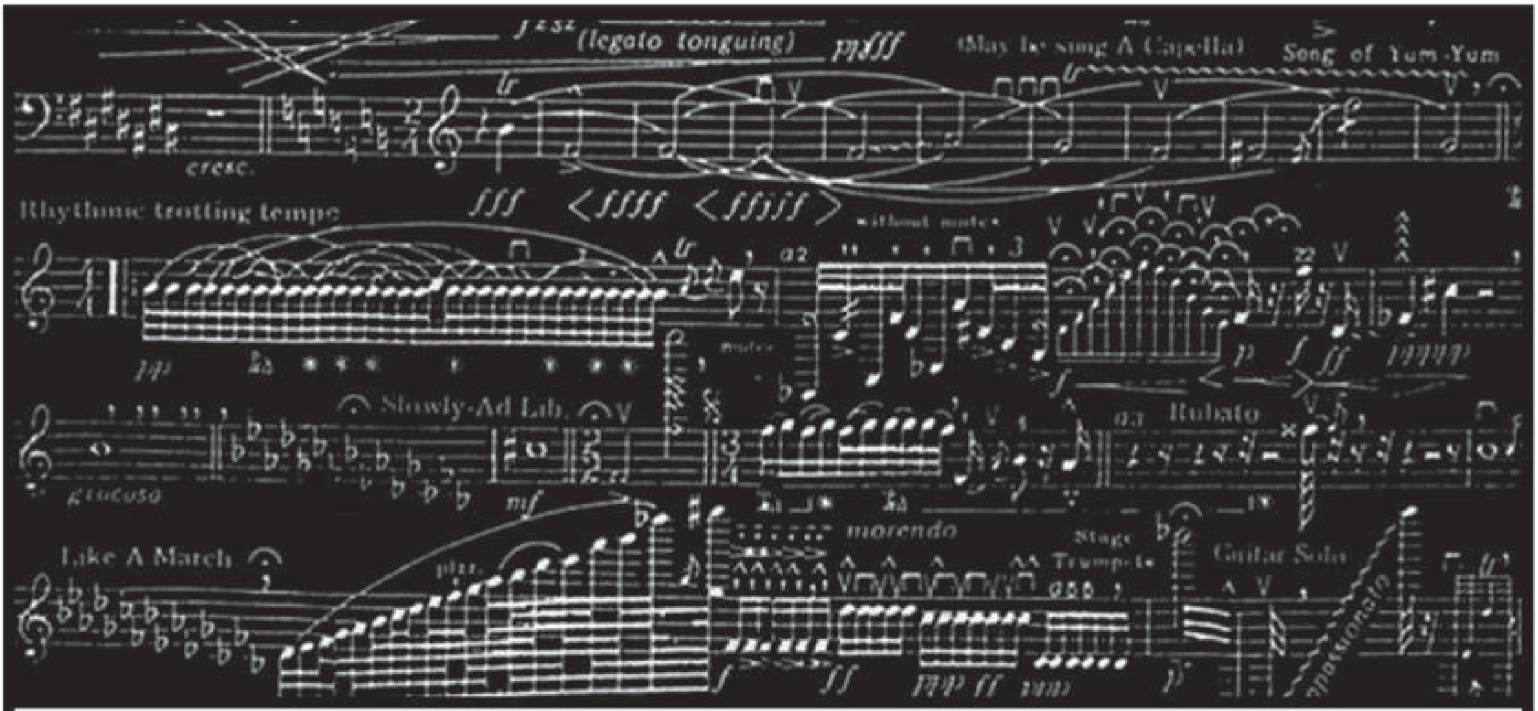

Myriam Verena Thoma

Psychobiological Mechanisms of the Effectiveness of Music Interventions

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PSYCHOBIOLOGICAL MECHANISMS OF THE EFFECTIVENESS OF MUSIC INTERVENTIONS

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CONTENTS

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ABSTRACT

The present thesis aimed to determine the psychobiological mechanisms of the purported beneficial effectiveness of music interventions. For this purpose, two studies were conducted. In a first study, the associations between music listening and health were investigated under consideration of predicted mediating mechanisms. In a second study, we set out to examine the assumed stress-reducing effect of listening to relaxing music in a rigorously controlled experiment in a laboratory setting across neuroendocrine, autonomic, cognitive, and emotional domains of the acute stress experience in healthy participants.

EMPIRICAL STUDY I

BACKGROUND & AIMS: Music listening has been suggested to have short-term beneficial effects upon the listener. Everyday music listening may lead to a habituation to these beneficial effects and may consequently be positively associated with health. However, no data exist on whether music listening is associated with health and what factors may mediate this association. The aim of the current study was therefore to address this gap in the literature by investigating the association and potential mediating variables between various aspects of habitual music-listening behavior and health indicators. METHODS: An internet-based survey was conducted in university students. A total of 1,230 individuals (mean = 24.89 ± 5.34 years), 55.3 % women, provided complete data sets. Habitual music-listening behavior, emotion regulation, stress and health variables were measured. RESULTS: Quantitative aspects of the habitual music-listening behavior, i.e. average duration of music listening and subjective relevance of music were not associated with health. In contrast, qualitative aspects, i.e. reasons for listening (especially ‘reducing loneliness and aggression’, and ‘arousing or intensifying specific emotions’) were significantly related to health (all p = 0.001). These direct effects were mediated by distress-augmenting emotion regulation and

individual stress reactivity. CONCLUSION: Our findings indicate that music listening is an essential ingredient of the everyday lives of individuals. The habitual music-listening behavior appears to be a multifaceted behavior that is further influenced by dispositions that are not usually related to music listening. Consequently, associations between habitual music-listening behavior and health do not seem to be obviously linked to health. Possible additional mediating factors of this association are discussed.

EMPIRICAL STUDY II

BACKGROUND & AIMS: Music listening has been suggested to beneficially impact health via stress-reducing effects. However, the exact mechanisms through which music exerts its positive consequences on the body are poorly understood. The aim of the current study was to address this gap in knowledge and to examine the underlying mechanisms of music effects across acute neuroendocrine, autonomic, cognitive, and emotional domains of the human stress response. METHODS: Sixty healthy female volunteers (mean = 25.27 years) were exposed to a standardized psychosocial stress test after being randomly assigned to one of three different conditions prior to the stress test: 1) relaxing music ('Miserere', Allegri) (RM), 2) sound of rippling water (SW) and 3) rest without acoustic stimulation (R). Salivary cortisol and alpha-amylase (sAA), anticipatory cognitive appraisal, subjective stress perception and anxiety were repeatedly assessed in all subjects. We hypothesized that listening to music prior to the stress test, compared to SW or R, would result in an attenuated stress reaction. RESULTS: The stress test caused significant changes in all measurements in all three groups over time. The three conditions differed significantly regarding cortisol responses ($p = 0.014$), with highest values in the RM and lowest values in SW. sAA recovery delta showed a statistical trend ($p = 0.060$) in favor of the RM. Psychological measures did not significantly differ between groups during the experiment. CONCLUSION: Our findings indicate that music listening differentially impacts the psychobiological stress system.

Listening to music prior to a psychological stress test increases rather than attenuates subsequent psychological and endocrine stress responses. In contrast, listening to the sound of water seems to result in an attenuated endocrine response to stress compared to no auditory stimulation. Listening to music seems to increase autonomic recovery more efficiently than listening to the sound of water or resting in silence. These findings bear potential to explain the effects of music on the human body.

TABLES

FIGURES

ABBREVIATIONS

ACTH	=	Adrenocorticotropin hormone
ANOVA	=	Analysis of variance
ANS	=	Autonomic nervous system
AUC_G	=	Area under the curve with respect to the ground
AUC_I	=	Area under the curve with respect to increase
BDI	=	Beck Depression Inventory
BMI	=	Body mass index
CNS	=	Central nervous system
CRH	=	Corticotropin-releasing hormone
DAR	=	Distress augmenting emotion regulation
EP	=	Epinephrine
ERI	=	Inventory for regulation of emotion
ERQ	=	Emotion Regulation Questionnaire
FBL	=	Freiburger Beschwerdeliste
FIML	=	Full information maximum likelihood
fMRI	=	Functional magnetic resonance imaging
GAS	=	General adaptation syndrome
HED	=	Hedonistic emotion regulation
HG	=	Heschl's gyrus
HPA axis	=	Hypothalamus-pituitary-adrenal axis
HR	=	Heart rate
IgA	=	Immunoglobulin A
LC	=	Locus ceruleus
MOD	=	Emotional moderation emotion regulation
NAc	=	Nucleus accumbens
NE	=	Norepinephrine

PAG	=	Periaqueductal grey
PNS	=	Parasympathetic nervous system
PVN	=	Paraventricular nucleus
QOL	=	Quality of life
R	=	Resting without acoustic stimulation
RM	=	Listening to relaxing music
RML	=	Reasons for listening to music
RR	=	Respiratory rate
sAA	=	Salivary alpha-amylase
SEM	=	Standard error of mean
SD	=	Standard deviation
SNS	=	Sympathetic nervous system
SRS	=	Stress reactivity scale
STAI	=	State-trait anxiety inventory
STG	=	Superior temporal gyrus
SW	=	Listening to sound of rippling water
TICS	=	Trier Inventory for the Assessment of Chronic Stress
TSST	=	Trier Social Stress Test
VAS	=	Visual analogue scale
VTA	=	Ventral tegmental area
WHOQOL	=	Quality of Life Questionnaire of the World Health Organisation

1 INTRODUCTION

The significance of music is mirrored in human being's history, in which music has always played an essential role (Huron, 2001; Sloboda & Juslin, 2001). Hence, music appears to be much more than only a product of sound waves. Listening to music is considered to be a stimulus capable to induce intense pleasure (e.g. Menon & Levitin, 2005). This comes as no surprise as the brain activation pattern of listening to music comprises much more than exclusively the auditory cortex (e.g. Bhattacharya, Petsche, & Pereda, 2001; Janata, Tillmann, & Bharucha, 2002; Jäncke, 2008a; Koelsch, 2010; Popescu, Otsuka, & Ioannides, 2004). Indeed, listening to music activates similar brain systems as biologically relevant stimuli (Blood & Zatorre, 2001). This fact is probably not an indicator of music's necessity for human being's survival, but may indicates its relevance for human being's health (Blood & Zatorre, 2001).

This observation has generated significant research efforts in examining the effect of music listening on health. It was found that music can exert intense (positive) effects on physiological and psychological health indicators and subjective well-being (e.g. Burns, Labbé, Williams, & McCall, 1999; Juslin & Sloboda, 2001; Nater, Abbruzzese, Krebs, & Ehlert, 2006; Nyklicek, Thayer, & Van Doornen, 1997). It has been suggested that the beneficial outcomes may be caused by the positive emotions inducing, relaxing, sedative, and tranquilizing effects of music listening, and thus, ultimately, may be due to a reduction of stress-related processes (Davis & Thaut, 1989).

Stress elicits a psychobiological stress response, including cognitive and emotional processes, as well as physiological, i.e. endocrine and autonomic, parameters. The sustained (i.e. chronic) stress experience and its psychological and physiological consequences negatively impact health (e.g. Esch, Stefano, Fricchione, & Benson, 2002a, 2000b, 2000c; McEwen, 1998, 2008). Moreover, the negative consequences of stress are expensive: conservatively estimated, 30% of the overall costs of illnesses and accidents across Western nations are caused by stress (Nater, Gaab, Rief, & Ehlert, 2006). Therefore, cost-efficient intervention techniques for the management of stress and stress-related health issues are warranted. Given that stress is a multi-faceted phenomenon, efficient stress intervention techniques should equally be effective in exerting influence on all domains of the psychobiological stress response. Consequently, the purported stress-reducing effect of listening to music is gaining increased attention as an economical, non-invasive, and highly accepted intervention tool.

Accordingly, passively listening to music has been implemented more and more in clinical settings, i.e. in potential stress-inducing environments. A multitude of studies have been conducted to investigate the purported stress-reducing effect of listening to music in these environments (e. g. Allen et al., 2001; Good, Anderson, Ahn, Cong, & Stanton-Hicks, 2005; MacDonald et al., 2003; McCaffrey & Locsin, 2006; Nilsson, Rawal, & Unosson, 2003; Nilsson, Unosson, & Rawal, 2005; Twiss, Seaver, & McCaffrey, 2006; Voss et al., 2004). In summary, listening to music may have beneficial effects on patients by attenuating stress-induced arousal in terms of physiological and psychological parameters. Consequently, listening to music might be a suitable tool for stress reduction, and, as a consequence, for the promotion of health.

Yet, findings of previous investigations are not always consistent and some results are even contradictory. Moreover, some studies have not found any influence of listening to music (for reviews see Evans, 2002; Nilsson, 2008; Pelletier, 2004; Richards, Johnson, Sparks, & Emerson, 2007). Given the fact that the vast majority of previous investigations were conducted in the context of medical interventions with patients in clinical environments, the inconsistent data may be attributable to this variability of settings. Moreover, the generalization of these findings beyond these specific samples is limited. What is more, many of these studies suffered from methodological and conceptual shortcomings, such as small sample sizes or lack of statistical significance, no control groups, or no randomization. Moreover, due to their quasi-experimental approach, these studies cannot provide sufficient insights into the psychobiological mechanisms of the effectiveness of music interventions.

Only a rigorously controlled experimental design in a laboratory environment with healthy subjects would allow a detailed understanding of the underlying mechanisms. Evidence from laboratory-based studies, however, is very limited and provides inconsistent data. Additionally, the broad majority of previous studies only focused on single aspects of the stress experience and neglected the notion that stress is best explained as a multidimensional phenomenon, as posited by modern stress research. This implies that individual susceptibility to stress, or individually different stress appraisal processes, should be controlled for as likely mediating variables. In addition, given Pelletier's (2004) finding that the total stress reduction through listening to music differed significantly according to many different influencing variables (e.g. age, sex, previous training in music, stress experience or intervention, musical preference, etc.) the experimental control of these variables would be of essential value. As music listening is extensively used for emotion regulation purposes (e.g. Juslin & Sloboda, 2001; Thoma, Ryf, Ehlert, & Nater, submitted), individual emotion regulation processes are also potential confounding mechanisms. Most previous studies neglected to control for these possible confounding variables. The shortcomings of previous studies may explain the fact that studies thus far have produced data that may collectively be regarded as confusing and inconsistent.

The aim of this thesis was therefore to investigate the association between music listening and health under consideration of predicted mediating mechanisms in a first step. In a second step, we set out to examine the assumed stress-reducing effect of listening to relaxing music in a rigorously controlled experiment in a laboratory setting. The effect of music listening was examined across neuroendocrine, autonomic, cognitive, and emotional domains of the stress experience in healthy participants. It was hypothesized that this integrative experimental approach would shed light on the underlying psychobiological mechanisms of the effectiveness of music interventions.

2 THEORETICAL BACKGROUND

Listening to music has been proposed as a suitable tool for stress reduction, and thus, as a consequence, for the promotion of health. In the following, the term *music* is firstly presented from a definitional and anthropological perspective, and then from the aspect of its specific neural processing, as well as from the perspective of its assumed beneficial influence (chapter 2.1). Following this, the term *stress,* which is understood as a multidimensional phenomenon, is described in detail (chapter 2.2). Finally, the influence of music listening on the most relevant stress parameters and the assumed underlying mechanisms are reported in an attempt to underline the possible role of music listening to function as a tool for the reduction of stress (chapter 2.3).

2.1 MUSIC

Before looking in more detail at the effect of music listening on particular human stress response parameters, the term *music*, as it is understood in this thesis, is described. Subsequently, the anthropological perspective on the evolution of music is presented in order to acknowledge the significance of the evolution of music. Additionally, the neural processing of music and its differentiation from language, as a similar human ability, is presented. Finally, the general health-promoting effect of listening to music is addressed from a historical and empirical perspective.

2.1.1 Definition

The term *music* derives from the Greek expression 'mousike', which may be best translated by '(art) of the Muses'. There is no final or interculturally accepted definition of the term music, nor does a commonly acknowledged concept exist regarding the necessary and sufficient conditions that distinguish music from other complex sounds (e.g. noise) or silence. Nevertheless, many attempts have been made to dissolve the issue of the ontology of music (for an overview see Levinson, 1996). Probably the only consensus of all previous definitions of music is that music necessarily has to be produced by sound waves, i.e. sound waves are the minimal prerequisites of music (Nattiez & Abbate, 1990). However, this irreducible given distinguishes music only from silence, but not yet from noise (Levinson, 1996). Music, in comparison to noise, is understood as a differentiated, organized, and thus rule-based sound. Defining music as organized or rule-based emphasizes simultaneously its own creator and site of origin: music is and has been made by human beings. It consists of the following properties: pitch (which governs melody and harmony), rhythm, dynamics, texture and timbre. Finally, in great contrast to noise, music is (more or less consciously) listened to or played with the intention to experience (intense) pleasure. Consequently, music may best be defined as an abstract, man-made, and organized product of sound waves, consisting of pitch, rhythm, dynamics, texture and timbre, which is listened to (played or singed) with the (un-) conscious intention to experience (intense) pleasure.

2.1.2 Anthropological perspective on the evolution of music

The origin, biological significance, and function of music is still an unsolved issue and many controversies enwind this stimulus (Cross, 2001; Huron, 2001; McDermott, 2008). Despite the fact that for some scientists or theorists music does not reflect evolved processes of our brain, and consider it as (a pleasurable but redundant) derivative of our evolution (e.g. Pinker, 1997), others argue that the development of music was essential for our evolutionary fitness (G. Miller, 2000). The discussed adaptive implications of the evolution of music are the following: sexual selection, the advancement of group cohesion in social interactions (e.g. war, military training, sports or religion), the basis for the later development of human language, or the calming effect of music on infants (and adults) (see McDermott, 2008). However, on the basis of almost no existing data, how could we test or narrow these theories? Furthermore, despite the original function music might have had as it origined, it is strongly assumed that this function has changed over time and is now different for the human beings living nowadays. What we know is that music, similar as language, is greatly used for the purpose of communication (Cross, 2001). Moreover, as music is able to elicit intense emotions and pleasure in the listeners (Blood & Zatorre, 2001), it may be concluded that the biological necessity of the evolution of music was (and remains) its significant operative value in the communication and the regulation of emotions.

Recent investigations found support for this assumption from a developmental perspective (e.g. Trehub, 2001; Trehub, Schellenberg, & Kamenetsky, 1999; Trehub et al., 1997), i.e. when examining the (emotional) communication between parents and infants. Parents around the world and across all cultures sing (or hum) to their infants, with the purpose of pacifying and soothing them (Peretz, 2001); they intuitively (verbally) communicate with them in a higher pitch (in comparison to interactions with adults) (Trainor, 2008), or speak in a singing manner (so called *motherese*) to emotionally mirror their (prelinguistic) infants (Bunt & Pavlicevic, 2001) in helping them to regulate their emotions. Moreover, infants are more interested in their mothers when they are singing as when they are speaking to them (Trehub, 2001). These findings point towards the likelihood that music may be deeply anchored in our brains by originally functioning to fulfill our emotional needs.

Recent findings in brain imaging studies provide additional support for this assumption. For instance Panksepp and Bernatzky, who propose that "..our love for music refects the ancestral ability of our mammalian brain to transmit and receive basic emotional sounds that can arouse affective feelings which are implicit indicators of evolutionary fitness." (Panksepp & Bernatzky, 2002, p. 134). This is in line with the view of Trainor, who stated that "..music is built on general, universal features of human sound processing that have deep evolutionary roots." (Trainor, 2008, p. 598). Evidence for this biological perspective on the origin and evolutionary significance of music can be seen in the actual neuronal processing of music, as music recruits similar limbic and paralimbic structures as biologically relevant stimuli (e.g. food and sex) (see Blood & Zatorre, 2001; Blood, Zatorre, Bermudez, & Evans, 1999).

On the basis of recent research, it is evident that music is to a great extent more than solely a by-product of evolution. Yet, the question of the biological necessity of the development of music is not fully answered. Not even Charles Darwin found an appropriate explanation for the prominent role music plays interculturally for human beings (McDermott, 2008). Nevertheless, there is increasing awareness of its crucial role in the communication and the regulation of emotions. Given the fact that music is a unique trait of human beings, it can be argued that it was the evolution of music that finally made us human (Juslin & Sloboda, 2001). Despite the fact that this is only an assumption that may or may not hold true, its possible verification justifies an in-depth scientific engagement with it.

2.1.3 Neuronal substrates of listening to music

In the following, the neuronal processing of music listening is described. Additionally, given the close relationship between music and language, basic differences between these two exclusively human abilities are highlighted.

2.1.3.1 The neuronal processing of music

Against earlier assumptions, recent brain imaging studies have shown that neural activity associated with music listening includes much more than exclusively the auditory cortex. Listening to music activates many psychological functions (i.e. cognitive and emotional components) in an extensive bilateral network including frontal, temporal, parietal, and subcortical areas related to attention, semantic and music-syntactic processing, emotion, memory, and motor functions (e.g. Baumgartner, Lutz, Schmidt, & Jancke, 2006; Bhattacharya, Petsche, & Pereda, 2001; Janata, Tillmann, & Bharucha, 2002; Jäncke, 2008b; Koelsch et al., 2004; Popescu, Otsuka, & Ioannides, 2004). However, music does not engage an own, exclusive brain circuitry; it does not recruit a neuronal pathway or a brain area that is exclusiverly dedicated to the processing of music (Peretz & Zatorre, 2005; Stewart, von Kriegstein, Warren, & Griffiths, 2006; Warren, 2008). Consequently, the neuronal system for the processing of the perceptional and cognitive properties of music is no other than that of the neuronal processing of other complex sounds.

