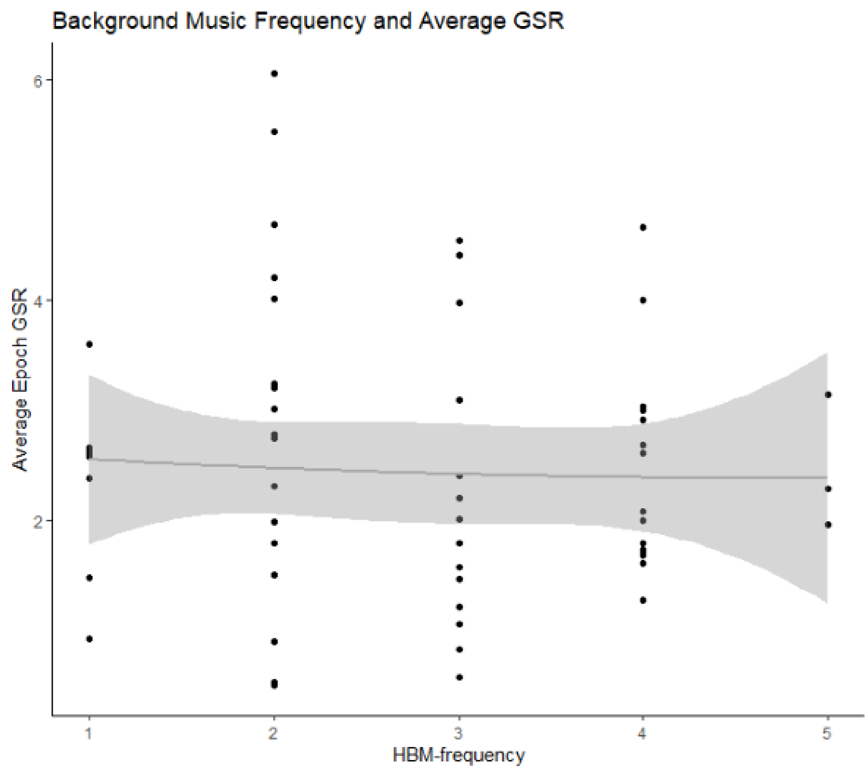


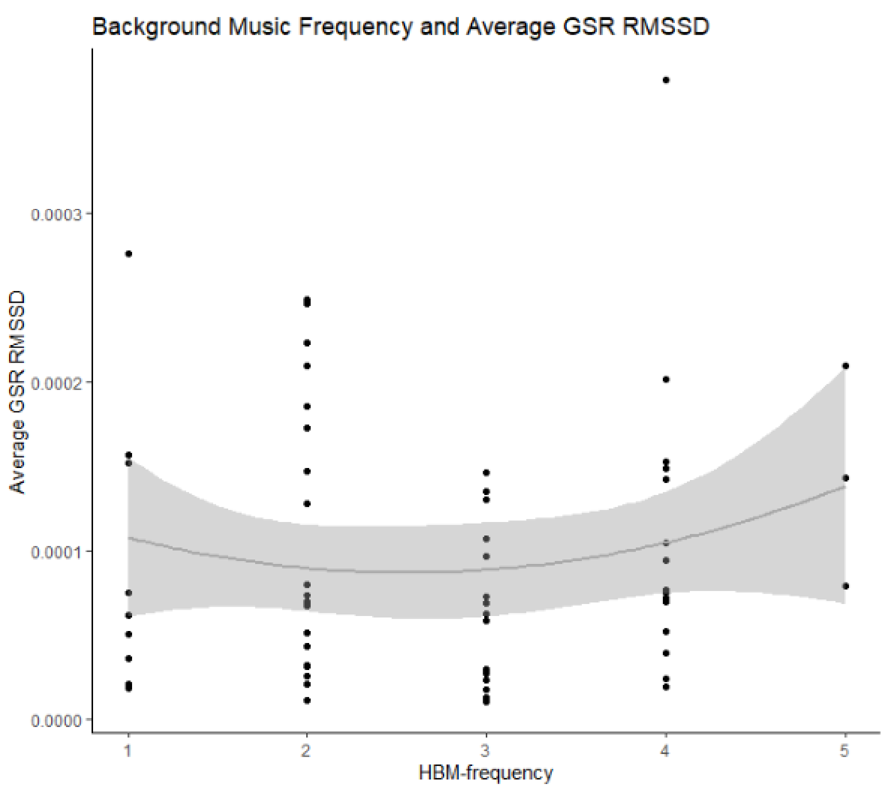

Background Music Frequency and HR Means
HR means
100
80
60
1
2
3
4
5
HBM-frequency


Background Music Frequency and Average HR R-R-Intervals
Average HR R-R-intervals
1100
1000
900
800
700
600
500
1
2
3
4
5
HBM-frequency


Background Music Frequency and Average HR RMSSD
Average HR RMSSD
100
200
300
400
1
2
3
4
5
HBM-frequency


Background Music Frequency and GSR Peaks per Minute
GSR peaks per minute
0
2
4
6
1
2
3
4
5
HBM-frequency


Background Music Frequency and Average GSR
Average Epoch GSR
6
4
2
1
2
3
4
5
HBM-frequency


Background Music Frequency and Average GSR RMSSD
Average GSR RMSSD
0.0003
0.0002
0.0001
0.0000
1
2
3
4
5
HBM-frequency