The perceptual and cognitive analysis of complex sounds, such as music, recruits following brain areas and cortical circuits (for an extensive overview see Warren, 2008): the primary auditory cortex (A1), the planum temporale[1] (engaged in the analysis of spatial location, identifying features and information about pitch patterns (Griffiths & Warren, 2002; Warren,

[1] corresponding to Wernicke's area in the left hemisphere

2008; Warren, Uppenkamp, Patterson, & Griffiths, 2003)), the superior temporal gyrus (STG) (implicated in the analysis of sentences or melodies) (Patterson, Uppenkamp, Johnsrude, & Griffiths, 2002; Warren, Uppenkamp, Patterson, & Griffiths, 2003)), temporal and parietal lobes (connect auditory to non-auditory sensory information (in particular vision), and special networks in the parietal and frontal lobes (for the mediation of "..working memory for music and other sounds to behavioral responses to sound." (Warren, 2008, p. 34)).

In comparison to the research efforts concerning the above mentioned neuronal processing of the perceptual and cognitive properties of complex sounds (i.e. music), the research efforts concerning the neuronal processing of emotional responses to music (i.e. musical emotions) has barely begun (Peretz, 2001). It has been demonstrated that there is not one single or uni-dimensional neuronal process underlying all emotional responses to listening to music (Juslin & Sloboda, 2001). An increasing number of research studying the neuronal processing of emotional responses is revealing that many distinct brain areas are participating in the neural processing of music (for an extensive overview see Koelsch, 2010). For instance, cortical circuits of reward and emotion are stimulated by the listening to (pleasant) music (e.g. Menon & Levitin, 2005): interestingly enough, as these systems are also recruited by stimuli such as food and sex (i.e. biologically relevant stimuli for survival), or also by drugs of abuse (Blood & Zatorre, 2001). These neural systems include key brain regions that are generally involved in affect processing: the ventral tegmental area (VTA), thalamus, hypothalamus, hippocampus, amygdala, prefrontal cortex, orbitofrontal cortex, midbrain/periaqueductal grey (PAG), insula, and nucleus accumbens (NAc) (e.g. Blood & Zatorre, 2001; Blood, Zatorre, Bermudez, & Evans, 1999; Brown, Martinez, & Parsons, 2004; Koelsch, 2010; Koelsch, Fritz, DY, Muller, & Friederici, 2006; Menon & Levitin, 2005). In comparison to several natural sounds (e.g. bird twitter, sound of the crashing seas), which may also have some emotional importance for the listener, the capacity of music to elicite such intense feelings and emotions is of much greater significance for us (Warren, 2008).

Menon and Levitin found that listening to (pleasant) music activates "..dynamic interactions between the NAc, the VTA, and the hypothalamus [that] may play an important role in regulating emotional responses to music." (Menon & Levitin, 2005, p. 182). Additionally, they documented "..that NAc and VTA activations were significantly correlated, suggesting an association between dopamine release and NAc response to pleasant music." (Menon & Levitin, 2005, p. 182). Further, it was reported that the administration of naloxone can block the pleasure experienced through the listening to music (Goldstein, 1980). Finally, Blood and Zatorre suggested that "..activation of the reward system by music may maximize pleasure, not only by activating the reward system but also by simultaneously decreasing activity in brain structures associated with negative emotions." (2001, p. 11823), such as for example the amygdala (Gosselin, Peretz, Johnsen, & Adolphs, 2007; Koelsch, 2010). It can be concluded that the listening to music activates not only the auditory system but a widespread network of cortical and subcortical brain areas in both hemispheres.

2.1.3.2 Differences between music and language

There is a close relationship between music and language. Both represent innate multidimensional and abstract systems of human beings. In order to differentiate these two, at first sight very similar human abilities from one another, basic differences between music and language shall be outlined below:

Both, music and language organize sound sequences, such as notes or phonemes, into complex structures, such as melodies or sentences. Thus, music and language convey special meanings on the basis of specific rules (Patel, 2005). The analysis of meaning, i.e. syntax, is a rather complex mechanism for the brain, which engages a specialized brain activation pattern (Kolb & Whishaw, 2005). As a consequence, brain areas associated with this complex mechanism of analyzing meaning on the basis of complex sound patterns might be the same or very similar for music and language (Patel, 2003).

It is therefore not a surprise that it was long assumed that music and language are two very similar human abilities and that their only (but profound) difference is that they are processed in the right and the left cerebral hemispheres, respectively. Indeed, music and language overlap in important ways (e.g. syntax, as seen above) (Patel, 2003). Nevertheless, the purported similarity between music and language is only superficial (Warren, 2008). On the basis of previous research conducted in the field of neuropsychology (mainly neurological case studies), it could have been shown that the loss of one ability (e.g. speech) does not necessarily include the loss of the other ability (e.g. musicality). This phenomenon of an indepentend occurrence of aphasia and amusia strongly indicates that langage and music cannot be considered as analogous human abilities that are solely processed in opposite hemispheres (Peretz, 2001). Finally, given that music appears to have much more impact on the limbic system (e.g. Peretz, 2006), it has been suggested that music and language have only few cognitive overlap (Warren, 2008).

Homo sapiens sapiens is incomparable in his ability to make sense out of complex sounds, as this is the case in language and music (Patel, 2008). Both, music and language, are man-made, this is both are uniquely human traits. This makes it almost impossible to gain an indepth insight in these extraordinary abilities by studying them from a non-human perspective, i.e. by comparing human beings to other organisms. Consequently, the comparison between music and language is still in its infancy (Patel, 2008), and is in need of further investigations.

2.1.4 Health promotion through listening to music

Recent brain imaging studies were able to demonstrate that music can recruit subcortical brain areas that specifically respond to biological stimuli which are necessary for survival (see chapter 2.1.3.1). However, as accentuated by Blood and Zatorre, music, as an abstract stimulus, has no known value for the survival of its own creator (2001). But how can such a widespread neural activity pattern for a stimulus, that has no obvious importance for human beings, be explained? Blood and Zatorre conclude that "..the ability of music to induce such intense pleasure and its putative stimulation of endogenous reward systems suggest that; although music may not be imperative for the survival of the human species, it may indeed be of significant benefit to our mental and physical well-being." (2001, p. 11823). Music may thus be functional in establishing or promoting psychological and physiological health.

However, the notion that music can have a beneficial impact on human health is nothing new. The alleged beneficial effect of music has been known since antiquity: from primitive man (e.g. Henry, 1995), to the Greek philosopher Pythagoras (e.g. White, 2001), to Florence Nightingale in the mid-1800s; music has been used as a means to positively affect human health and well-being by appeasing the Gods, by reestablishing and preserving the harmony of body and soul, or to promote healing in wounded soldiers, respectively (for an extensive overview see Nilsson, 2008).

Ever since these early beginnings, a multitude of studies have been conducted (e. g. Allen et al., 2001; Good, 1995; Good, Anderson, Ahn, Cong, & Stanton-Hicks, 2005; Good, Anderson, Stanton-Hicks, Grass, & Makii, 2002; MacDonald et al., 2003; McCaffrey & Freeman, 2003; McCaffrey & Locsin, 2006; Nilsson, 2003; Nilsson, Rawal, Unestahl, Zetterberg, & Unosson, 2001; Nilsson, Rawal, & Unosson, 2003; Nilsson, Unosson, & Rawal, 2005; Taylor, Kuttler, Parks, & Milton, 1998; Twiss, Seaver, & McCaffrey, 2006; Voss et al., 2004; Yung, Chui-Kam, French, & Chan, 2002). These studies found that music decreases blood pressure, heart rate, heart rate variability, respiratory rate, galvanic skin responses, and cortisol concentrations. Furthermore, they reported increases in skin temperature, in the feeling of well-being, relaxation, and perception of control. Moreover, the authors found reductions in pain, and reduced anxiety, anger, and fear, as positive outcomes of listening to music.

The findings of these studies indicate that listening to music can have health-promoting effects by exerting intense and profound psychological and physiological effects upon the listener. It appears that listening to music affects health through its emotional, sedative, distracting, and tranquilizing effects, possibly due to music's capacity to reduce the psychological and physiological experience of stress. It can be summarized that listening to music may function as a medium to reduce stress and that it is therefore effective in the promotion of health.

Before addressing in detail the proposed stress-reducing effect of music listening on the most relevant stress response patterns, the terminology and conceptualization of *stress*, as well as the physiology of the most important stress systems, is described in detail below.

2.2 STRESS

The term *stress* has become an often cited expression in describing the lifestyle of today's Western society. The concept of *stress* helps to explain the multiple bodily and psychological complaints of (yet) unknown origin (Pohlman & Becker, 2006). An acute, short-term response to stress is associated with positive influences on health and increases immunological function and thus ensures an organism's survival. The sustained (i.e. chronic) stress experience and its biological consequences are associated with negative influences on psychological and physiological health (e.g. Esch, Stefano, Fricchione, & Benson, 2002a; 2002b; 2002c; McEwen, 1998, 2008). Conservative estimates suggest that stress accounts for approximately 30% of the overall costs of illnesses and accidents across Western nations (Nater, Gaab, Rief, & Ehlert, 2006).

In the following, a brief introduction to the most prominent stress concepts will be outlined in order to provide a better understanding of how the term *stress* is used in health sciences. Furthermore, the physiological mechanisms that underlie the stress concept will be presented.

2.2.1 The concept of stress

The physiologist Walter Cannon is considered a pioneer in stress research. He coined the term of 'homeostasis', a concept that describes the sum of an individual's capacity to maintain most of the steady states in the organism by compensatory mechanisms to equilibrate environmental changes (Cannon, 1932). Stress, as an unspecific and uniform pattern of physiological processes, is considered to disturb the homeostatic equilibrium of the organism. If this is the case, the organism may react with 'fight-or-flight' responses (Cannon, 1915). Cannon suggested the sympathetic nervous system (SNS) to be the essential homeostatic system. Some years later, Selye proposed a three-phasic process model, the ‘general adaptation syndrome’ (GAS), which describes stress in terms of external events that excite certain unspecific biological distress responses (Selye, 1950). He described this reaction by three consecutive steps: 1) alarm reaction (activation of SNS and the hypothalamus-pituitary-adrenal (HPA) axis), 2) resistance phase (organism is still in a state of heightened arousal, and adaptive mechanisms are intensified), and 3) exhaustion phase (gradual decrease of resistance to stress).

Both Cannon and Seyle proposed reaction-oriented stress theories, including non-specific and uniform stress reactions. These theories were of limited utility for the understanding of interindividual differences in biological stress responses. The increased awareness of individual differences to the same stressors initiated the development of extended theories. Mason, for instance, found that physical stressors influence the hormonal system only when the stressor is emotionally perceived as aversive (Mason, 1975; Mason, Giller, Koster, Ostroff, & Podd, 1986). Particular relevance in this context was given to the transactional stress model by Lazarus and colleagues (Lazarus & Folkman, 1984), in which psychological appraisal processes play a central role. The original concept has been modified over the past years. In the most recent version, the authors defined stress as 'a particular relationship between the person and the environment that is appraised by the person as taxing or exceeding his or her resources and endangering his or her well-being' (Lazarus & Folkman, 1984). Two central concepts, i.e. evaluation (primary appraisal) and coping (secondary appraisal), play an essential role. In the primary appraisal phase, an individual decides whether a situation is relevant or irrelevant, with the former being distinguished as benign or stressful. In the phase of the secondary appraisal, the individual considers alternative solutions, coping abilities, and consequences of a potential action. Additionally, coping strategies can be further divided into *problem-focused* or *emotion-oriented* coping strategies (Folkman, 1997). The former strategy is used when one is actively seeking to solve a problem; the latter is characterized by more passive and avoidant coping strategies.

Nevertheless, even when exposed to the same stressors, in terms of stress appraisal and coping, some individuals tend to respond more strongly to stressful situations than others. This disadvantageous pattern describes an individual's susceptibility to respond to a stressor with an immediate, intense, and long-lasting stress response (Schulz, Jansen, & Schlotz, 2005). In summary, (real or anticipated) stress emerges when perceived demands of a situation (primary appraisal) exceed the perceived resources (secondary appraisal) (Lazarus & Launier, 1981). Consequently, stress is the result of a cognitive appraisal process which, in a given situation, results in an emotional, physiological, and behavioral stress response.

McEwen finally introduced the term 'allostasis' and 'allostatic load' (McEwen, 1998). Allostasis, similarly to homeostasis, describes a process that actively maintains internal stability, but encompasses a wider concept and involves whole-organism mechanisms to preserve survival of the organism. Acutely, allostasis supports the adaptation to and the coping with a stressor – short-term stress is generally not harmful. Persisting allostasis, which is the maintaining of allostatic processes over too long periods, results in an 'allostatic load', i.e. maladaptive consequences of a sustained activation of primary regulatory systems (McEwen, 1998, 2000a). This framework also accounts for psychological factors, suggesting that cognitive processes moderate the physiological stress response and explain the existence of interindividual differences (McEwen, 2007, 2008).

2.2.2 Physiology of the stress systems

The entire stress system is understood as a complex physiological system that is located in the central nervous system (CNS) and peripheral parts of the organism. In the following, the major physiologic stress response systems in the body, the hypothalamus-pituitary-adrenal (HPA) axis and the autonomous nervous system (ANS), and their biomarkers, i.e. cortisol and salivary alpha-amylase (sAA), are described in detail.

2.2.2.1 The hypothalamus-pituitary-adrenal (HPA) axis

In order to provide a better understanding of the neuroendocrinological mechanisms of the stress response, the following paragraph will outline basic information about the HPA axis and its main biomarker, cortisol.

2.2.2.1.1 Anatomy and physiology of the HPA axis

The HPA is a regulatory system of the organism that links the CNS via the endocrine signaling with the periphery, mainly through the following three key hormones: the corticotropin-releasing hormone (CRH), adrenocorticotropin hormone (ACTH), and cortisol (Tsigos & Chrousos, 2002). These hormones are thought to ensure the maintenance of homeostasis. This is achieved through the activation and coordination of various psychological (e.g. memory, consolidation) and physiological (immune functioning, cardiovascular activation, glucose metabolism) processes, and emotional processing (Sapolsky, Romero, & Munck, 2000; Schulkin, McEwen, & Gold, 1994).

Psychosocial stress leads to the activation of the HPA axis. The central control of the HPA axis is governed by the hypothalamic paraventricular nucleus (PVN). The PVN receives input from stress-excitatory and stress-inhibitory circuits, which can be differentiated with regard to the central nervous system structures involved (limbic-insensitive vs. limbic-sensitive), the processing of sensory information (systemic vs. processive), or the type of perceived homeostatic disruption (reactive vs. anticipatory) (Herman & Cullinan, 1997; Herman et al., 2003; Lopez, Akil, & Watson, 1999). From this perspective, psychosocial stress activates the HPA axis on a hypothalamic level through processive stress pathways, involving inhibitory (mediated through indirect input from the ventral subiculum and the medial prefrontal cortex) and excitatory (mediated through indirect input from the amygdale) limbic-sensitive structures (Herman et al., 2003). The experience of psychosocial stress leads to the activation of various pathways that culminate in the release of CRH from the PVN of the hypothalamus. With this, stress has activated the HPA axis and triggered the so-called 'endocrine cascade' through the release of the above-mentioned hormones. Cortisol specifically binds mainly on glucocorticoid receptors, but also on mineralocorticoid receptors or erythrocytes (DeRijk, Schaaf, & de Kloet, 2002). Only small proportions are unbound and biologically active (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999).

To protect the system from an overshooting response, several negative feedback loops are initiated immediately after activation of the HPA axis (D. B. Miller & O'Callaghan, 2002). ACTH inhibits further CRH release through inhibitory feedback from the pituitary glands to the PVN of the hypothalamus, and similarly, cortisol attenuates ACTH and CRH through negative feedback from the adrenal cortex to the pituitary and the PVN, respectively. CRH release is under excitatory input from the amygdalae and inhibitory control from the hippocampus and mediates autonomic, immune, behavioral, and visceral responses (Owens & Nemeroff, 1991). Given that the HPA tends to react slower than the SNS, the secretion and physiological effects of glucocorticoids are generally delayed. According to Sapolsky et al., “..preventing water damage rather than putting out the fire..” is a fitting description for the physiological role of HPA axis hormones (Sapolsky, Romero, & Munck, 2000, p. 56).

HPA reactivity is influenced by several cortical areas, the ANS, and the immune system (Birbaumer & Schmidt, 2003; McEwen, 2007). Moreover, a multitude of biological and psychological factors, such as age, pharmaceuticals, lifestyle indicators (e.g. smoking, alcohol) are known to lead to intra- and interindividual differences in stress-induced HPA axis functioning (Clow, Thorn, Evans, & Hucklebridge, 2004; Kudielka, Hellhammer, & Wüst, 2009; Kudielka, Schommer, Hellhammer, & Kirschbaum, 2003; Smyth et al., 1997). Moreover, sexual dimorphism of the HPA response to psychosocial stress has been observed in the past (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999; Stroud, Salovey, & Epel, 2002). Further, the prolonged experience of stress, i.e. chronic stress, may lead to more permanent alterations along the HPA axis including both hypo- and hyperreactivity (Chrousos & Gold, 1992; Raison & Miller, 2003), which exerts negative long-term effects on somatic and mental well-being (Heim, Ehlert, & Hellhammer, 2000; Seeman, McEwen, Rowe, & Singer, 2001). Depression is one example that has been associated with some malfunctions along the HPA axis, including increased basal cortisol levels (Halbreich, Asnis, Shindledecker, Zumoff, & Nathan, 1985; Rubin, Poland, Lesser, Winston, & Blodgett, 1987), or non-suppression in response to dexamethasone, which suggests blunted negative feedback (American Psychiatric Association, 1987; Carroll, 1982; Carroll, Feinberg, & Greden, 1981).

2.2.2.1.2 Cortisol: Indicator of the HPA axis

The hormone cortisol constitutes a reliable indicator of HPA axis activation (Hellhammer, Wuest, & Kudielka, 2009). Cortisol can be measured in several bodily fluids, such as saliva, plasma, urine, or sweat. Measuring cortisol in saliva is a non-invasive, non-traumatic, and discrete method of sampling. Given that the diffusion of unbound cortisol into saliva happens passively, it is independent of the salivary flow rate (Kirschbaum & Hellhammer, 1994). Salivary and plasmatic cortisol correlate highly (r=0.71 - 0.96) (Gunnar, Connors, & Isensee, 1989; Harris et al., 1990; McCracken & Poland, 1989; Reid, Intrieri, Susman, & Beard, 1992; Woodside, Winter, & Fisman, 1991). Cortisol in saliva, similar to plasma cortisol, peaks about 20 - 30 minutes after termination of acute stress exposure (Kirschbaum & Hellhammer, 1994; O'Connor & Corrigan, 1987). In addition to the mediating function in the organism's adaptation to stress, the HPA axis underlies a constant diurnal and circadian rhythm: within the first half hour after awakening, cortisol levels rise (50 – 160%) and decline thereafter over the course of the day to reach a minimal value at midnight (Edwards, Clow, Evans, & Hucklebridge, 2001). Cortisol concentrations over the course of the day may be opposite to those related to stress (Sapolsky, Romero, & Munck, 2000). Acknowledging this circadian rhythm of cortisol, the exclusive description of this substance as 'stress hormone' would probably oversimplify the dynamics of cortisol (McEwen, 2000b).

2.2.2.2 The autonomous nervous system (ANS)

The following paragraph is devoted to describing the autonomous nervous system, as another major physiological stress system besides the HPA axis.

2.2.2.2.1 Anatomy and physiology of the ANS

The autonomous nervous system (ANS) is a part of the peripheral nervous system. It functions as a subconscious control system, and modulates the activity of the body's organs by regulating gastrointestinal, cardiovascular, electrodermal, respiratory, endocrine, and exocrine functions. It is classically divided into the parasympathetic nervous system (PNS), the sympathetic nervous system (SNS), and the enteric nervous system (ENS). Besides the HPA, the SNS is an important psychobiological stress system (Chrousos & Gold, 1992). Its general function is to mobilize the organism's resources under stress; to induce the flight-or-fight response. Even in the absence of stress, the SNS is constantly active at a basal level in order to maintain homeostasis (Bordal, 2004).

When a person experiences stress, the sympathetic nervous system (SNS) is stimulated, and the secretion of epinephrine (EP) and norepinephrine (NE) from the adrenal medulla increases. Adrenal medullary cells are modified postganglionic neurons, and postganglionic autonomic nerve fibers lead to them directly from the CNS. Cells of the adrenal medulla are therefore intimately connected with the SNS. EP, a derivative of NE, is a powerful vasopressor, increases blood pressure, stimulates the heart muscle, accelerates the heart rate, and increases cardiac output, and, consequently, leads to hypertension. For this reason, NE is also known as the 'fight-or-flight' hormone. NE is also a neurotransmitter that is released at the postganglionic synapses in the SNS (Lehnert, Schulz, & Hiemke, 1999). NE helps in converting glycogen to glucose in the liver; it increases the conversion of fats into fatty acids and also helps in relaxing the bronchial muscles in order to open up the air passage to the lungs. All of these actions are related to the calming down of the body in a stressful situation. It also increases the secretion of CRH, which facilitates general arousal. CRH then inhibits growth hormone and sexual activity, as growth and reproduction are not useful functions during the experience of stress. EP and NE are also important hormones affecting wound healing (McCarthy, Quimet, & Daun, 1991).

2.2.2.2.2 Salivary alpha-amylase (sAA): Indicator of the ANS

Salivary alpha-amylase (sAA) has recently been established and evaluated as a valid biomarker for SNS activity (Nater & Rohleder, 2009). sAA is one of the most important enzymes in saliva, which is synthesized and secreted locally by the salivary glands (Buddecke, 1981). Therefore, sAA levels in the oral fluids do not represent levels in the general circulation, nor do they reflect levels in the gastrointestinal system. The main function of sAA is the enzymatic digestion of carbohydrates (Baum, 1993). Further, it has also been proposed that sAA has an important bacterial interactive function (Scannapieco, Torres, & Levine, 1993). The release of sAA is controlled by the autonomous nervous system (ANS) (Ehlert, Erni, Hebisch, & Nater, 2006; Malfertheiner & Kemmer, 1987), i.e. the sympathetic nervous system (SNS) in particular (for a review see Nater & Rohleder, 2009). There is a body of evidence that sAA levels rise in response to both physical and psychological stress: Levels of sAA increase in response to stressful conditions including exercise, heat and cold stress, and written examinations (Chatterton, 1996, 1997; Skosnik, 2000). More recent studies report large sAA increases in response to a psychosocial stressor (Trier Social Stress Test, TSST) (Gordis, 2006; Nater et al., 2006; Nater et al., 2005; Stroud et al., 2006), to watching highly negative emotional pictures of mutilation or accidents (van Stegeren, Rohleder, Everaerd, & Wolf, 2006), and to participating in athletic competition (Kivlighan & Granger, 2006). The salivary enzyme alpha-amylase can therefore be regarded as a good indicator of stress-related body changes (Chatterton, 1996; Granger, Kivlighan, Sheikh, Gordis, & Stroud, 2007; Nater, 2007; Rohleder, Nater, Wolf, Ehlert, & Kirschbaum, 2004).

The assumed association between SNS activation and sAA can be supported by findings derived from animal and human studies (for a review see Nater & Rohleder, 2009). Animal studies indicate that beta-adrenergic mechanisms are the main contributing factor for sAA secretion; this indicates the involvement of the ANS, and, in particular, the SNS for the secretion of sAA. Also in humans, it was found that beta-adrenergic agonists can stimulate sAA release without increasing salivary flow (Gallacher & Petersen, 1983). A placebo-controlled study indicated that increases in sAA due to stress can be inhibited by the administration of the beta-adrenergic blocker propranolol (van Stegeren, Rohleder, Everaerd, & Wolf, 2006). Moreover, in a study assessing the indirect effect of yohimbine hydrochloride (alpha-2-adrenergic receptor antagonist), it was found that sAA level increases may mirror the interaction of sympathetic and parasympathetic stimulation via central nervous noradrenergic input (Ehlert, Erni, Hebisch, & Nater, 2006). Finally, in a study using a psychosocial stress test, it was reported that sAA and the low frequency / high frequency ratio (thought to mirror sympathetic tone) correlated positively (Nater et al., 2006). On the basis of this knowledge, it can be deduced that the same stimuli that result in the release of catecholamines in the blood and peripheral tissues activate sympathetic input to the salivary glands. It may therefore be concluded that the ANS plays a substantial role in the secretion of sAA, with a contributing involvement of both the alpha- and beta-adrenergic mechanisms (for a review see Nater & Rohleder, 2009). From today's perspective, sAA is established and evaluated as a valid marker for SNS activity (Nater et al., 2006; Nater & Rohleder, 2009; Rohleder, Nater, Wolf, Ehlert, & Kirschbaum, 2004; van Stegeren, Rohleder, Everaerd, & Wolf, 2006).

The response profile of sAA due to stress is characterized by an sAA-level increase of 50 – 60% (Stroud et al., 2006) to 145 % (Gordis, 2006) on average over baseline levels, a peak at approximately 10 minutes following the onset of the stressor (Stroud et al., 2006), and a return to baseline by 10 minutes post-stress (Gordis, 2006). Individual differences in sAA are related to various different variables, such as age and pubertal development (Gordis, 2006; Susman, Granger, & Dockray, 2006). Further, Susman and colleagues reported a positive association between sAA and body mass index (BMI) in adolescent males and females (Susman, Granger, & Dockray, 2006). No study so far has examined stress-related sAA differences between men and women.

2.2.2.3 Comparing cortisol and sAA response patterns

The diurnal rhythms of sAA and cortisol are distinct (Nater, Rohleder, Schlotz, Ehlert, & Kirschbaum, 2007). Whereas sAA activity decreases in the first half hour after awakening, and thereafter rises towards the afternoon and evening (Nater, Rohleder, Schlotz, Ehlert, & Kirschbaum, 2007), cortisol activity shows an opposite diurnal pattern (see chapter 2.2.2.1.2) (Edwards, Clow, Evans, & Hucklebridge, 2001). Also, the stress-related changes in sAA levels and the response profile of salivary cortisol do not correspond (Nater & Rohleder, 2009; Rohleder & Nater, 2009). In comparison to cortisol, sAA levels increase over baseline levels in response to stress in a larger percentage of cases, and the magnitude of the rise in sAA may be larger, on average, than salivary cortisol (Gordis, 2006; Kivlighan & al., 2005; Nater et al., 2006; Nater et al., 2005). Salivary alpha-amylase reaches its peak response faster (10 min) than salivary cortisol (20 – 30 min). Furthermore, recovery (peak back to baseline) is faster for sAA than for cortisol. SNS reactivity may occur to challenges that are more mild than those required to activate the HPA axis, i.e. the SNS may has a more sensitive threshold reactivity than the HPA axis (Lovallo & Thomas, 2000). Given that sAA is, in comparison to cortisol, directly released by the salivary glands into the mouth, differences in the peaks of sAA and cortisol may also at least be partly due to specialized issues of cortisol measurement in saliva (Granger, Kivlighan, Sheikh, Gordis, & Stroud, 2007). Moreover, the lack of correlation between levels of sAA and salivary cortisol also suggests a different stress-response system.

2.3 EFFECTS OF LISTENING TO MUSIC ON STRESS

As seen above, stress is a multi-faceted phenomenon that includes cognitive and emotional processes, as well as physiological, i.e. endocrine and autonomic, parameters (see chapter 2.2). Listening to music, on the other hand, has previously been proposed to have a beneficial impact on these parameters. Listening to music has consequently received special interest as a coping strategy to deal with stress and stress-related health issues.

In the following chapter, the effect of listening to music is described in detail, separately for each component of the stress response.

2.3.1 The effect of music listening on the psychological stress response

The following paragraph describes the effect of music listening on psychological stress responses, i.e. on cognitive and emotional components of the human stress response.

2.3.2 The effect of music listening on cognitive stress components

Listening to music is a multi-faceted process as it generates many different cognitive components in the brain (Peretz & Zatorre, 2005). In view of the many studies that have reported positive findings of the influence of music listening on cognitive abilities and functions, it might be assumed that listening to music also has a positive impact on stress-related cognitive processes. In the following, the general influence of music listening on cognitive abilities and functions is described in detail. Furthermore, the few studies examining the influence of music listening on stress-related cognitive processes are summarized. Finally, the assumed underlying mechanisms of the effectiveness of music listening on cognitive parameters are discussed.

2.3.2.1.1 The effect of music listening on cognitive abilities and functions

Previous investigations on the effect of music listening on cognition suggest that specific kinds of music may be able to enhance a variety of cognitive functions and performances, such as attention, learning, communication, verbal fluency, creativity, spatial-temporal abilities, and memory (e.g. Miskovic et al., 2008; Schellenberg, Nakata, Hunter, & Tamoto, 2007; R. G. Thompson, Moulin, Hayre, & Jones, 2005; W. F. Thompson, Schellenberg, & Husain, 2001; Wallace, 1994). Does music listening therefore make you smarter (for an extensive overview see Jäncke, 2008a)?

This was first assumed by Rauscher et al. (Rauscher, Shaw, & Ky, 1993), who found superior spatial abilities for subjects who listened to Mozart music compared to controls who sat with no acoustic stimulation or listened to relaxation instructions. This finding has become broadly known as the so-called ‘Mozart effect’. Ever since, a multitude of studies have tried to replicate the findings by Rauscher and colleagues, but with only modest or no success (Chabris, 1999; Steele, Brown, & Stoecker, 1999). It was speculated that the ‘Mozart effect’ may be best explained as being an artifact of arousal. Indeed, the short-term increases in the spatial abilities were better explained by the *arousal-and-mood theory* (see chapter 2.3.2.1.3) than by the direct effect of the specific influence due to listening to Mozart’s music. The question of whether music listening does make one smarter can therefore be answered positively. However, the following limitations apply: The duration of the effect is only short-term (10 – 15 min) and is not specific to music; other stimuli capable of optimizing arousal level or eliciting mild positive affects have the same effect. Consequently, on the basis of recent research, it can be concluded that music listening bears a rather unspecific effect on cognitive abilities and functions (Särkämö et al., 2008).

2.3.2.1.2 The effect of music listening on stress-induced cognitive processes

In light of the positive, although non-specific reported findings of music listening on cognitive abilities and functions (see chapter 2.3.2.1.1), it might be assumed that listening to music also influences stress-related cognitive processes, such as cognitive appraisal or subjective perception of stress (see chapter 2.3.1). Previous research indicates that this might indeed be the case. Some studies found reductions in perceived levels of psychological stress, increased coping abilities, or altered levels in perceived relaxation after listening to music in the context of a stressful situation. For instance, in a study by Burns et al. (1999), the authors found that the participants' physiological measures of stress before, during, and after listening to different types of music were not significantly different, but their perceived levels of relaxation changed significantly. Furthermore, Allen and colleagues investigated whether cognitive appraisal of stress levels in response to outpatient ophthalmic surgery can be decreased by patient-selected music in geriatric patients (Allen et al., 2001). The authors found significant reductions in perceived stress and increased coping abilities in those patients who could listen to music during the surgery. The effect of music listening was found regardless of the type of music chosen. No effects on these parameters were found in the non-music group.

However, not all studies found effects of music listening on cognitive processes due to stress. For example, Scheufele (2000) examined the process of relaxation by exposing healthy male participants to a stressor and subsequently to either soothing music or silence. The author measured effects of the listening to music on self-reported attention and relaxation. Subjects in the music group were more distracted after listening to music than before. Listening to music appeared to distract the listeners from the experimental stressor, which resulted in beneficial physiological effects (i.e. lower heart rates). Although the subjects in the music group did experience decreases in arousal, they did not report to feel more relaxed.

In summary, many studies exist on the influence of music listening on cognition, in terms of cognitive abilities or functions. However, very few data are available in the current literature on the beneficial effect of music listening on stress-induced cognitive components, such as cognitive appraisal processes or subjective perception of stress. Moreover, the few investigations that have been conducted in this context report conflicting data; some studies found an effect, while others did not. This might be explained by methodological issues, such as the lack of control for confounding variables. Consequently, there is a lack of studies examining changes in stress-induced cognitive components through listening to music in a laboratory environment. Therefore, no final conclusions can be drawn as to whether and how music listening influences stress-induced cognitive components.

2.3.2.1.3 Influence of music listening on cognition: Assumed underlying mechanisms

A challenging question regarding the beneficial influence of music listening on cognition concerns its underlying mechanisms. The majority of previous studies have ascribed the beneficial influence of listening to Mozart (or any music that is perceived as pleasant) "..to a general positive affective state or enhanced arousal and attention, which … seems a plausible mechanism." (Särkämö et al., 2008, p. 873). Särkämö and colleagues further acknowledge that "..this is in line with the 'arousal-and-mood theory' (W. F. Thompson, Schellenberg, & Husain, 2001), which states that any enjoyable stimuli, such as music, that induces positive affect and heightened arousal can lead to improved performance on cognitive tasks." (Särkämö et al., 2008, p. 873). Consequently, effects on cognitive abilities and functions, development or recovery due to preceding listening to (pleasant) music may, for this reason, be the result of an induction of a general positive affective state.

As a consequence, Särkämö and colleagues have developed a noteworthy theoretical framework of the underlying neuronal mechanisms that shall be briefly summarized below (for an extensive overview see Särkämö et al., 2008):

Given that listening to (pleasant) music has repeatedly been shown to recruit subcortical and cortical brain areas (Blood & Zatorre, 2001; Blood, Zatorre, Bermudez, & Evans, 1999; Brown, Martinez, & Parsons, 2004; Koelsch, Fritz, DY, Muller, & Friederici, 2006; Menon & Levitin, 2005) (for a detailed overview, see chapter 2.3.2.2.3), such as for example the dopamine releasing ventral tegmental area (VTA), the authors suppose that the positive effects on cognitive abilities and functions is due to the increased dopamine concentrations (which has been found to increase the speed of information processing and attention (e.g. Schück et al., 2002)), induced by the positive affective state. In conclusion, the underlying neuronal system responsible for the effectiveness of listening to (pleasant) music on cognition constitutes the dopaminergic mesocorticolimbic system (for an extensive overview see Särkämö et al., 2008).

However, whether this mechanism also explains possible music-induced changes in cognitive parameters due to stress cannot be answered at this point.

2.3.2.2 Effect of music listening on emotional stress components

The experience of stress includes adaptive emotional responses, such as anxiety. Given the fact that listening to music is strongly associated with the induction of (intense) emotions (e.g. Blood & Zatorre, 2001; Kreutz, Russ, Bongard, & Lanfermann, 2003; Menon & Levitin, 2005), listening to music might also be effective in the moderation of emotional responses elicited by the experience of stress.

In the following, the effect of listening to music on emotion is described in detail. As music listening is most often associated with emotion, it is first described how music listening influences the emotion system in general. Furthermore, a summary of studies that have investigated the effect of music listening on stress-induced emotions is presented. Finally, the assumed underlying mechanisms of the effectiveness of music listening on emotional parameters are presented.

2.3.2.2.1 General influence of music listening on emotion

The ability of music to induce all kinds of (intense) emotions in the listeners is broadly acknowledged; it is probably because of this emotion-inducing capacity that made music one of the most popular stimulus and activity all over the world (see Juslin & Sloboda, 2001). "Somewhat paradoxically, the cognitive and structural aspects of music have been the most extensively studied, perhaps because methods for studying them have been part of the standard cognitive psychology paradigms for decades." (Menon & Levitin, 2005, p. 175) (see also chapter 2.3.1). The investigation of the emotional influence of music listening has only recently been initiated (Blood & Zatorre, 2001; Blood, Zatorre, Bermudez, & Evans, 1999; Panksepp & Bernatzky, 2002). It may be because of this relatively novel research interest in musical emotions[2], that there exist very little consensus regarding almost every topic in the literature in this field (for an extensive overview, see Juslin & Västfjäll, 2008). This chapter offers a short overview of the rather controversially discussed topic *music and emotion*.

2.3.2.2.1.1 Musical emotions versus *real* emotions

The basic question of whether music is actually able to induce emotional responses in the listeners, and whether these emotional responses induced by music represent *real* emotions[3], has been controversially discussed in the past. In this discussion, a crucial distinction between the perception (*cognitivism*) and production (*emotivism*) of emotions through music has been established (e.g. Kivy, 1989, 1990). On the one hand, for *cognitivists*, music is simply able to express / represent emotions without really inducing them in the listener. The vast majority of previous investigations have concentrated on this position by examining the representational aspects of music which should be the basis for the perception of emotions in the listeners. The position of the *emotivists*, on the other hand, which holds that music elicits real emotional responses in the listener, has mostly been neglected thus far. This imbalanced empirical approach has led to the incorrect conclusion that musical emotions may only mirror cognitive appraisal processes and do not correspond to *real* emotions (Juslin & Västfjäll, 2008). However, recent research vehemently rejects these views. In the following, a summary of evidence of effects of music listening on emotion is presented from several different psychological and physiological perspectives.

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[2] A short term for 'emotions that are induced by music'.
[3] "Relatively intense affective responses that usually involve a number of sub-components – subjective feeling, physiological arousal, expression, action tendency, and regulation – which are more ore less synchronized. Emotions focus on specific objects, and last from minutes to a few hours." (Juslin & Västfjäll, 2008, p. 5).

2.3.2.2.1.2 Summary of evidence of effects of music listening on emotion

Juslin and Västfjäll have developed an all-encompassing theoretical framework regarding *musical emotions*, which shall be briefly presented below (for an extensive overview see Juslin & Västfjäll, 2008). For the authors, listening to music elicits emotional responses in the listeners by interfering with all relevant emotion subcomponents: *physiological arousal* (i.e. psychophysiology and brain activation), *subjective feeling*, *expression*, and *emotion regulation*. In the following, each emotion subcomponent will be regarded in the light of research on the effects of listening to music on emotion:

Psychophysiology The psychophysiological reactions in response to music listening include modulations in heart rate, heart rate variability, skin temperature, electrodermal response, respiration, and hormone secretion (e.g. Baumgartner, Esslen, & Jancke, 2006; Baumgartner, Willi, & Jancke, 2007; Halpern, Kwak, Bartlett, & Dowling, 1996; Khalfa, Bella, Roy, Peretz, & Lupien, 2003; Krumhansl, 1997; Nyklicek, Thayer, & Van Doornen, 1997). On the basis of previous research, it can be concluded that the elicited psychophysiological reactions to music listening equal psychophysiological reactions to other *emotional* stimuli.

Brain activation The neuropsychology of musical emotions is a relatively novel research field (Peretz, 2001). Nevertheless, current research points towards the verification that musical and non-musical emotions are processed by similar neural systems (for a detailed overview, see chapter 2.1.3.1).

Subjective feeling and emotional expression Numerous studies conducted in field or laboratory settings were able to show that music listening gives rise to various different emotions in the listener, which may be accompanied by different emotional expressions (e.g. laughing, crying, smiling, etc.), independent of the study design (e.g. experiments, self-reports, electromyographic measures (EMG), observations, questionnaires, diary studies, or qualitative interviews). In general, subjects report more often the experience of positive than negative emotions in response to music listening (e.g. Behne, 1997; Gabrielsson, 2001; Juslin & Laukka, 2004; Sloboda & O'Neill, 2001; Witvliet & Vrana, 2007).

Emotion regulation Listening to music is largely used to regulate emotions actively and passively (e.g. Gabrielsson, 2001); in other words, to change emotions, to match the current emotion, to enjoy or comfort oneself, and to relieve stress (Behne, 1997; Juslin & Laukka, 2004; Sloboda & O'Neill, 2001; Zillmann & Gan, 1997). In one of our own studies, we investigated how music is used for emotion regulation purposes (Thoma, Ryf, Ehlert, & Nater, submitted). A clear music selection pattern emerged, showing that emotionally congruent music is selected according to emotions involved in a specific everyday situation. We also demonstrated that this emotion-congruent music selection pattern is influenced by specific emotion regulation styles.

From the perspective of the most recent line of research on all relevant emotion subcomponents, Juslin and Västfjäll conclude that music does indeed elicit emotions in human beings and that emotional responses elicited by listening to music correspond to *real* emotions (for an extensive overview, see Juslin & Västfjäll, 2008).

2.3.2.2.2 The effect of music listening on stress-induced emotional processes

In his systematic review, Evans (2002) evaluated in a total of 12 randomized controlled trials the impact of music listening on stress-induced emotions, in particular anxiety, in adult patients during hospitalization. The findings of this meta-analysis reveal that music listening is effective in reducing anxiety. Recent investigations indicate that decreases in anxiety through pre-, peri-, or postoperative music listening is one of the most consistent findings reported in clinical settings with patients (e.g. Brunges & Avigne, 2003; Buffum, Lanier, Sasso, Rodahl, & Hayes, 2003; Bulfone, Quattrin, Zanotti, Regattin, & Brusaferro, 2009;

Davis & Thaut, 1989; Keegan, 2003; Kotwal, Rinchhen, & Ringe, 1998; MacDonald et al., 2003; Nielsson, 2009; Nielsson, Rawal, Unestahl, & al., 2001; Pothoulaki et al., 2008; Voss et al., 2004; Wang, Kulkarni, Dolev, & Kain, 2002; Winter, Paskin, & Baker, 1994). The use of listening to music for anxiety reduction purposes seems to be beneficial in the time around surgery (Ebneshahidi & Mohseni, 2008):

Pre-operative music listening

In the clinical study conducted by Wang et al., the authors investigated the effect of listening to self-selected music on anxiety in adult patients before undergoing anesthesia and surgery (Wang, Kulkarni, Dolev, & Kain, 2002). The authors found significantly less anxiety after the intervention compared with the non-music control group. In a laboratory environment, reductions of stress-induced anxiety through listening to music were also reported. In the study by Knight and Rickard (2001), relaxing music listening was found to reduce subjective anxiety in comparison to a non-music control group. Furthermore, the authors found that the effect of music on anxiety remained significant regardless of participants' liking of the stimulus, familiarity with it, and whether or not they experienced the music as relaxing.

Peri-operative music listening

For instance, listening to music during general anesthesia seems to minimize patient's anxiety (Nilsson, Rawal, Unestahl, Zetterberg, & Unosson, 2001). Moreover, Pothoulaki et al. reported evidence of the effectiveness of music listening in reducing anxiety in patients during haemodialysis sessions (Pothoulaki et al., 2008). The authors concluded that listening to music might distract the listener from the clinical (i.e. distressing and / or non-stimulating) setting and simultaneously induce relaxation in the listener. Furthermore, Bulfone et al. investigated the effect of music listening on anxiety in women, suffering from breast cancer, undergoing chemotherapy treatment (Bulfone, Quattrin, Zanotti, Regattin, & Brusaferro, 2009). The authors found significant reductions in state anxiety in the experimental group (music listening) in comparison to a non-music control group. Listening to music was effective in the reduction of patients' anxiety and their physiological arousal and additionally enhanced the patients' sense of well-being and feeling of control. The authors therefore concluded that listening to music can be considered as a supplement to traditional medical interventions for the reduction of stress-related anxiety in relation to chemotherapy in women with breast cancer (Bulfone, Quattrin, Zanotti, Regattin, & Brusaferro, 2009). Finally, in a systematic review of recent studies, Nilsson (2008) analyzed the clinical effects of music interventions for hospitalized patients in peri-operative settings. She concluded that music interventions do reduce patients' anxiety in the peri-operative setting.

Post-operative music listening

Voss et al. examined the effects of calming music on self-reported anxiety during 30 min of chair rest[4] in patients that underwent an open-heart surgery (Voss et al., 2004). The authors hypothesized that listening to calming music would act as a distracter by turning attention away from anxiety onto something more pleasant, and that it would also stimulate relaxation (e.g. Good et al., 2000; Good et al., 2001). Results indicate that after the chair rest period, patients in the experimental group (music listening) reported 72 % less anxiety than the control group. MacDonald et al. investigated the anxiolytic effect of music listening on patients after a minor foot surgery (included general anesthetics) (MacDonald et al., 2003) and found significantly less anxiety in the experimental group (listening to subjectively preferred music) than in the non-music control group. Additionally, as the authors wanted to extend their results, they also examined the anxiety-reducing effect of post-operative music listening in female patients undergoing a more major surgery, i.e. a total abdominal hysterectomy. Post-operative measures of anxiety were taken, but no differences between the music and non-music group were found. The authors explain their conflicting results in their two experiments as follows: the hysterectomy is a much longer surgery that requires increased intra-operative anesthesia (in comparison to minor foot surgery). Moreover, hysterectomies result in more complex psychological changes. It is therefore the specific

[4]Eight – 12h after surgery, patients (still in the intensive care unit) are helped into a sitting position in a chair (= chair rest); this maneuver triggers anxiety in patients (Voss et al., 2004).

characteristic associated with the medical procedures involved in these experiments and associated (psychological) consequences that explain the diversity in the findings (MacDonald et al., 2003). Labbé et al. (Labbé, Schmidt, Babin, & Pharr, 2007) exposed N = 56 subjects to different types of music genres (classical, self-selected[5], and heavy metal music) and silence after having completed a stressful test. They found that listening to classical or self-selected music significantly decreased negative arousal states, e.g. anxiety and anger, following the exposure to a stress inducing situation in comparison to listening to heavy metal music or sitting in silence.

Nevertheless, not all investigations found anxiety reductions through music listening in their subjects (see reviews in Evans, 2002; Nilsson, 2008; Richards, Johnson, Sparks, & Emerson, 2007). Music listening seems to have no impact on anxiety scores of people undergoing major stressors, i.e. invasive or unpleasant procedures such as hysterectomies, Caesarean section surgery, or heart surgery (Ebneshahidi & Mohseni, 2008; Evans, 2002; MacDonald et al., 2003). For instance, Ebneshahidi and Mohseni (2008) recently investigated the effect of music (patient-selected) on anxiety measures and opioid requirement after a surgical intervention. A total of N = 80 patients, scheduled to undergo general anesthesia and elective Caesarean section surgery, were enrolled in the experiment. Patients were randomly assigned to the experimental group (listening for 30 minutes to music via headphones, post-operatively) or control group (resting with no acoustic stimulation). The authors found that the post-operative use of music in Caesarean section surgery reduced the need for analgesics but did not reduce anxiety scores. Finally, also Nilsson (2009) who investigated the influence of music listening in bed-resting patients who had undergone heart surgery the day before, found no difference in the anxiety levels between the music and control group.

[5] Self-selected music = music that the participants chose as relaxing (Labbé, Schmidt, Babin, & Pharr, 2007).

In summary, despite the fact that the anxiolytic effect of music listening was considered to be the most consistent finding in previous investigations on the effectiveness of music listening, many studies did not find any anxiety reductions through music. A closer look at previous studies reveals that many of them suffer from various different issues regarding their applied methods or their conceptualization of the research question (e.g. small sample sizes, lack of a control groups, lack of power, no randomization, selection bias, non-objective outcome measures, and non-standardized protocols) (Wang, Kulkarni, Dolev, & Kain, 2002). Controlled laboratory-based studies are necessary to reduce variability in such investigations. Thus, no final conclusions can be drawn as to whether, and under what conditions, music listening has an anxiety-reducing effect upon the listener.

2.3.2.2.3 Influence of music listening on emotion: Assumed underlying mechanisms

If there is an anxiolytic effect of music listening, what are the underlying mechanisms? It is suggested that the anxiety-reducing effect is mediated by the influence of positive emotions induced through listening to music. As shown above, studies using functional neuroimaging methods demonstrated that listening to music can induce changes in all key limbic and paralimbic brain structures, i.e. structures which are significantly implicated in the modulation of emotions (see chapter 2.1.3.1). The *undoing* hypothesis by Levenson (1994) holds that the induction of a positive affective state is functional in reducing negative emotions (e.g. anxiety) and the physiological arousal provoked by them. The positive emotion inducing ability of listening to music appears to be useful in helping to recover from the consequences of the physiological arousal associated with the experience of negative emotions (e.g. anxiety) (Levenson, 1994). Indeed, previous research indicates that positive emotions may indeed facilitate the overcoming of the disadvantageous physiological and psychological health outcomes elicited by negative emotions (Tugade, Fredrickson, & Feldman Barrett, 2004).

Sokhadze (2007) investigated whether positive emotions may support the process of physiological recovery after the experience of negative emotions (i.e. *undoing* hypothesis). The author examined the assumingly differential influence of different types of music (subjectively pleasant and sad music) and an artificial acoustic stimulus (white noise) on the recovery of physiological measures after the experience of a stressor. The author found a differential influence between the application of pleasant music when compared to white noise. This effect was reported for various different physiologic parameters (HR, RR, and peripheral blood flow) in the recovery phase. Both types of music (pleasant and sad) exerted a positive influence on cardiovascular and respiratory activity. Therefore, on the basis of the data gained in the presented study by Sokhadze, it can be concluded that the *undoing* hypothesis is only moderately supported. The emotional valence of the music stimulus seems not to be of significant relevance. It therefore appears that other mechanisms may also play a role in the mediation of the anxiety-reducing effect of music listening.

One potentially mediating factor might be the variable sex. In a recent study by Chikahisa et al., the authors examined the anxiolytic effect of music exposure (Mozart's piano sonata, K. 488) in mice (Chikahisa, Sano, Kitaoka, Miyamoto, & Sei, 2007). Only the female mice population profited from the exposure to Mozart’s music. The authors concluded that the anxiolytic effect due to the exposure to music was mediated by ovarian steroids, in particular progesterone. Consequently, Chikahisa and colleagues suggest anxiolytic treatment with music in the luteal phase of the menstrual cycle in women (high progesterone levels).

Taken together, on the basis of previous investigations, it cannot be concluded which mechanisms underlie the anxiolytic effect of music listening. It appears that other mechanisms besides the induction of positive emotions through music listening may play a role in mediating the anxiolytic effect. However, no laboratory-based investigation has studied the underlying psychobiological mechanisms of the anxiety-reducing effect through music listening in humans.

2.3.3 Effects of listening to music on the physiological stress response

Most studies examining the influence of music listening on psychological and physiological parameters support the notion that music can cause physiological changes in humans as well as in animals (see reviews in Bartlett, 1996a; Standley, 1986). Moreover, there is consensus that slow, soothing and relaxing music is commonly correlated with lower physiological arousal and that faster music is commonly associated with increases in physiological responses. The most recent line of research comprises the assessment of biochemical responses to listening to music (Halpern, Kwak, Bartlett, & Dowling, 1996). In the context of my thesis, cortisol and sAA, two of the most important indicators of the psychobiological stress system, were of main interest.

In the following sections, the effect of listening to music on HPA axis and ANS activity is described in detail. It is first explained how music listening influences HPA axis activation, with special focus on cortisol. Then, the assumed underlying mechanisms of the hormonal change induction through music listening will be presented. Furthermore, a summary of studies that have investigated the effect of music listening on stress-induced ANS activation will be given. Finally, the assumed underlying mechanisms of the effectiveness of music listening on ANS parameters will be presented.

2.3.3.1 Influence of music listening on HPA axis activation

Previous research on the influence of music listening on stress-induced HPA axis activation was mainly conducted in the context of field studies, in particular medical settings with patients. Medical settings, such as stays in hospitals or clinics involving (ambulatory) surgery, can be very potent stressors for patients. Most studies examining the influence of music listening on HPA axis activation have focused on cortisol, which is one of the best examined parameters of the endocrine system and constitutes a reliable indicator of HPA axis activity (Kirschbaum & Hellhammer, 1994; Vining & McGinley, 1987) (see chapter 2.2.2.1). In the systematic review by Bartlett on the physiological responses to music and sound stimuli (see Bartlett, 1996a), the author concluded that hormones that are related to the experience of stress (i.e. cortisol and immunoglobulin A, IgA), can be positively modulated through music listening (e.g. Moeckel et al., 1994; VanderArk & Ely, 1993).

Significantly attenuated increases in cortisol were reported when patients listened to music *during medical procedures*. For instance, Leardi et al. reported significant reductions in (plasma) cortisol in patients who were allowed to listen to music (self-selected) either before or during different kinds of surgeries (Leardi et al., 2007). Escher et al. (1993) found that the increase in cortisol (plasma levels) during gastroscopy were significantly lower when the patients were allowed to listen to music. Uedo et al. (2004) examined the influence of listening to music on cortisol (salivary levels) in patients undergoing screening colonoscopy. The participants listened to ‘easy-listening’-style music. The authors found a significantly lower rise in cortisol in the experimental group (music listening) in comparison to the non-music group. Schneider et al. investigated the influence of music listening on stress reaction in terms of plasma cortisol in 30 patients during cerebral angiography, with or without listening to music (self-selected) (Schneider, Schedlowski, Schurmeyer, & Becker, 2001). Patients in the non-music condition exhibited increasing levels of plasma cortisol, while cortisol levels in patients examined with music remained unchanged. Wang et al. (Wang, Kulkarni, Dolev, & Kain, 2002), on the other hand, found no influence of the listening to self-selected pre-operative music in comparison to silence on plasma cortisol levels. Migneault et al. (2004) examined the influence of music listening on plasma cortisol responses to surgical stress (with general anesthetics). Thirty female patients were assigned in random order to an intra-operative music listening group (music was applied following the induction of anesthesia to the end of the surgery) and a non-music group. No significant group differences in terms of plasma cortisol were found. The authors concluded that intra-operative music listening has no significant effect on neurohormonal processes. Fukui and Yamashita (2003) examined the purported sexual dimorphism in terms of salivary cortisol changes with music and visual stress. The authors examined their hypothesis using a between-subject design. There were four different conditions (each à 30 min): 1) music listening alone, 2) visual stress and music listening together, 3) visual stress alone, and 4) silence. The authors found no sex-related differences in the cortisol levels. Moreover, they found that cortisol decreased only in the music condition (music listening alone) but increased in all other conditions. Stress-like hormonal changes occurred due to music listening similar to those in response to stress alone. One might summarize that in clinical settings, listening to music during a stressful intervention may lead to decreases in salivary and / or plasma cortisol levels.

Significant positive changes in cortisol, i.e. greater reductions in cortisol levels, were found when music was listened to *after a medical procedure*. Supportive confirmation can be found in the observation that one hour of listening to music, immediately following the instruction about the upcoming surgery (which was about to take place the following day), resulted in a clear reduction in salivary cortisol levels in patients (Miluk-Kolasa, Obminski, Stupnicki, & Golec, 1994). Nilsson et al. found significantly greater reductions in cortisol (plasma levels) in response to one hour music listening (new age music) following general anesthesia compared with a control group (Nilsson, Unosson, & Rawal, 2005). In a recent study by Nilsson (2009), the author reported data of significantly lower cortisol in plasma in patients who listened to soothing music for 30 minutes during bed rest on the first day after surgery compared with a control group. It may be concluded that in clinical settings, listening to music after a stressful medical procedure may lead to decreases in salivary and / or plasma cortisol levels.

Laboratory-based studies are still rare in comparison to field studies. To the best of my knowledge, only two published studies exist, which investigated the effect of music listening on stress-induced cortisol levels. Knight and Rickard (2001) examined the effect of relaxing music listening (Pachelbel's ‘Canon in D major’) prior to an upcoming cognitive stressor on HPA axis activity by measuring salivary cortisol in healthy participants. Neither the anticipation of the stressor nor listening to music had an effect on cortisol levels. The authors explained their results in terms of the high variability in cortisol measures in their participants, which may have masked the effects. Further, they assume that the applied cognitive stressor and the music piece may simply not have an effect on HPA processes. Khalfa et al. (2003) replicated the study by Miluk-Kolasa et al. (1994) in a laboratory setting with healthy individuals. They found that listening to relaxing music (authors' choice) resulted in lower salivary cortisol levels in students engaged in a stressful task, in comparison to control subjects (no music listening). They interpreted their results by “..suggesting that relaxing music after a stressor can act by decreasing the poststress response of the hypothalamic-pituitary-adrenal axis.” (Khalfa, Bella, Roy, Peretz, & Lupien, 2003, p. 376).

Given the few laboratory-based investigations examining the effect of music listening on stress-induced HPA axis activation, no final conclusions can be drawn about how music listening influences stress-induced cortisol levels.

2.3.3.1.1 Influence of music listening on HPA axis activation: Assumed underlying mechanisms

Up to now, the underlying mechanisms responsible for the modulation of hormone secretion due to music listening in human beings are still vaguely understood. It has been proposed, however, that the specific neuronal activation patterns involved in music listening may mediate this effect. Fukui and Yamashita have developed a model of the supposed underlying mechanisms in this cascade (for an extensive overview see Fukui & Yamashita, 2003): They assume that the listening to music, as a form of sensory (i.e. auditory) stimulation, is transmitted via the thalamus to the hypothalamus. The hypothalamus plays an essential function in the onset of emotions and the modulation of autonomic responses (e.g.

regulation of hormone release of the pituitary glands). Listening to music may thus have an influence on stress-induced hormonal output, because music listening and the experience of stress are known to activate similar brain regions (e.g. hypothalamus).

2.3.3.2 Effect of music listening on the ANS activation

Previous investigations examining the influence of music listening on ANS parameters were mainly interested in the arousing / stimulating versus calming / sedating effects of different types of and characteristics in the music (Burns et al., 2002; Burns, Labbé, Williams, & McCall, 1999; Iwanaga, Ikeda, & Iwaki, 1996). Bartlett (1996) concluded that in the majority of previous studies, listening to music affects different ANS parameters consistent with the postulated hypothesis; arousing music increases heart rate and muscle tension in comparison to calming music, which leads to decreased heart rate and muscle tension, increased skin temperature, and increased skin conductance.

Miluk-Kolasa and Matejek (1996) found that music listening helped pre-operative patients to calm down physiologically. The researchers reported changes in arterial pressure, heart rate, cardiac output, skin temperature, and glucose count. Patients in the non-music condition (before the surgical intervention) remained in a physiologically aroused state. However, not only the stress levels of patients but also those of operating physicians can be decreased through listening to music (Allen & Blascovich, 1994). The authors found decreased physiological arousal when measuring skin conductance and blood pressure in 50 surgeons who listened to music while operating on patients. Listening to music also reduced physiological arousal (heart rate and systolic and diastolic blood pressure) due to anxiety in ambulatory patients undergoing colonscopy (Smolen, Topp, & Singer, 2002). Sokhadze (2007) examined the effects of music on post-stress recovery, and compared the effect to white noise. Stress was induced by a visual stimulation using pictures that are supposed to induce disgust in the subject. Immediately after the stress induction, the subjects could (in three consecutive sessions) listen to music (subjectively pleasant and sad music), and to white noise. The authors found significantly different effects on heart rate, respiratory rate and peripheral blood flow. One might summarize that listening to music can have an effect on various different ANS parameters.

As a consequence of the relative novelty of sAA as a marker for ANS activity (see chapter 2.2.2.2.2), almost no data exist regarding how sAA levels change due to listening to music. With the valuable exception of one study by Nater et al. (Nater, Abbruzzese, Krebs, & Ehlert, 2006), no previous studies have investigated the effect of music listening on sAA levels. These authors found higher levels in sAA in men in response to listening to heavy metal music in comparison to women. However, no study so far has investigated the effect of listening to relaxing music on stress-induced sAA levels. One investigation by Arai and colleagues (Arai et al., 2008) investigated the effect of relaxing sound, i.e. natural sound of wind and bird twitter during epidural anesthesia on sAA activity. The patients were randomly assigned to intra-operatively listening to natural sounds (S group) or to having no acoustic stimulation (N group). The authors found significant decreases in sAA activity in the S group. They were able to show that intra-operative application of sound that is perceived as soothing decreases sAA. It might therefore be assumed that relaxing music may lead to similar responses in stress-induced sAA levels.

2.3.3.2.1 Influence of music listening on ANS activation: Assumed underlying mechanisms

Music and physiological processes (e.g. heart rate, blood pressure, and body temperature) are both reliant on environmental vibrations that consist of particular waves (Landreth & Landreth, 1974). It is assumed that when two objects resonate at similar frequencies, they start to synchronize over time, which finally results in both objects resonating at the same frequency (entrainment). Entrainment has been defined as the disposition of an organism's physiologic processes to respond to and synchronize with its internal and external environments, including sound and rhythm (Schneck & Berger, 2006). Rhythm and tempo can automatically affect the organism by synchronizing the rhythms of the organism (e.g. heart rate and respiration) (Saperston, 1995). The altered physiological condition is then perceived by the individual. Consequently, some characteristics of music (e.g. lower than 80 beats per minute and a regular rhythm) can be used to induce relaxation in the listener, by synchronizing the rhythms of the body through entrainment processes with the slow and steady rhythm of the music (Robb, Nichols, Rutan, Bishop, & Parker, 1995). Previous findings reporting increases in physiological parameters through arousing (high beat) music and decreases in physiological parameters through calming (low beat) music are therefore in line with the 'entrainment' hypothesis.

A further plausible explanation for the underlying mechanisms of the effectiveness of music interventions on autonomous parameters may be seen in the activation of specific brain regions. Indeed, listening to music induces activation in the hypothalamus, which is an important part of the limbic system and a brain region that modulates autonomic responses (Menon & Levitin, 2005).

It is assumed that both mechanisms, i.e. entrainment processes and specific brain activation patterns, are separately or conjointly responsible for the effectiveness of music listening on ANS parameters. “A possible explanation is that these effects could be mediated through sensory–motor feedback circuits, which have been much discussed in neurophysiology; that is, through the so-called mirror-neuron system (Rizzolatti & Arbib, 1998).” (Zatorre, 2005, p. 314).

2.3.4 Common limitations of previous studies

Various different shortcomings of previous investigations, which examined similar research questions to that of this thesis, were addressed in detail above (see chapters 2.3.2.1.2, 2.3.2.2.2, 2.3.3.1, and 2.3.3.2). In addition to these rather minor shortcomings, the vast majority of previous studies have one or more of the following major limitations in common:

1) Most studies examining the purported health-promoting effect of listening to music have been conducted in clinical settings. Due to their quasi-experimental approach, the control of mediating variables is either limited or not possible. However, the control of various different variables would be of essential value to avoid confounded results. For instance, the control of variables such as individual susceptibility to stress or individually different stress appraisal processes are probable mediating variables (for an overview see chapter 2.2.1). Moreover, as music listening is a potential source of eliciting emotions (see chapter 2.3.2.2) and as it is also extensively used for emotion regulation purposes (e.g. Juslin & Sloboda, 2001; Thoma, Ryf, Ehlert, & Nater, submitted), individual emotion regulation processes are potential confounding mechanisms that should be controlled. To the best of my knowledge, neither of these essential confounding variables has been acknowledged in previous research.

2) Most of the previous research has neglected to control for the influence that is due to a simple acoustic stimulation. It is assumed that any acoustic stimulation that is perceived as relaxing might have the same influence on the examined parameters as music. Strictly speaking, the control of a mere relaxing acoustic stimulation that lacks the essential characteristics of music (e.g. rhythm, melody, etc.) is one of the most important requirements to permit any conclusions to be drawn about the specific influence of music listening on psychological and physiological parameters of interest. Otherwise, it would not be possible to make any specific statements on what exerted

the effects on stress parameters: Is it music itself or merely the acoustic stimulation that has a relaxing effect? This essential confounding influence has been broadly neglected in previous research.

3) The application of a valid and standardized stressor that is capable of inducing arousal in all relevant aspects of the stress response is essential when examining the influence of music listening on stress. The use of non-valid stressors prevents any conclusions from being drawn regarding the stress-reducing effect of music listening. Despite the fact that some studies did use a valid and standardized stressor, such as the TSST (e.g. Khalfa, Bella, Roy, Peretz, & Lupien, 2003), these authors only measured single parameters of the stress response, for instance cortisol. They neglected the view that stress is a multidimensional phenomenon that includes cognitive, emotional, neuroendocrine, and autonomic parameters. Examining isolated parameters of the stress response does not allow ultimate conclusions to be drawn about the effect of music on the stress response.

These major shortcomings of previous investigations may be responsible for the fact that studies thus far have produced data that are collectively seen as somewhat confusing and inconsistent. Consequently, although previous investigations do point towards health-promoting effects through listening to music, no final conclusions can be drawn as to whether and how music listening does beneficially impact health via presumed stress-reducing effects. It is thus the major focus of my thesis to develop a framework in which I will attempt to examine the underlying mechanisms of positive health effects of listening to music.

2.4 METHODOLOGICAL ASPECTS OF RESEARCH WITH MUSIC

Several methodological factors have to be taken into account when examining the influence of music listening in a laboratory environment. In the following, the most important methodological factors in the research with music are reported.

2.4.1 Choice of music stimulus

In any study examining effects of music listening on physiological and psychological parameter changes due to stress, the music stimulus must be carefully chosen. Several factors have to be taken into account for the appropriate music stimulus choice; the subject's individual music preference and special features and aspects of the music (i.e. rhythm, instruments, tonality, chords, complexity, vocals, pitch, etc.) are important factors (Bartlett, Kaufman, & Smeltekop, 1993; Clair, 1996). Moreover, it is well known that some specific types of music, such as baroque / classical and New Age music, are more efficient than others in producing physiological benefits in the listener (Mornhinweg, 1992). Assumingly, the beneficial effects on physiology of baroque and classical music are due the particular beat (i.e. slower than normal heart rate (68-72 beats / minute)), of its inner stability (i.e. use of dissonance vs. consonance), and diversity (i.e. variety of timbres) (Mornhinweg, 1992). Contrary to baroque or classical music, New Age music (which lacks a natural beat) was particularly developed (in the 1960s) for the promotion of psychological and physiological health, for the facilitation of relaxation and well-being and for the use in meditative practices (Mornhinweg, 1992; Rosenfeld, 1985).

A great deal of controversy exists concerning the question of whether the music stimulus should be chosen by the authors (based on empirical evidence) or by the participants themselves, i.e. their favorite / preferred music. It has been shown that participants' level of self-reported relaxation is not dependent on whether the stimulus has been selected by the author (based on previous research) or by the subject (individually preferred) (Thaut & Davis, 1993). A meta-analysis conducted by Pelletier, in which the author reviewed and analyzed numerous quantitative studies investigating the effectiveness of music listening on stress, reveals that music chosen by the author, in comparison to music chosen by the subject, is more effective in the reduction of stress (Pelletier, 2004). It is further proposed that subjectively preferred music should not be used when investigating stress reduction effects of listening to music in order to avoid possible distraction effects due to influences of memory or subjective associations with self-chosen music by participants. It might be assumed that these associations may interfere with the ‘pure’ effect of the music; possible effects of music listening and the emotional meaning of music may no longer be ascribed to the structural features of the music stimulus itself. Indeed, the fact that music does not evoke the same emotional experiences interindividually across all listeners or also intraindividually over time point out that music is strongly dependent on the individual meaning ascribed to it (MacDonald & Miell, 2000).

Pelletier places emphasis on the fact that the above mentioned recommendation deviates from other research areas in the field of music therapy (e.g. pain reduction through the listening to music), where subject-selected music provokes better effects on participation and response (Pelletier, 2004). An important factor that probably mediates the effect of self-selected music (that is believed to be relaxing) on pain reduction is the enhanced experience of control over the clinical setting (Brannon & Fiest, 2007; Labbé, Schmidt, Babin, & Pharr, 2007; Magill-Levreault, 1993).

2.4.2 Known influencing factors mediating the effectiveness of music interventions

Less is known about what mechanisms mediate the effect of listening to music on health indicators. In the following, those factors that are known to have an impact on the effectiveness of music interventions are presented.

2.4.2.1 Musical training

Music listening interventions should always control for formal musical training of the participants. Musically trained and untrained subjects are differentially affected by music listening. In the systematic review by Pelletier, the author concluded that music listening has a greater effect on musicians, i.e. in participants with previous training in music, than in non-musicians (Pelletier, 2004). Concerning neuroendocrine responses, significant differences in cortisol concentrations were detected in the reaction to music listening between music and non-music students (VanderArk & Ely, 1992). Moreover, in a further study by VanderArk and Ely (1993), the authors reported that music majors, in great contrast to biology majors, had a significantly higher cortisol mean response due to listening to music that induces the emotion of horror and also found differences in liking of the music stimulus (the music was liked by music majors but not by the biology majors).

Brain imaging studies indicate that there are also structural differences in the brains of musicians and non-musicians, but with no noticeable difference in the overall brain volume (e.g. Jäncke, 2002, 2008a). Concerning neuronal activation, previous research indicates a diverse processing pattern of music between musicians (i.e. use the dominant hemisphere, and show no clear pattern of hemispheric asymmetry) and non-musicians (i.e. use the non-dominant hemisphere) (Agrawal & Sherman, 2004; Bernardi, Porta, & Sleight, 2006; Evers, Dannert, Rodding, Rotter, & Ringelstein, 1999). Explanations for this may lie in the fact that musicians seem to be more attentive or focused when listening to music and in the fact that musicians listen to music more analytically than non-musicians, on the basis of their previous musical training and experience, respectively.

Differences were also found in the emotional response and various autonomous parameters in response to music listening in musicians and non-musicians (Bernardi, Porta, & Sleight, 2006; Kreutz, Bongard, & Von Jussis, 2002). For instance, Kreutz et al. found weaker sympathetic activation in non-musicians (Kreutz, Bongard, & Von Jussis, 2002), but no signs of enhanced reactivity in terms of psychological or physiological responses due to music between musicians and non-musicians. Further, the author documented differences in the respiratory sinus arrhythmia in response to happy and sad pieces of music. Bernardi et al. assessed the potential clinical use of listening to music (i.e. modulating stress responses) in musically trained and musically untrained subjects (Bernardi, Porta, & Sleight, 2006) by measuring changes in different aspects of the ANS due to different aspects of music. Also here, the authors found differences between musically trained and untrained subjects, e.g. musically trained subjects breathed differentially in response to the tempo (i.e. faster with faster tempi and slower baseline breathing rates) in comparison to musically untrained subjects).

In light of these findings, musical training of the participants has to be controlled for in studies examining the influence of music on psychological and physiological parameters, as music listening activates different brain areas (Agrawal & Sherman, 2004; Evers, Dannert, Rodding, Rotter, & Ringelstein, 1999), produces different ANS activation (Bernardi, Porta, & Sleight, 2006), leads to different emotional responses (Kreutz, Bongard, & Von Jussis, 2002), and appears to have more effects in musicians than non-musicians (Pelletier, 2004).

2.4.2.2 Sex differences

Several investigations were able to demonstrate sex differences in response to musical stimuli. Female subjects respond more to music listening interventions in relation to stress than men (Pelletier, 2004). In a study by Nater et al, female subjects, in comparison to male subjects, responded to an arousing and unpleasant musical stimulus with an increased response (Nater, Abbruzzese, Krebs, & Ehlert, 2006) which indicates females' disposition to respond physiologically more sensitive to emotional stimuli than men (Kring & Gordon, 1998). Moreover, Kenntner-Mabiala et al. reported that in their study, tempo of the music exerted an influence on the ratings of pain intensity and unpleasantness in female but not in male subjects (see Kenntner-Mabiala, Gorges, Alpers, Lehmann, & Pauli, 2007). McFarland and Kadish found sex dependent effects on the finger temperature due to music listening, independent of the arousal of the music played (i.e. high versus low) (McFarland & Kadish, 1991). The authors assume that one possible explanation may lie in the difference between males and females in their vascular autonomic sensitivity to music. Pelletier concluded in his systematic review that music listening "..is most beneficial.." in female subjects (Pelletier, 2004, p. 207). To conclude, sex is a factor that should be controlled for in studies examining the effect of music listening on psychological and physiological parameters.

2.4.2.3 Music preference / Liking of music

The consideration of individual music preference of participants is an essential variable when investigating music (Pelletier, 2004). Music preferences develop until the age of 20 years and remain relatively stable thereafter (Gembris, 2005). Differences in music preferences between younger and older adults are therefore due to a cohort effect (Abeles & Chung, 1996). Besides cohort effects, individual differences in music preferences are also due to ethnicity and social class (Frith, 1981; Gans, 1974). Differences in music preferences were also examined in relation to personality factors (e.g. Dollinger, 1993; Little & Zuckerman, 1986; Rentfrow & Gosling, 2006). For instance, Rentfrow and Gosling (2003) found differences in music preference depending on the Big Five personality traits.

Some controversy exists concerning the necessity of the liking of a music stimulus as indispensable precondition to be effective in exerting a beneficial influence on stress parameters. Several authors argue that the degree of liking a music stimulus is a more important factor in increasing a state of relaxation than the particular type of music (Allen & Blascovich, 1994; Labbé, Schmidt, Babin, & Pharr, 2007; Siedliecki & Good, 2006; Stratton & Zalanowski, 1984). They found the extent to which a piece of music is liked by the subject to be positively related to the degree of self-reported relaxation. However, other studies did not find this association and suggest that the degree of preference and the level of relaxation obtained from music can be distinct (e.g. Davis & Thaut, 1989; Knight & Rickard, 2001). The individual music preferences and the liking or non-liking of a specific music stimulus should therefore be measured and controlled for.

2.4.2.4 Listeners' reasons for listening to music

The reasons for listening to music also seem to be important in mediating the effect of music listening on health (Mitchell, MacDonald, Knussen, & Serpell, 2007). Mitchell et al. reported significant positive correlations between personal importance of music and ratings for the reason for listening 'to help pain'. The reasons why a person listens to music are manifold and seem to be dependent on age, music preference, actual situation and mood (Thoma, Ryf, Ehlert, & Nater, submitted), but, as seen in the study by Mitchell et al., also on actual health status. For instance, while in the clinical sample (chronic pain sufferers) by Mitchell et al., the reasons for listening were strongly associated with the actual health status (e.g. 'to help pain', 'to relieve tension and stress', 'to feel relaxed'), reasons for listening in the sample of North et al. (healthy adolescents) were predominantly associated with age-dependent issues (e.g. 'to relieve boredom', 'to be cool', 'to help me through difficult times', 'to please friends’) (North, Hargreaves, & O'Neill, 2000). The reason why a person engages with music seems to be an important component of the general music-listening behavior, as it may mediate the effect of music.

3 STUDY IDEA AND HYPOTHESIS

The above-discussed findings point towards the evidence that listening to music may serve as a means to reduce stress and may, as a consequence, be effective in the promotion of health. Previous research has found that listening to music can exert positive influences on all relevant components of the human stress response, i.e. on cognition, emotion, endocrine and autonomic dimensions. Due to several conceptual and methodological, minor and major shortcomings, however, available data are to some extent confusing and inconsistent. As a consequence, no final conclusions can be drawn as to whether and how listening to music is associated with health, and whether and how it may serve as a stress-reducing tool. Accordingly, there is a lack in the current literature of investigations examining the underlying psychobiological mechanisms of the effectiveness of music interventions.

Hence, the first aim of the present thesis was to study the general association between music listening and specific health indicators under consideration of assumed mediating variables. For this purpose, an internet-based study was conducted in apparently healthy university students. The findings are presented in chapter 4.

The second aim was to examine the assumed stress-reducing effect of listening to (relaxing) music in a rigorously controlled experiment in a laboratory setting with healthy subjects. In an integrative experimental approach, encompassing all significant stress dimensions, the aim was to shed light on the underlying mechanisms of the effectiveness of music interventions. The findings are presented in chapter 5.

4 EMPIRICAL STUDY I: 'DOES LISTENING TO MUSIC IMPROVE HEALTH? – A STRUCTURAL EQUATION MODEL IN HEALTHY INDIVIDUALS'[6]

4.1 INTRODUCTION

The development of effective stress prevention or management has become an important endeavor of current research efforts in health psychology. In particular, cost-efficient interventions, such as music therapy, have received special interest in terms of coping with stress and stress-related health issues. The potential of music to trigger intensive emotions (e.g. Blood & Zatorre, 2001; Juslin & Sloboda, 2001) and to attenuate psychophysiological activation (e.g. Khalfa, Bella, Roy, Peretz, & Lupien, 2003; Nater, Abbruzzese, Krebs, & Ehlert, 2006; Nyklicek, Thayer, & Van Doornen, 1997) might be the main reason for its beneficial effect and, consequently, for its increased therapeutic use in health care (see reviews in Evans, 2002; Nilsson, 2008).

Previous research has investigated the beneficial effect of listening to music in the context of medical settings (e.g. Bulfone, Quattrin, Zanotti, Regattin, & Brusaferro, 2009; Ebneshahidi & Mohseni, 2008; Koch, Kain, Ayoub, & Rosenbaum, 1998; Pothoulaki et al., 2008; Voss et al., 2004) and in laboratory-based studies (e.g. Khalfa, Bella, Roy, Peretz, & Lupien, 2003; Roy, Peretz, & Rainville, 2007; Sokhadze, 2007). These studies found that listening to music has an acute, i.e. *short-term* beneficial effect on various psychological and physiological parameters in the listener. In addition, these short-term effects seem to vary depending on the type of music (e.g. Burns et al., 2002; Gerra et al., 1998; Labbé, Schmidt, Babin, & Pharr, 2007; Mockel et al., 1994; Roy, Peretz, & Rainville, 2007; Umemura & Honda, 1998).

[6] This study is submitted for publication (Thoma, Scholz, Ehlert, & Nater, 2010)

Listening to music on a regular basis can be understood as habituation to music. From this perspective, the question arises of whether short-term beneficial effects accumulate over time; i.e. are there any *long-term* beneficial effects of listening to music? Long-term effects have mainly been studied in the context of formal music training and potential enhancement of cognitive development (for a review see Schellenberg, 2001). Research into beneficial long-term effects of listening to music on health has largely been neglected, with a few notable exceptions. In animals, for instance, repeated music exposure significantly altered concentrations of neurotrophins in the hypothalamus (Angelucci, Ricci, Padua, Sabino, & Tonali, 2007), which may alter hypothalamus-pituitary-adrenal (HPA) axis activation. In humans, repeated music listening resulted in the following significant benefits: less depressed and confused mood in patients after stroke (Särkämö et al., 2008), reductions in high systolic blood pressure (Teng, Wong, & Zhang, 2007), better sleep quality in elderly patients (Lai & Good, 2005), and reduced depression, fatigue, total mood disturbance, and decreases in cortisol concentration in healthy adults (McKinney, Antoni, Kumar, Tims, & McCabe, 1997). Repeated everyday listening to music may therefore also have a beneficial long-term effect.

Barely any attempts have been undertaken to reveal the underlying mechanisms or variables that mediate the effect of repeated music listening on health. Mitchell et al. conducted a cross-sectional survey with chronic pain sufferers in which the authors assessed music-listening behavior and quality of life as well as pain levels (Mitchell, MacDonald, Knussen, & Serpell, 2007). Their findings indicate that specific aspects of music-listening behavior, such as the average amount of time per day spent listening to music, subjective relevance of music, and reasons for listening to music, may play an essential role. The latter were all concerned with pain-related coping (e.g. ‘to help pain’, ‘to relieve tension and stress’, ‘to feel relaxed’, ‘to express emotions’). However, it is to be expected that a variety of other reasons for listening are relevant in healthy participants. For example, in the sample by North et al., healthy adolescents’ reasons for listening differed quite widely, e.g. ‘to relieve boredom’, ‘to help me through difficult times', 'to please friends', 'to reduce loneliness' (North, Hargreaves, & O'Neill, 2000). However, these authors did not examine associations between reasons for listening and health indicators in their participants. Thus, there are no data regarding the relationship between reasons for listening to music and health indicators in healthy adults.

Moreover, no explanation was provided by Mitchell et al. (2007) regarding the underlying mechanism that may mediate the purported association between reasons for listening and health. Upon closer inspection, the above-named reasons for music listening can be categorized into reasons to regulate emotions (e.g. 'to help me through difficult times', 'to express emotions', 'to reduce loneliness') and to reduce stress (e.g. 'to relieve tension and stress', 'to feel relaxed'). This assumption is in line with previous research indicating that music listening is extensively used to regulate emotions (e.g. Juslin & Sloboda, 2001; Thoma, Ryf, Ehlert, & Nater, submitted) and stress-reducing purposes (e.g. Thayer, Newman, & McCain, 1994). It might be assumed that, depending on how individuals habitually regulate their emotions, and depending on the individual susceptibility to stress (i.e. individual stress reactivity), people's reasons for listening to music may also differ. Nevertheless, potential mediating effects of dispositional emotion regulation processes and individual stress reactivity on the association between listening to music and health have not been described in the literature so far.

In the current research literature on the beneficial effect of listening to music, we identified a lack of studies investigating associations between various aspects of habitual music-listening behavior and general health status in adults. Potential mediating mechanisms, such as emotion regulation processes or individual stress reactivity, have not yet been examined. We therefore set out to investigate the interrelation between various aspects of habitual music-listening behavior and health, and the potential mediating influence of emotion regulation processes and individual stress reactivity.

4.2 METHOD

4.2.1 Participants and data collection procedure

A large online survey in a student population at the University of Zurich and the Zurich Federal Institute of Technology was conducted. Potential participants were contacted by email using the electronic mailing list provided by the two institutions. The email recipients were sent an invitation email with the invitation to enroll online for a survey about music, body, and emotion. In the case of interest, the potential participants had access to the survey via an anonymous internet link embedded in the email. In order to ensure higher participation rates (Bosnjak & Tuten, 2003), six cinema tickets and a dining coupon were raffled off.

The survey was programmed online using the software *unipark* (unipark, Germany). For statistical analysis, the collected data were exported into SPSS 17.0 (SPSS, Chicago, Illinois). In a pilot study, a minimum time requirement of 25 minutes to complete the questionnaire was determined; participants who answered all questions substantially more quickly than others were excluded from the data set. To navigate within the questionnaire, participants had to press the 'continue' or 'back' button. By pressing the 'continue' button, data were automatically transferred into the database. If data were missing or not plausible, an error message appeared after the 'continue' button had been pressed, with the option to revise or ignore. The 'revise' button redirected the participant to the previous page, and the 'ignore' button took the participant to the next page.

At the end of the survey, participants were given the option to leave a comment on the survey. They were also provided with clinical contact information in case responding to stress or somatic symptoms questions resulted in awareness of psychological problems. All participants took part in the survey voluntarily and provided informed consent. The study was approved by the Swiss ethics committee of the Canton of Zurich.

4.2.2 Materials

The complete online survey consisted of 292 items. The first section consisted of the informed consent and questions addressing sociodemographic and general health-related variables. Participants who did not provide informed consent were unable to continue with the questionnaire and were automatically directed to exit the questionnaire. The second section comprised questions about habitual music-listening behavior (average duration of music listening per day, reasons and motivations for listening to music (RML), preferred music styles, and subjective relevance of music), emotion regulation (dispositional emotion regulation), stress variables (dispositional stress reactivity), and health variables (somatic complaints and quality of life (QOL)). The following questionnaires were presented in random order:

Music-listening behavior and music preference. The Music Preference Questionnaire (MPQ; (Nater, Krebs, & Ehlert, 2005)) was used to assess music-listening behavior in terms of subjective importance of music, time spent listening to music, and reasons for music listening (RML), as well as general music preference. As RML's, the following options (10) were given: to relax, be activated, be distracted, reduce aggression, reduce loneliness, arouse specific emotions, increase specific emotions, work better, and avoid boredom. The respondents could additionally add their own reasons under 'others'.

Health status In the current study, *health* was operationalized by the German self-report Freiburg Complaint List (FBL, [Freiburger Beschwerdeliste]; (Fahrenberg, 1994) and a German version of the Quality of Life Questionnaire of the World Health Organization (WHOQoL-5; (Angermeyer, Kilian, & Matschinger, 2000).

The FBL assesses a broad spectrum of somatic complaints, health concerns, and utilization of health services. The questionnaire consists of nine subscales (General Condition, Tiredness, Cardiovascular, Gastrointestinal, Head-Throat, Tenseness, Emotional Reactivity, Pain, and Sensory) and a summary scale, which are derived from the 80 items. Fifty-seven items, such as “Do you get headaches?” have to be answered by indicating one of five frequency categories (almost everyday, about three times a week, about twice a month, about twice a year, almost never). Twenty-three items, such as “Are you sensitive to pain?”, have to be answered by indicating one of five intensity categories (very strongly, strongly, moderately, barely, insensitive).

The WHOQoL assesses participants’ quality of life. This instrument measures the subjective well-being of the participants in the last two weeks. Answer options range from 0 (at no time point) to 5 (the whole time).

Emotion regulation The German Inventory for Regulation of Emotion (ERI, [Inventar zur Emotionsregulationswirksamkeit]; (Mohiyeddini, 2005; see also Wirtz et al., 2006) was used to assess the dispositional regulation of emotions. The ERI has 34 items and comprises a hedonistic (HED) way of emotion regulation, a distress-augmenting regulation (DAR), i.e. intensifying of negative emotions, and an emotional moderation regulation (MOD), i.e. buffering of emotions. Using a 6-point Likert scale ranging from 1 (hardly ever) to 6 (almost always), the participants were asked to rate how often they use specific strategies (*e.g.* go out with friends, thinking of something cheerful) to regulate their emotions.

Inter-individual stress reactivity The German Stress Reactivity Scale (SRS, [Stress-Reaktivitaets-Skala]; (Schulz, Jansen, & Schlotz, 2005)) was used to assess general susceptibility to stress, i.e. the disposition to respond to stressors with intense, immediate, and long-lasting stress reactions. Four personality characteristics are assumed to determine stress reactivity: high intrusiveness, low self-efficacy, high arousability of the central nervous system, and high negative affectivity. The SRS assesses general and specific stress reactivity in different stressor domains.

4.2.3 Data analyses

Data were analyzed by means of regression analyses using path models with AMOS 17.0 (Arbuckle & Wothke, 1999). Mediator hypotheses were tested according to recommendations by Baron and Kenny (1986). For each full model, three regression analyses were conducted. The first tested whether the predictor was significantly associated with the outcome. The second tested whether the predictor was significantly associated with possible mediators, and the final analysis included the predictor and the mediator variables as predictors of the outcome. When the previously significant direct effect of the predictor on the outcome decreases to a non-significant level after the mediator variables are included, the effect can be regarded as fully mediated. Reduction in strength of the association can be seen as a partial mediation. Furthermore, the indirect effect from the predictor through the mediator on the outcome was tested for statistical significance (i.e., whether or not it is different from zero) by using the Sobel test (Sobel, 1982).

Missing data were treated using the Full Information Maximum Likelihood (FIML) algorithm. FIML is a method that uses all available information of all observed (also incomplete) cases in order to enhance the validity of parameter estimation. FIML is superior to common methods such as listwise or pairwise deletion (Enders & Bandalos, 2001) and was thus chosen for the present studies. Univariate and multivariate outliers were routinely screened and treated as suggested by Tabachnick and Fidell (Tabachnick & Fidell, 2001).

4.3 RESULTS

4.3.1 Participants' characteristics

A total of *N* = 1,230 individuals (24.89 ± 5.34 years old; 683 females (55.3%) and 547 males), completed the survey. All participants were students and were therefore highly comparable with regard to their level of education.

4.3.2 Descriptive statistics

Table 1 displays correlations between all variables of interest included in the current study as well as their means, standard deviations, and ranges. Time spent listening to music and subjective relevance of music were not substantially correlated with the two outcomes QOL and the sum scores of the FBL. For the control variables age and gender, only two substantial associations emerged between gender and the sum scores of the FBL and stress reactivity, indicating that women reported more symptoms of the FBL and higher stress reactivity. Therefore, gender was controlled for in the main analyses. In terms of reasons for listening to music (RML), only four of the nine reasons assessed resulted in substantial associations ($r > 0.15$) with QOL and symptoms: RML reducing aggression, RML reducing loneliness, RML arousing specific feelings, and RML intensifying specific feelings. Due to the very small (although significant) associations between RML arousing specific feelings and RML intensifying specific feelings with QOL, no mediator model was tested for this constellation as a substantial direct effect of the predictor variable and the outcome is a precondition for mediator testing (Baron & Kenny, 1986). Moreover, emotional moderation regulation was not suitable as mediator as there were no associations with any of the predictor or with the outcome variables. Thus, four models were tested: the first mediator model specified RML reducing loneliness, the second RML reducing aggression as predictor, distress-augmenting regulation and stress reactivity as mediators and QOL and sum scores of the FBL as outcomes. The third and fourth mediator models specified RML arousing specific feelings and RML intensifying specific feelings as predictors, distress-augmenting regulation and stress reactivity as mediators and only the sum scores of the FBL as outcomes.

TABLE 1: Correlations between all variables in the study

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	M	SD	Range
1	quality of life (QOL)																		55.00	17.88	4-100
2	symptoms	-.31																	165.22	33.51	88-323.29
3	time listened to music (log transformed)	.06[a]	-.01[b]																201.30[c]	244.10[c]	0-1260
4	Subjective relevance of music	.03[b]	.07[a]	.34															4.34	.88	1-5
5	RML: reducing aggression	-.15	.18	.12	.18														2.39	1.27	1-5
6	RML: reducing loneliness	-.21	.25	.11	.09	.24													2.38	1.22	1-5
7	RML: arousing specific feelings	-.09	.16	.13	.26	.23	.25												3.22	1.29	1-5
8	RML: intensifying specific feelings	-.09	.18	.11	.23	.25	.27	.76											3.27	1.31	1-5
9	RML: activation	-.01[b]	.09	.30	.30	.28		.24	.27										3.65	1.19	1-5
10	RML: distraction	-.11	.10	.14	.10	.31	.28	.14	.13	.18									3.13	1.28	1-5
11	RML: improving work	.06[a]	.02[b]	.30	.20	.13	.12	.08	.09	.17	.12								2.61	1.36	1-5
12	RML: relaxation	.01[b]	.06[a]	.22	.28	.18	.14	.18	.16	.24	.24	.10							4.02	1.07	1-5
13	RML: reducing boredom	-.06[a]	.10	.09	.02[b]	.13	.39	.12	.11	.06[a]	.36	.06[b]	.05[b]						2.67	1.30	1-5
14	distress-augmenting regulation	-.17	.32	.07[a]	.16	.18	.23	.28	.31	.14	.09	.03[b]	.12	.03[b]					34.62	8.30	12-68
15	emotional moderation regulation	-.10	.09	-.01[b]	-.13	.06	.08	-.04[b]	-.02[b]	.05[b]	.11	.04[b]	.09	.10	-.23				29.95	6.94	10-58
16	stress reactivity	-.38	.49	-.10	-.05[b]	.14	.24	.11	.08	.04[b]	.08	-.07[a]	.03[b]	.07[a]	.27	.13			5.89	1.82	1-11.25
17	age	-.01[b]	-.04[b]	-.03[b]	-.05[b]	-.09	-.08[a]	-.07[a]	-.08[a]	-.05[b]	-.14	-.06[a]	-.10	-.19	-.03[b]	-.05[b]	-.01[b]		24.88	5.35	11-64
18	gender	-.02[b]	.28	-.03[b]	.03[b]	.05[b]	.06[a]	-.01[b]	-.05[b]	.08[a]	.05[b]	-.05[b]	.08[a]	-.03[b]	.10	-.03[b]	.30	.02[b]	-	-	-

Note. RML: reasons for listening to music.
Unless otherwise noted, all coefficients were significant at the $p = .001$ level; a: significant at $p < .05$; b: non-significant; c: M and SD for untransformed variable; gender: 1 = men, 2 = women

4.3.3 Mediator model with RML reducing loneliness

In a first model, we tested whether there were direct effects of RML reducing loneliness on QOL and the sum scores of the FBL when controlling for gender. Results are displayed in Figure 1. The substantial associations between RML reducing loneliness and QOL (β = -.21) and sum scores of the FBL (β = .24) remained when controlling for gender (β = .27 for the association with the sum scores of the FBL, indicating higher reporting of symptoms of the FBL for women; β = -.01, n.s. for the association with QOL). The definite mediator model included stress reactivity and DAR as mediator variables. Indirect effects between RML reducing loneliness via stress reactivity to QOL (Sobel Z = -7.22, p = .001) and the sum scores of the FBL (Sobel Z = 7.39, p = .001) as well as via DAR to sum scores of the FBL (Sobel Z = 5.30, p = .001) reached significance. The indirect effect between RML reducing loneliness via DAR to QOL (Sobel Z = -1.82, p = .07) was not significant at the 5% level. Overall, due to the considerable reduction of the direct effects, the associations between RML reducing loneliness and QOL and sum scores of the FBL are mediated by stress reactivity and for values of sum scores of the FBL as outcomes also in part by DAR.

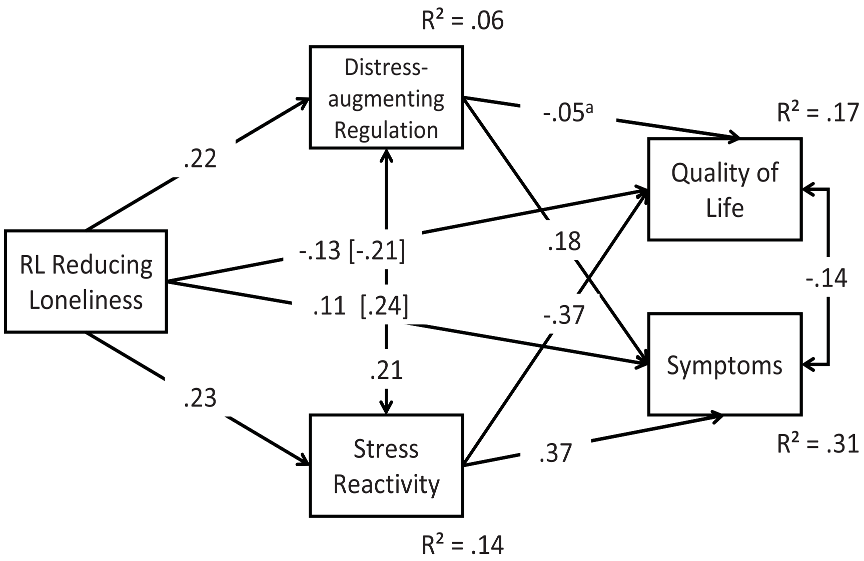

FIGURE 1: Mediator model with RML reducing loneliness
Note. Coefficients in parentheses: direct effects without mediator variables. All coefficients reported are controlled for gender. Associations with gender: β = .09, with distress-augmenting regulation; β = .29 with stress reactivity; β = .16 with quality of life; β = .14 with sum scores of the FBL; *r* = .05[a] with RML reducing loneliness. Gender-coded 1 = men, 2 = women. Unless otherwise indicated, all coefficients were significant at $p < .01$; a = $p < .10$.

4.3.4 Mediator model with RML reducing aggression

In a second model, we tested whether there were direct effects of RML reducing aggression on QOL and sum scores of the FBL when controlling for gender. The associations between RML reducing aggression and QOL (β = -.15) and sum scores of the FBL (β = .17) remained almost unchanged when controlling for gender (β = .27 for the association with the sum scores of the FBL, indicating higher reporting of symptoms of the FBL for women; β = -.01, n.s. for the association with QOL). The definite mediator model included stress reactivity and DAR as mediator variables. Results are displayed in Figure 2 and are comparable to RML reducing loneliness. Indirect effects between RML reducing aggression via stress reactivity to QOL (Sobel Z = -4.37, p = .001) and sum scores of the FBL (Sobel Z = 4.41, p = .001) as well as via DAR to sum scores of the FBL (Sobel Z = 4.73, p = .001) reached statistical significance. The indirect effect between RML reducing aggression via DAR to QOL (Sobel Z = -1.95, p = .05) was not significant at the 5% level. Overall, due to the considerable reduction of the direct effects, the associations between RML reducing aggression and QOL and sum scores of the FBL were mediated by stress reactivity and for sum scores of the FBL as outcomes also by DAR.

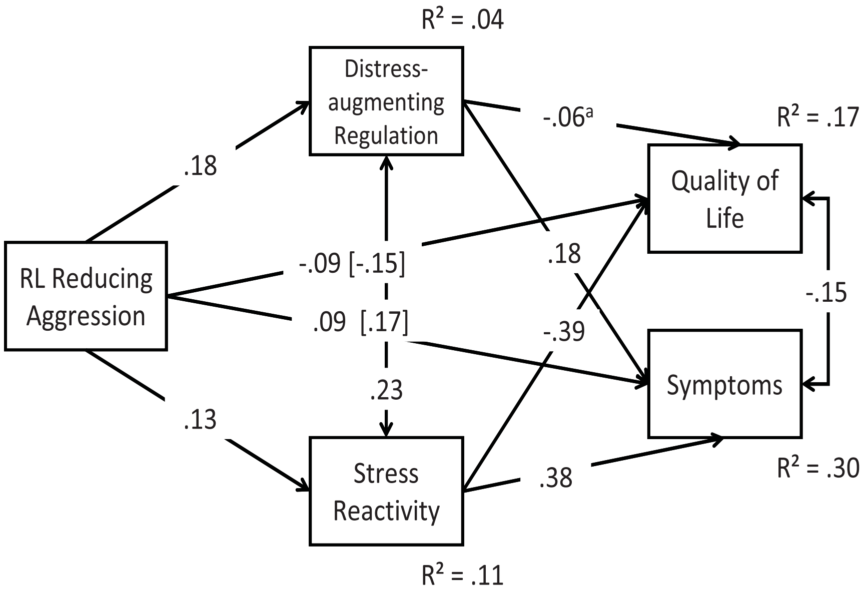

FIGURE 2: Mediator model with RML reducing aggression
Note. Coefficients in parentheses: direct effects without mediator variables. All coefficients reported are controlled for gender. Associations with gender: β = .10, with distress-augmenting regulation; β = .29 with stress reactivity; β = .11 with quality of life; β = .14 with sum scores of the FBL; *r* = .05, $p < .10$ with RML reducing aggression. Gender-coded 1 = men, 2 = women. Unless otherwise indicated, all coefficients were significant at $p < .01$; a = $p < .05$.

4.3.5 Mediator model with RML arousing specific feelings

In a third model, we tested whether there were direct effects of RML arousing specific feelings on the sum scores of the FBL when controlling for gender. The associations between RML arousing specific feelings and sum scores of the FBL (β = .16) remained unchanged when controlling for gender (β = .28 for the association with the sum scores of the FBL, indicating higher reporting of symptoms in the FBL for women; β = -.01). The definite mediator model included stress reactivity and DAR as mediator variables. Results are displayed in Figure 3. Both indirect effects between RML arousing specific feelings via stress reactivity to sum scores of the FBL (Sobel *Z* = 3.54, *p* = .001) as well as via DAR to sum scores of the FBL (Sobel *Z* = 5.69, *p* = .001) reached significance. Overall, due to the reduction of the direct effect, the association between RML arousing specific feelings and sum scores of the FBL was mediated by stress reactivity and by DAR.

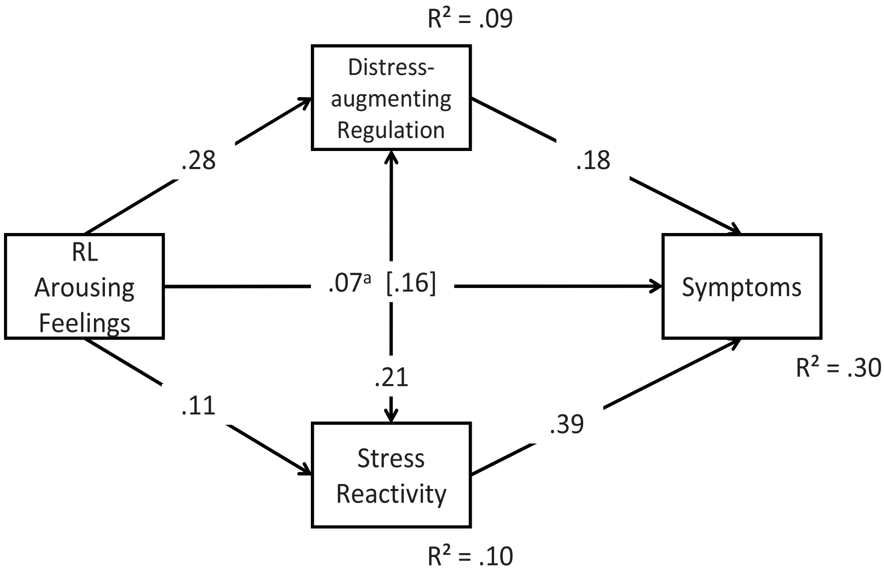

FIGURE 3: Mediator model with RML arousing specific feelings
Note. Coefficient in parentheses: direct effect without mediator variables. All coefficients reported are controlled for gender. Associations with gender: β = .11, with distress-augmenting regulation; β = .30 with stress reactivity; β = .14 with sum scores of the FBL; *r* = -.01, n.s. with RML arousing specific feelings. Gender-coded 1 = men, 2 = women. Unless otherwise indicated, all coefficients were significant at *p* < .01; a = *p* < .05.

4.3.6 Mediator model with RML intensifying specific feelings

In a fourth model, we tested whether there were direct effects of RML intensifying specific feelings on sum scores of the FBL when controlling for gender. The associations between RML intensifying specific feelings and sum scores of the FBL (β = .19) remained unchanged when controlling for gender (β = .29 for the association with sum scores of the FBL, indicating higher reporting of symptoms in the FBL for women). The definite mediator model included stress reactivity and DAR as mediator variables. As results are very similar to those for RML arousing specific feelings, no additional figure is provided. RML intensifying specific feelings was associated with β = .10 (*p* = .001) to stress reactivity and with β = .32 (*p* = .001) with DAR. Stress reactivity and DAR, in turn, were significantly related to sum scores of the FBL (β = .39, *p* = .001 for stress reactivity and β = .16, *p* = .001 for DAR). Both indirect effects between RML intensifying specific feelings via stress reactivity to sum scores of the FBL (Sobel $Z = 3.39$, $p = .001$) as well as via DAR to sum scores of the FBL (Sobel $Z = 5.51$, $p = .001$) reached significance. Overall, due to the reduction of the direct effect, the association between RML intensifying specific feelings and sum scores of the FBL was mediated by stress reactivity and by DAR.

4.4 DISCUSSION

The present study examined the interrelation between habitual music-listening behavior and (self-reported) health status. We hypothesized that emotion regulation processes and individual stress reactivity accounted for potential associations between habitual music-listening behavior and health indicators. Our findings indicate that average duration of music listening or subjective relevance of music are not associated with health status. In contrast, reasons for listening to music (especially ‘reducing loneliness and aggression’, and ‘arousing or intensifying specific emotions’) seem to play a much more crucial role. These effects were mediated by distress-augmenting emotion regulation and individual stress reactivity.

It appears that in healthy adults, qualitative aspects of listening to music, i.e. reasons related to emotion regulation, are more important for the general health status than quantitative aspects, i.e. average duration of music listening or subjective relevance of music. This result is in contrast to findings by Mitchell et al. (2007), who found that both frequent music listening and subjective importance of music were related to enhanced quality of life and reduced requirement of medical treatment in pain sufferers. In our study, the mean ratings of subjective relevance of music were rather high in most participants. Consequently, the fact that we did not find an interrelation between the subjective relevance of music and health indicators may be due to a ceiling effect. Moreover, given the particular characteristics of the sample by Mitchell et al. (2007), i.e. chronic pain sufferers, comparisons with our sample, i.e.

healthy adults, are limited. Differences in the basic health status of the two samples are probably the main reason for the identified discrepancies between the results of the two studies.

We found a direct negative association between the reason for listening ‘to reduce loneliness’ and health indicators (i.e. negative association with quality of life and positive association with number of somatic symptoms). Other studies examining chronic pain sufferers (Mitchell, MacDonald, Knussen, & Serpell, 2007) and adolescents (North, Hargreaves, & O'Neill, 2000) also reported that reducing loneliness was a major reason for listening to music. However, the negative association with health has not yet been documented in the literature. Although we did not measure loneliness per se, we might assume that those respondents who reported listening to music in order to reduce loneliness may also experience this feeling more often. The distressful feeling of loneliness arises when one’s social network is experienced as less satisfying than desired (Peplau & Perlman, 1982). Loneliness and the related social isolation have been associated with increased physical health risks (Cole, 2008), reduced longevity (Peel, McClure, & Bartlett, 2005), increased risk of cancer (Reynolds & Kaplan, 1990), increased depressive symptoms (Cacioppo & Hawkley, 2003), and poor lifestyle behavior, such as smoking, physical inactivity, and overweight (e.g. Hawkley, Thisted, & Cacioppo, 2009; Lauder, Mummery, Jones, & Caperchione, 2006). Our finding of a negative association between the reason of listening to reduce loneliness, as an indirect indicator of loneliness, and health is therefore in line with previous studies relating to the topic of ill health through loneliness.

Further, we found a direct negative association between the reason for listening ‘to reduce aggression’ and health (i.e. negative association with quality of life and positive association with number of somatic symptoms). This is a novel finding, which has not been reported previously. As with loneliness, we did not measure aggression as such, but we may assume that those respondents reporting to listening to music in order to reduce (feelings or behavioral tendencies associated with) aggression may also experience it more often. Aggression is intended to injure someone or to induce damage to others who dislike and do not want to be a victim of that behavior (R. A. Baron & Richardson, 2004). It has previously been associated with several health issues, such as depression and chronic stress, or poor lifestyle behavior, such as smoking and drinking (e.g. Johnson, 1990; Raine, 2002). Our finding of a negative association between the reason of listening to reduce aggression (as an indirect indicator of aggression) and health is therefore consistent with previous findings relating to the topic of ill health through aggression.

Finally, we found a direct negative association between the reasons for listening 'arousing and intensifying specific feelings' and health (i.e. positive association with number of somatic symptoms). This is in line with previous studies (Mitchell, MacDonald, Knussen, & Serpell, 2007; North & Hargreaves, 2000). The emotion-eliciting capacity of music is considered to be the main reason for actively engaging with music (Juslin & Sloboda, 2001). Accordingly, our finding appears rather surprising and raises new questions. This observation can only be interpreted when the mediating variables, i.e. distress-augmenting regulation and individual stress reactivity, are taken into account. Distress-augmenting regulation describes the disposition of an individual to intensify negative emotions. It is therefore assumed that individuals who have the disposition to intensify negative emotions also listen to music with the purpose of arousing or intensifying *negative* emotions. Previous research indicates that negative emotions are associated with negative health outcomes (Frasure-Smith, Lespérance, & Talajic, 1995; Kubzansky & Kawachi, 2000; Watson & Pennebaker, 1989). Our finding is therefore consistent with results of previous investigations. The same explanation might also be valid for the second mediating variable, i.e. stress reactivity. The construct of stress reactivity describes the disposition of an individual to respond to stressors with immediate, strong, and long-term stress reactions (Schulz, Jansen, & Schlotz, 2005). We therefore assume that respondents with this disposition also experience emotions associated with stress more often (such as anxiety or anger) and consequently preferentially listen to music with the purpose of arousing or intensifying these emotions. Sustained stress experience is associated with poor health outcomes (e.g. Esch, Stefano, Fricchione, & Benson, 2002a; 2002b; 2002c). Thus, the negative association between the reason for listening ‘arousing and intensifying specific feelings’ and health indicators can be explained by the mediating influence of stress reactivity.

Does listening to music improve health? Our findings indicate that it might not be possible to answer this question with a simple yes or no. Habitual music-listening behavior appears to be a multifaceted behavior that consists of many different aspects. In addition, the use of music seems to be further influenced by individual dispositions (emotion regulation and susceptibility to stress). Moreover, it is likely that use and subsequent effects of music listening are further influenced by other variables, such as personality factors (e.g. Chamorro-Premuzic, Swami, Furnham, & Maakip, 2009). Finally, the health status itself is also further influenced by various habitual behaviors, such as physical exercise (e.g. Bucksch & Schlicht, 2006; Lee & Buchner, 2008; Waddington, Malcolm, & Green, 1997) or diet (e.g. Cordain et al., 2005). From this perspective, it is rather astonishing that we were still able to detect some associations between habitual music-listening behavior and health indicators. However, to achieve a better understanding of this association, future studies should also include the above-mentioned influencing factors.

There are several limitations to this study that should be acknowledged.

Survey respondents: As we were studying the associations between music listening and health in a wide student population, the generalization of our results beyond this sample is restricted. It is to be assumed that participants in our sample, consisting mainly of university students, have different everyday lives than other samples, and might therefore show different music-listening behavior. Moreover, as respondents were aware of the topic of the survey, i.e. music, and due to the voluntary nature of study participation, a selection bias may have confounded our results. The high amount of average time spent listening to music and the high values of the subjective relevance of music are indicators of this assumption. Consequently, the findings should be replicated in a larger and more heterogeneous sample consisting of respondents who are more naïve to the intentions of the survey.

Setting: A web-based data collection has many advantages: Besides its convenience and anonymity for respondents, it is cost-effective and allows access to a broad and homogeneous sample as well as the assessment of data in a short period of time. The shortcomings of this approach are the generally lower response rates in comparison to conventional paper-and-pencil methodology.

Cross-sectional design: Given the fact that our survey was a cross-sectional study, we are only able to reveal associations between the variables of interest and are unable to establish any causal interpretations between them. Only a broadly constructed prospective study design, i.e. a longitudinal correlational study, which controls for a multitude of influencing variables, might provide a comprehensive answer to the question of whether listening to music in everyday life does indeed have a positive long-term impact on health.

In conclusion, this was the first study to investigate the associations between music-listening behavior and health in a sample of healthy adults. We were able to demonstrate that qualitative aspects of music-listening behavior, i.e. specific (negative) emotion-regulated reasons for listening, are directly associated with health indicators. We also found that these associations are mediated by dispositional emotion regulation processes and individual stress reactivity. Thus, individuals use music differentially, depending on their habitual way of regulating their emotions and on their individual susceptibility to stress. Based on this knowledge, music listening might be more systematically used in therapeutic settings, thus enhancing its clinical relevance.

5 EMPIRICAL STUDY II: 'THE EFFECT OF MUSIC ON ACUTE NEUROENDOCRINE, AUTONOMIC, COGNITIVE, AND EMOTIONAL STRESS RESPONSE'[7]

5.1 INTRODUCTION

A prolonged experience of stress and its biological consequences are associated with poor health outcomes. Conservative estimates suggest that stress accounts for approximately 30% of the overall costs of illnesses and accidents across Western nations (Nater, Gaab, Rief, & Ehlert, 2006). As a consequence, further development of cost-effective stress prevention or management has become an important endeavor of current research efforts. Stress is a multi-faceted phenomenon that comprises physiological (endocrine and autonomic parameters), cognitive, and emotional components, and efficient stress intervention techniques should equally affect all of these components. The use of listening to music, as an economical, non-invasive, and highly accepted intervention has received special interest in coping with stress and stress-related health issues, as it is assumed to similarly affect physiological activation (e.g. Khalfa, Bella, Roy, Peretz, & Lupien, 2003; Nater, Abbruzzese, Krebs, & Ehlert, 2006; Nyklicek, Thayer, & Van Doornen, 1997) and cognitive (e.g. Burns, Labbé, Williams, & McCall, 1999) and emotional processes (e.g. Blood & Zatorre, 2001; Juslin & Sloboda, 2001).

The hypothalamus-pituitary-adrenal (HPA) axis is a major endocrine stress system (Chrousos & Gold, 1992). Cortisol constitutes a reliable indicator of HPA axis activity (Kirschbaum & Hellhammer, 1994; Vining & McGinley, 1987). Previous research investigated the assumed stress-reducing effect of music listening on cortisol release in the context of field studies; i.e. in medical, thus potentially stress-inducing, settings with patients. Significant

[7] This study is in preparation for submission (Thoma, La Marca, Brönnimann, Finkel, Ehlert, & Nater, 2010)

positive changes in cortisol were reported when listening to music during interventions (lower increases in cortisol) (Escher et al., 1993; Uedo et al., 2004) and after interventions (greater reductions in cortisol) (Miluk-Kolasa, Obminski, Stupnicki, & Golec, 1994; Nilsson, Unosson, & Rawal, 2005). The few laboratory-based studies show inconsistent findings. Faster decrease of cortisol concentrations were found when listening to music after a stressor (Khalfa, Bella, Roy, Peretz, & Lupien, 2003), but no changes in cortisol were observed when listening to music before a stressor (Knight & Rickard, 2001). As a consequence, no final conclusions can be drawn about how music listening influences stress-induced cortisol levels in a laboratory environment.

The sympathetic nervous system (SNS) is another important psychobiological stress system (Chrousos & Gold, 1992). Salivary alpha-amylase (sAA) has recently been established and evaluated as a valid marker for SNS activity (Nater & Rohleder, 2009). Changes in autonomic responses often occur in association with the pleasurable experience of listening to music (e.g. Goldstein, 1980; Krumhansl, 1997). Moreover, a series of clinical and laboratory-based studies revealed that listening to music can attenuate stress-increased indices of the SNS (for a review see Bartlett, 1996b; Standley, 1992). Given that most studies did not control for the effectiveness of a non-music acoustic stimulation on SNS activation, e.g. a calming sound that lacks the characteristics of music, the particular effectiveness of music listening on the SNS cannot be determined.

In a given situation, stress is the result of cognitive appraisal processes (Lazarus & Folkman, 1984). In the brain, music listening activates a cascade of cognitive components (Peretz & Zatorre, 2005). It might therefore be assumed that music also influences stress-related cognitive processes. Previous investigations found reductions in perceived levels of psychological stress, increased coping abilities, or altered levels in perceived relaxation after listening to music in the context of a stressful situation (e.g. Allen et al., 2001; Burns, Labbé, Williams, & McCall, 1999). However, there is insufficient laboratory-based evidence regarding the impact of music listening on the cognitive component of the stress experience.

Anxiety is an adaptive response to the experience of stress. Given that music listening can exert effects on all essential limbic and paralimbic brain areas (e.g. Blood & Zatorre, 2001; Koelsch, 2010; Menon & Levitin, 2005), listening to music might also moderate anxiety levels induced by the experience of stress. Indeed, a decrease in anxiety is one of the most consistent findings reported in field studies with patients (e.g. Voss et al., 2004; Wang, Kulkarni, Dolev, & Kain, 2002). In addition, laboratory studies found reductions of stress-induced anxiety through listening to music (Knight & Rickard, 2001; Labbé, Schmidt, Babin, & Pharr, 2007). Nevertheless, not all investigations found anxiety reductions through music listening in their subjects (see reviews in Evans, 2002; Nilsson, 2008; Richards, Johnson, Sparks, & Emerson, 2007). Controlled laboratory-based studies are necessary in order to reduce variability in such investigations.

In sum, it appears that listening to music is efficient in attenuating the most important domains of the stress response. Despite the large number of studies, outcomes are often inconsistent, mainly due to the fact that many previous studies were conducted in clinical populations, including various different medical settings and heterogeneous patient samples. Consequently, on the basis of previous work, no conclusions can be drawn about the mechanisms underlying the effect of music listening on psychobiological stress responses. Besides the valuable attempt of a small number of studies to investigate the effect of music listening in a laboratory environment, these investigations suffered from methodological shortcomings, such as small sample size (Khalfa, Bella, Roy, Peretz, & Lupien, 2003) or lack of a valid stressor (Knight & Rickard, 2001). Moreover, few attempts have been reported to measure or control confounding variables. Differences in chronic stress levels, emotion regulation strategies, or current depression of subjects may play a substantial role in explaining variability in psychological and physiological responses to stressors. Furthermore, the broad majority of previous work used only one control group (silence), and did not additionally control for effects that might have been merely a consequence of acoustic stimulation alone. Finally, to the best of our knowledge, the concurrent assessment of HPA axis and SNS activity, cognition and emotion has not been described in the literature thus far. Only an integrative approach will shed light on the underlying psychobiological mechanisms of the effectiveness of music interventions.

In light of these considerations, we set out to examine the assumed positive effect of listening to relaxing music before a stress task across neuroendocrine, autonomic, cognitive, and emotional domains of the stress experience in healthy participants in a laboratory setting. We hypothesized that those participants who listen to relaxing music prior to the stress task would show significantly attenuated stress responses in terms of salivary cortisol, sAA, cognitive appraisal processes, subjective perception of stress, and anxiety in comparison to non-music control groups, i.e. listening to the sound of rippling water and rest with no acoustic stimulation.

5.2 METHODS

5.2.1 Participants

Participants were recruited by advertisements at two universities in Zurich. In a telephone screening, major criteria for eligibility of interested participants were verified. Inclusion criteria were female sex, 20 – 30 years of age, and a regular menstrual cycle. Female sex was chosen to control for gender differences, as sexual dimorphism in the HPA response to psychosocial stress (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999; Stroud, Salovey, & Epel, 2002) and also in physiological and emotional reactions to music listening

(McFarland & Kadish, 1991; Nater, Abbruzzese, Krebs, & Ehlert, 2006; Standley, 1992) have been observed in the past.

Exclusion criteria were current depression, self-reported acute and chronic somatic or psychiatric disorders, medication, use of hormonal contraceptives, use of psychoactive substances, and excessive consumption of alcohol (> 2 alcohol beverages / day) or tobacco (> 5 cigarettes / day). Additional exclusion criteria were self-reported hearing deficits or tinnitus. Musically trained people were not allowed to take part in the study. If eligibility requirements were met, appointments were scheduled in the follicular phase (days 4-10) of the menstrual cycle. Participants were sent an information set and a battery of questionnaires. They were instructed not to drink alcohol or caffeinated beverages 48 hours prior to the study. Additionally, they were told to refrain from any sporting activities 24 hours prior to the experiment. Furthermore, subjects had to refrain from brushing their teeth or eating at least 60 minutes before the study.

Subjects were informed about the course of the study but were not given detailed information about the experimental stress paradigm. Written informed consent from all subjects was obtained. For their participation in the study, the subjects were reimbursed with 50 Swiss Francs. The study was conducted in accordance with the declaration of Helsinki. The study protocol was approved by the ethics committee of the Canton of Zurich.

5.2.2 Study design and procedures

Participants were randomly assigned to the music condition (relaxing music listening prior to TSST, (RM)) or to one of the two control conditions (listening to the sound of rippling water (SW), or resting without acoustic stimulation prior to TSST (R)). Randomization was accomplished through the use of a computer-generated randomization list.

All participants underwent a standardized psychosocial laboratory stress protocol. The Trier Social Stress Test (TSST) consists of a short introduction (Intro) and a public speech followed by a mental arithmetic task in front of an audience. It has repeatedly been found to be a reliable tool to produce a physiological stress response by activating the HPA axis and the SNS (see Dickerson & Kemeny, 2004; Kirschbaum, Pirke, & Hellhammer, 1993; Kudielka, Buske-Kirschbaum, Hellhammer, & Kirschbaum, 2004). In the current study, the standard TSST procedure reported in the literature was slightly modified. The subjects were not told (in the Intro) about the exact nature of the upcoming speech (i.e. simulated job interview) in order to avoid cognitive preparation for it.

Examinations were scheduled to take place between 1200 and 1700h in order to minimize confounds by circadian fluctuations of hormone levels. Participants arrived at the laboratory 60 min prior to the onset of the TSST. After an adaptation period of 30 min, a basal saliva sample (T1) was taken. Twenty minutes prior to the public speech, the subjects were introduced to the TSST (Intro, 2 min). The subjects were then returned to a different room, seated in a comfortable chair, and provided with headphones. All participants had to adjust a test signal (sinus tone, sound pressure = - 70dB) to the individual hearing threshold level for the calibration of the volume. Depending on the condition, subjects either listened for ten minutes to a relaxing musical stimulus (RM), to the sound of rippling water (SW) or rested without any acoustic stimulation (R). Immediately after the intervention, a second saliva sample was taken (T2). Following this, subjects were taken back into the TSST room where they underwent the TSST. After completion of the TSST, the subjects were then returned to a separate room and a third saliva sample was taken (T3). Further samples were taken 15 min (T4), 30 min (T5), 45 min (T6), and 60 min (T7) after the TSST. In addition, the subjects completed various self-report stress measures (see below) at baseline (T1), before and after (T2) the interventions, immediately (T3) and 15 min (T4) after the challenge.

5.2.3 Music and control acoustic stimulus

'Miserere' by Allegri (CD Gimell 454 939-2) is a soothing and calming piece of music (Latin choral singing), which was chosen to induce relaxation in our subjects. The stimulus was selected on the basis of previous research (Nater, Abbruzzese, Krebs, & Ehlert, 2006). We decided to use one standardized music stimulus for all participants, as this is assumed to display more influence on decreasing a stress reduction than music stimuli selected by the subjects themselves (Pelletier, 2004). Finally, we wanted to avoid possible influences of memory or subjective associations with self-chosen music stimuli by participants.

In the current investigation, we applied a control acoustic stimulus, i.e. sound of rippling water. This control condition was chosen to control for effects caused by a solely acoustic stimulation on psychological and physiological parameters. The sound of rippling water lacks the typical characteristics of music: loudness, pitch, and quality (timbre). Nevertheless, it is an acoustic stimulus with perceptual quality for the listener. In comparison to artificially produced sounds (such as white or pink noise or only tones), the sound of rippling water can be presented for extended periods.

5.2.4 Measures

5.2.4.1 Sampling methods and biochemical analysis

For the analysis of cortisol and alpha-amylase, saliva was collected using small cotton swabs (Salivettes, Sarstedt, Sevelen, Switzerland). Stimulated saliva was taken by having the subjects gently chew the cotton roll for 1 min. Thereafter, the cotton roll was placed into a small plastic tube. Samples were stored at -20°C until biochemical analysis took place. *Salivary free cortisol* was determined using a commercial chemiluminescence immunoassay (LIA) (IBL Hamburg, Germany). Inter- and intraassay coefficients of variation were below

10%. All samples of one subject were analyzed in the same run in order to reduce error variance caused by imprecision of the intraassay. *Salivary alpha-amylase (sAA)* activity was analyzed using the automatic analyzer Cobas Mira and assay kits obtained from Roche. The procedure is described in detail in Nater et al. (2006). The assay is a kinetic colorimetric test. Inter- and intraassay variance was below 1%.

5.2.4.2 Psychometric measurements

To investigate the role of psychological factors, the following questionnaires were used:

Music-listening behavior and music preference: The *Music Preference Questionnaire* (MPQ) (Nater, Krebs, & Ehlert, 2005) was used to assess music-listening behavior (*e.g.* reasons why somebody listens to music, subjective importance of music, and time spent listening to music) and general music preference.

Depression: The *Beck Depression Inventory* (BDI) (Beck, 1961) was used to control for a possible impact of depression on the HPA response (Gotthardt et al., 1995). Scores that are higher than 18 are considered to be clinically relevant depressive symptoms.

Emotion regulation: To test the use of the two common trait emotion regulation strategies, *reappraisal* and *suppression*, the validated German version (Abler & Kessler, 2009) of the *Emotion Regulation Questionnaire* (ERQ) by Gross and John (2003) was used. Depending on the habitually preferred emotion regulation strategy, different cognitions, emotions, and behavior result during and after emotional situations.

Stress: Visual analog scales (VAS) were employed to repeatedly measure subjective perception of stress during the experiment. The transactional 16-item stress questionnaire *Primary Appraisal and Secondary Appraisal* (PASA) (Gaab, Rohleder, Nater, & Ehlert, 2005) was used to assess relevant anticipatory cognitive processes during expectation of a stressful situation. A mean score for primary and secondary stress appraisal can be calculated. A stress index results from the difference between these two scales. The PASA was administered immediately after the 'Intro' to the TSST and again after the three different interventions (T2). The PASA was employed twice so as to assess possible changes in anticipatory cognitive processes due to the intervention. Perceived chronic stress was determined with a 57-item instrument, the *Trier Inventory for the Assessment of Chronic Stress* (TICS) (Schulz, Schlotz, & Becker, 2004). Participants were required to rate how often they had experienced the described stressful situations in the past three months on a 5-point scale.

Anxiety: The German version of the *State and Trait Anxiety Inventory* (STAI) (Laux, Glanzmann, Schaffner, & Spielberger, 1981) was used to assess anxiety. The STAI consists of two 20-item questionnaires which assess state and trait levels of anxiety in clinical and non-clinical populations. The STAI-state was used as a continuous measurement for possible changes in anxiety during the experiment (Spielberger, Gorsuch, & Lushene, 1970).

Stimuli questionnaires: The questionnaires addressing the stimuli (music and sound of rippling water) were used to assess the subjective perception of these stimuli. Subjects were required to rate how much they liked the stimulus, and how relaxing they perceived the stimulus to be on a 5-point scale.

5.2.5 Statistical analysis

Data analysis was performed using SPSS (17.0) software packages (SPSS, Chicago, IL, USA). Normal distribution and homogeneity of variance were tested using a Kolmogorov-Smirnov and Levene's test before statistical analyses were applied. All reported results were corrected by the Greenhouse-Geisser procedure where appropriate (violation of sphericity assumption) (Greenhouse & Junker, 1992; Vasey & Thayer, 1987). Results were considered statistically significant at the $p \leq 0.05$ level, and all tests were two-tailed. In the case of missing data, cases were excluded listwise. Analyses of variance (ANOVAs) for repeated measures were computed to analyze possible time, condition and interaction effects. For comparison of the scale means of the questionnaires with normative samples, Student's t-tests were computed. Cortisol and sAA levels (baseline to 70 min after the start of the stress protocol) were evaluated according to an area under the curve with respect to increase (AUC_I) methodology. The AUC_I is related to the sensitivity of the biological system; it reflects pronounced changes over time, and is characterized by accumulation of the error of the baseline, as the formula is based on the difference between the baseline and the subsequent measures (Pruessner, Kirschbaum, Meinlschmidt, & Hellhammer, 2003). The change from cortisol and sAA concentration from baseline to peak (peak delta) and from peak back to baseline (recovery delta) was computed. Calculated measures of AUC_I metric, peak delta and recovery delta were analyzed using ANCOVAs. For all analyses, the significance level was ά= 5%. Unless indicated otherwise, all results shown are means ± standard deviations (SD).

5.3 RESULTS

5.3.1 Sample characteristics

Sixty female healthy subjects participated in the study (age: mean = 25.27 years, SD = 3.21 years; BMI: mean = 21.63, SD = 2.34). Randomization resulted in 3 groups, with 20 participants undergoing the experimental condition (RM), 20 participants undergoing control condition 1 (SW), and 20 participants undergoing control condition 2 (R). One participant of the RM exhibited a baseline cortisol level which was more than 3 standard deviations higher than the mean. As a consequence, this participant was excluded from all analyses. The randomized assignment to groups was evaluated by comparing demographic (age, BMI) and means of all control variables (BDI, ERQ, STAI-trait, TICS) (all p = *n.s.*) (TABLE 2). The randomization was therefore successful.

TABLE 2: Sample characteristics (means ± SD (*n*))

Characteristic	RM (*n*=19)	SW (*n*=20)	R (*n*=20)	*p*-value[a]
Age (years)	25.13 ± 2.86	25.0 ± 3.71	25.57 ± 3.18	0.85
BMI[b]	21.28 ± 2.08	21.83 ± 2	21.96 ± 2.87	0.62
BDI	4.76 ± 3.77	5.65 ± 4.46	6.18 ± 4.33	0.62
ERQ reappraisal	4.75 ± 0.89	4.98 ± 0.98	4.75 ± 1.18	0.71
ERQ suppression	3.0 ± 1.07	3.68 ± 0.93	3.09 ± 1.12	0.1
STAI-trait	35.8 ± 8.91	38.35 ± 10.35	38.68 ± 10.06	0.61
TICS	16.75 ± 7.77	16.05 ± 8.92	19.26 ± 5.86	0.4

n = valid cases, *SD* = standard deviation, RM = listening to relaxing music, SW = listening to the sound of rippling water, R = resting without acoustic stimulation, BMI = Body Mass Index, BDI = Beck Depression Inventory, ERQ = Emotion regulation questionnaire, STAI = State and Trait Anxiety Inventory, TICS = Trier Inventory for the Assessment of Chronic Stress

[a] Probability value from one-way ANOVA.

[b] Calculated as weight in kilograms divided by the square of height in meters.

5.3.2 Stimuli characteristics

The piece of music ('*Miserere*' Allegri) and the sound of rippling water were both positively evaluated (music: mean=3.21; SD=1.36; sound of rippling water: mean=3.84; SD=1.17) and perceived as relaxing (music: mean=4.0; SD=0.88; sound of rippling water: mean=4.0; SD=1.2).

5.3.3 Salivary cortisol responses

The stress protocol induced significant increases in salivary cortisol over time ($F(2.22/124.53)=15.03$; $p<0.001$). For all further analyses, age, BDI, BMI, TICS, and ERQ were entered as covariates. Cortisol concentrations differed significantly between groups, with highest values in the RM and lowest values in the SW (*F*(5.15/42)=2.98; *p*=0.014) (FIGURE 4). This finding was also reflected by significant differences in the AUC_I (*F*(2/42)=3.43; *p*=0.042), in the peak delta (*F*(2/42)=4.67; *p*=0.015), and with a trend toward significance in the recovery delta (*F*(2/42)=2.68; *p*=0.080) (TABLE 3).

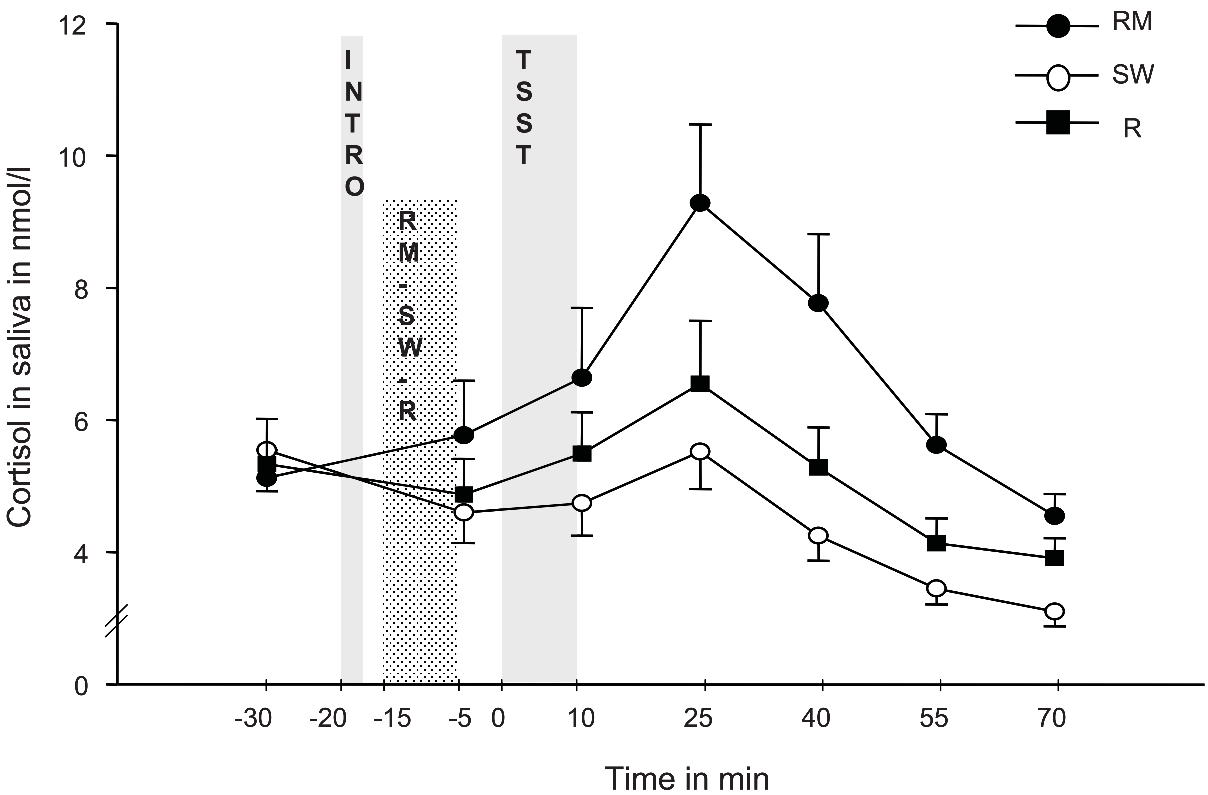

FIGURE 4: Salivary cortisol levels in response to the TSST (means ± SEM), in the experimental group listening to relaxing music (RM), the control group listening to the sound of rippling water (SW), and the control group resting without acoustic stimulation (R).

5.3.4 Salivary alpha-amylase responses

The sAA levels increased significantly over the course of the stress task over time (*F*(2.72/149.48)=15.35; *p*<0.001). For all further analyses, age, BDI, and BMI were entered as covariates. This result shows a significant activation of the SNS due to the applied stress protocol. Concerning the interaction, there were no significant differences in the alpha-amylase concentrations (*F*(5.22/44)=1.06; *p*=0.388) (FIGURE 5). This result was also mirrored by the AUC_I (*F*(2/41)=0.73; *p*=0.491) and the peak delta (*F*(1/41)=0.66; *p*=0.420).

Recovery delta shows a trend toward significance ($F(2/44)=3.00$; $p=0.060$) (TABLE 2); the sAA levels of the RM are back at baseline at T4 whereas SW and R are back at baseline at T5 (i.e. 15 min later).

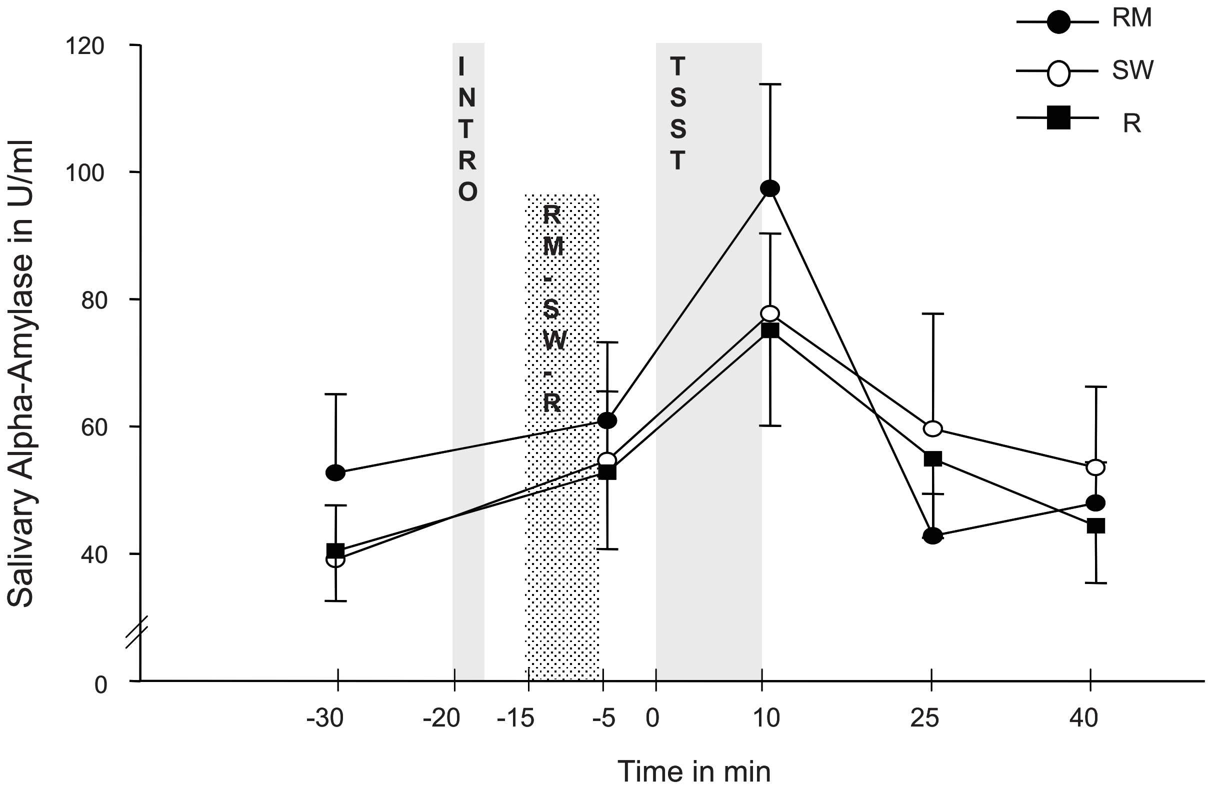

FIGURE 5: Alpha-amylase levels in response to the TSST (means ± SEM) in the experimental group listening to relaxing music (RM), the control group listening to the sound of rippling water (SW), and the control group resting without acoustic stimulation (R).

TABLE 3: Area under the curve with respect to increase (AUC_I), peak delta, and recovery delta values for cortisol (controlled for age, BMI, BDI, ERQ, TICS) and alpha-amylase (controlled for age, BMI, BDI) in the RM and SW and R (mean ± SD).

Characteristic	RM (*n*=17)	SW (*n*=17)	R (*n*=17)	*p*-value
Cortisol				
AUC_I	-11.12 ± 461.16	268.96 ± 286.99	-179.23 ± 334.14	0.042 [a]
Peak delta	4.16 ± 7.28	-0.02 ± 2.57	1.21 ± 4.27	0.015 [b]
Recovery delta	-4.74 ± 5.24	-2.42 ± 1.58	-2.64 ± 3.33	0.080 [a]
Alpha-Amylase				
AUC_I	-1118.39 ± 4749.72	284.87 ± 1034.34	-14.82 ± 3225.48	0.065
Peak delta	44.68 ± 59.36	38.64 ± 25.79	34.65 ± 41.58	0.864
Recovery delta	-54.60 ± 54.99	-18.11± 42.94	-20.17 ± 34.05	0.060 [c, d]

n = valid cases, *SD* = standard deviation, RM = listening to relaxing music, SW = listening to the sound of rippling water, R = resting without acoustic stimulation, AUC_I = area under the curve with respect to increase.
Probability value from univariate analysis of variance: [a] RM vs. SW: $p < 0.05$, [b] RM vs. SW: $p < 0.01$, [c] RM vs. SW: $p < 0.1$, [d] RM vs. R: $p < 0.1$

5.3.5 Psychological stress measures (PASA, VAS, STAI-state)

Anticipatory cognitive processes, which were assessed with the PASA prior to and after the experimental and control interventions, significantly changed over time (F(1/55)=18.51; p<0.001). The PASA did not significantly differ between groups (F(2/55)=2.17; p=0.124). The subjective perception of stress during the experiment (VAS) changed significantly over time (F(2.57/141.13)=18.79; p<0.001). The VAS did not significantly differ between groups (F(5.13/55)=0.81; p=0.548). The anxiety (STAI-state) changed significantly during the experiment over time (F(2.9/50)=22.55; p<0.001). The STAI-state did not significantly differ between groups (F(5.79/50)=1.46; p=0.2).

5.4 DISCUSSION

The purpose of the current study was to examine the assumed beneficial effect of listening to relaxing music before a stress task across neuroendocrine, autonomic, cognitive, and emotional domains of the stress experience in healthy female participants in a laboratory setting. It was hypothesized that those participants who listened to relaxing music prior to a stress task would show significantly attenuated stress responses in terms of salivary cortisol, sAA, cognitive appraisal processes, and subjective perception of stress and anxiety in comparison to non-music control groups, i.e. listening to the sound of rippling water and rest without acoustic stimulation. We found that cortisol concentrations differed significantly between groups, with highest values in the music group and lowest values in the control condition who listened to the sound of rippling water. There were no significant differences in the sAA concentrations between groups. Salivary alpha-amylase recovery delta, however, showed a trend toward significance in favor of the music group, whose sAA levels returned to baseline twice as fast as in the two control groups. Psychological measures did not significantly differ between groups during the experiment.

In comparison to both control groups, listening to music prior to an artificially induced stressor resulted in an increase rather than a decrease of stress-induced endocrine activity. The lack of an observed attenuated stress response in terms of salivary cortisol in the music group is consistent with findings by the study conducted by Knight and Rickard (2001). To the best of our knowledge, the investigation by Knight and Rickard is the only laboratory based study to have investigated the influence of music listening before a stressor on the subsequent cortisol response. Their findings were somewhat limited by the fact that there was no cortisol response due to their stressor. It might be because of this lack of a stress-induced HPA axis activation that the researchers did not find any influences of the music intervention. Moreover, the authors examined their participants in small groups (à 6 – 12 participants / intervention), whereas an individual intervention might have been more effective (Pelletier, 2004). The fact that we also did not find an attenuation in cortisol levels due to music listening likely confirms the findings by Knight and Rickard (2001).

The fact that listening to music resulted in a relative increase of the endocrine activity, compared to the control groups indicates that listening to music activates brain regions related to the activation of the HPA axis. Indeed, psychosocial stress and music listening seem to activate similar brain regions, such as the hypothalamus. The hypothalamus regulates neuroendocrine functions due to stimulations to the sensory organs and cerebrum (see Fukui & Yamashita, 2003). Music may, for this reason, affect hypothalamic functions as well. Indeed, the hypothalamus has been found to be activated through listening to music (e.g. Angelucci, Ricci, Padua, Sabino, & Tonali, 2007; Boso, Politi, Barale, & Enzo, 2006; Menon & Levitin, 2005). Accordingly, it might be argued that the relative increase in cortisol through listening to music, compared to both control groups, might be attributable to its activation of the hypothalamus and consequently the HPA axis. However, given the fact that the increase was only of minor magnitude and well within the normal and healthy range, it might be interpreted as beneficial for the subjects. Through an increase in the activation of the neuroendocrine system, music listening might prepare an individual to cope with a stressor more efficiently.

The influence on HPA axis activation through listening to music may depend on the time point of music listening, i.e. before or after a stressor, as the laboratory-based study by Khalfa et al. indicates (Khalfa, Bella, Roy, Peretz, & Lupien, 2003). They found that listening to music following the experience of stress decreased cortisol levels in their subjects. Consequently, it seems that the time point of music listening, i.e. prior to or after the stressor, appears to be crucial for the explanation of how neuroendocrine activation due to stress is changed through music listening. One may conclude that listening to music prior to a stressor increases stress-provoked neuroendocrine activity, whereas listening to music after a stressor decreases it. Nevertheless, the difference in the outcome between the study by

Khalfa et al. and the current study may not be due to the time point of applying music listening, but might be explained by sexual dimorphisms in the neuroendocrine system or reaction in response to music listening (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999; McFarland & Kadish, 1991; Nater, Abbruzzese, Krebs, & Ehlert, 2006; Standley, 1992; Stroud, Salovey, & Epel, 2002), as Khalfa et al. only examined male participants and not female participants as we did. Further studies should investigate the influence of music listening after a stressor also in women in order to exclude sexual dimorphism as an alternative explanation.

Changes in the cortisol levels in the current study were not mirrored in the psychological measures. This result is consistent with previous work. In the study by Scheufele, subjects who could listen to music after the experience of a stressor reported themselves to be more distracted after the stressor regardless of having a lower physiological arousal (i.e. heart rates) in comparison to other control groups (Scheufele, 2000). Self-reports of relaxation also differed from physiological measurements associated with listening to relaxing music in the study by Davis and Thaut (1989). In this study, some subjects who reported feeling relaxed showed decreased heart rates, while others did not. One might conclude that physiological stress responses may not be mediated by cognitive or emotional processes, but may reflect more fundamental biological processes.

Regardless of the significant cortisol responsiveness due to the stress test in all groups over time, our values were, in comparison to other samples, relatively small (e.g. Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999). This may be explained by the fact that we examined female respondents in the follicular phase of the menstrual cycle. In comparison to men, or females in the luteal phase of the menstrual cycle, women in the follicular phase show lower cortisol reaction patterns (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999). Nevertheless, although our sample had comparable cortisol responsiveness to that of the female subjects in the follicular phase in the sample by

Kirschbaum et al., our values were relatively smaller. This may be explained on the one hand by the modification of the standardized stress protocol in the current study, and on the other hand by diverse immunoassays for the biochemical analysis of cortisol used in both studies.

In the current study, we observed faster autonomic recovery in the music group in comparison to control groups 1 and 2. Salivary alpha-amylase levels in the music group returned to baseline levels twice as fast, i.e. 15 min earlier than those of the control groups. Thus, listening to relaxing music prior to a stressor seems to facilitate autonomic recovery from a stressor more efficiently than listening to the sound of rippling water or rest without acoustic stimulation. This finding corresponds to previous investigations, which reported beneficial changes in various autonomic parameters, such as heart rate, blood pressure, or respiration rate, due to music listening (e.g. Knight & Rickard, 2001; Miluk-Kolasa & Matejek, 1996; Nater, Abbruzzese, Krebs, & Ehlert, 2006; Sokhadze, 2007). Moreover, as we were able to show that listening to music, unlike the sound of rippling water, affected autonomic activity, we can conclude that the increased efficiency in the recovery of the ANS is due to listening to music and not to an acoustic stimulation alone. Nevertheless, the fact that this finding in the current study only showed a statistical trend toward significance narrows its implications. Other investigations using ANS indicators derived from plasma, e.g. epinephrine and norepinephrine, also failed to find effects due to music listening (e.g. Migneault et al., 2004; Wang, Kulkarni, Dolev, & Kain, 2002). In conclusion, our results indicate that music listening prior to a stress task may affect ANS indicators differentially.

In the current study, music listening had no differential effect on psychological measures in terms of cognitive appraisal processes, subjective perception of stress, and anxiety compared to listening to the sound of rippling water or resting with no acoustic stimulation. It remains to be explained why we did not find any anxiety-reducing effects of music listening in our participants, as many previous studies were able to show (Labbé, Schmidt, Babin, & Pharr, 2007; Voss et al., 2004; Wang, Kulkarni, Dolev, & Kain, 2002). It might be that the stressor in our study (TSST) was too strong. Music listening might only reduce anxiety in response to a mild stressor. Knight and Rickard (2001), for example, who used a (mild) cognitive stressor in the laboratory, found significant effects of pre-stress music listening on anxiety. Macdonald and colleagues conducted two field studies and found anxiety reductions through music listening only in those patients who had undergone a minor surgery and not in those who had undergone a major surgery (MacDonald et al., 2003). Evans (2002) systematically reviewed studies of the effectiveness of music for patients in hospitals. He found that music listening was effective for the reduction of anxiety during normal care delivery (mild stressor), but not for patients undergoing invasive or unpleasant procedures (strong stressor). One might summarize that music listening might help to reduce anxiety only in the presence of mild stressors.

Our findings need to be considered in the light of the following limitations.

Choice of music stimulus: Standardized music stimuli, as used in the current study, might have a different effect than stimuli chosen by the participants. However, we decided to use a music piece that has already been evaluated as relaxing in previous research (see Nater, Abbruzzese, Krebs, & Ehlert, 2006), as using such a standardized music stimulus is assumed to be more effective in the reduction of stress than music stimuli chosen by the subjects themselves (Pelletier, 2004).

Control stimulus (sound of rippling water): Although a noteworthy strength of the current study lay in its use of two control groups, one might criticize that the sound of rippling water does not constitute a 'neutral' control stimulus, such as (white) noise or the application of pure tones. Given that no study so far has investigated the effect of the sound of rippling water on HPA axis, SNS activity, and cognitive and emotional parameters, the choice of the sound of rippling water was not based on previous research. The sound of rippling water lacks the definitive characteristics of music, but it is an acoustic stimulus with perceptual quality for the listener. Moreover, unlike artificially produced sounds, such as (white) noise or only tones, the sound of rippling water can be listened to for extended periods of time

(McFarland & Kadish, 1991). Furthermore, using (white) noise instead of the sound of rippling water as the ‘neutral’ acoustic stimulus did not seem appropriate, as white noise can induce stress in rats when applied loudly (Rex, Voigt, & Fink, 2005). Listening for 10 minutes to white noise may also induce stress in humans.

Sample: The use of only healthy young female participants, who were non-smokers, did not take any oral contraceptives, and who were in the follicular phase of the menstrual cycle, restricts the generalization of the results beyond this particular sample. The exclusion of probable confounding variables improves the internal validity at the expense of the external validity. Further research should also investigate men, and a mixed sample of men and women with more liberal inclusion criteria, to enable general conclusions to be drawn.

In conclusion, the findings of the present study demonstrate that listening to relaxing music prior to a stress task differentially affects subsequent stress response domains. Listening to relaxing music does not attenuate the neuroendocrine stress response domain, but tends to increase it. Moreover, concerning the SNS activation, music listening helps subjects to recover from a stressor more efficiently. Cognitive (cognitive appraisal processes and subjective perception of stress) and emotional (anxiety) processes are not influenced by listening to relaxing music in a different way than by listening to the sound of rippling water, or resting with no acoustic stimulation. As a consequence, our findings do not fully support the notion of applying music listening prior to a stressor as a successful stress management tool. The implications of the small increase in HPA axis activation, indexed by salivary cortisol and the faster recovery in SNS, in terms of sAA, through the listening to relaxing music as an assumed beneficial effect should be further studied. Finally, studies are needed to replicate our findings and reveal the relevance of listening to the sound of rippling water to attenuate basal, i.e. neuroendocrine stress response. Our findings may help to elucidate the underlying mechanisms of the effectiveness of music interventions by showing that music listening differentially impacts the psychobiological stress system.

6 GENERAL DISCUSSION

This project about the psychobiological mechanisms of the effectiveness of music interventions consisted of two studies, an online survey and an experimental, laboratory-based study. The key findings of the two empirical studies (study I and study II) will be briefly summarized below. Subsequently, the theoretical implications of the data reported will be discussed and limitations of the presented studies will be outlined. Finally, suggestions for implications and directions for future studies will be presented.

6.1 SUMMARY OF THE RESULTS OF STUDY I AND STUDY II

In this section, the key findings of the two empirical studies (study I and study II) will be briefly summarized.

6.1.1 STUDY I: ‘Does listening to music improve health? – A structural equation model in healthy individuals’

Using an internet-based survey, we set out to examine the assumed beneficial association between the general music-listening behavior and various health parameters. Potential mediating variables, such as dispositional emotion regulation processes and individual stress reactivity, were considered. Quantitative aspects of music-listening behavior, i.e. average duration of music listening or subjective relevance of music, were not associated with health status. In contrast, qualitative aspects of music-listening behavior, i.e. reasons for listening to music (especially ‘reducing loneliness and aggression’, and ‘arousing or intensifying specific emotions') play a much more crucial role. These effects were mediated by distress-augmenting emotion regulation and individual stress reactivity. Consequently, individuals use music differentially, depending on their habitual way of regulating their emotions and on their individual susceptibility to stress. Accordingly, music listening might be more systematically used in therapeutic settings, thus enhancing its clinical relevance.

6.1.2 STUDY II: 'The effect of music on acute neuroendocrine, autonomic, cognitive, and emotional stress responses'

The aim of the second study was to examine the underlying mechanisms of the effectiveness of listening to music across neuroendocrine, autonomic, cognitive, and emotional domains of the human stress response, in the context of a rigorously controlled laboratory study. Sixty healthy female volunteers were exposed to a standardized stress test after being randomly assigned to one of three different conditions prior to the stress test: 1) relaxing music ('Miserere', Allegri), 2) sound of rippling water, and 3) rest without acoustic stimulation. The stress test induced significant changes over time on all measured parameters. The three conditions differed significantly regarding cortisol responses; highest values were observed in participants who listened to music prior to the beginning of the actual stress test and lowest values were found in those who were listening to the sound of rippling water. sAA recovery delta showed a statistical trend in favor of the music group. Psychological measures did not significantly differ between groups during the experiment. In summary, listening to music prior to a psychological stress test increases rather than attenuates subsequent psychological and endocrine stress responses. Moreover, listening to music seems to increase autonomic recovery more efficiently than listening to the sound of water or resting in silence. Finally, listening to music does not seem to influence stress-induced cognitive and emotional processes differently than listening to the sound of rippling water or resting with no acoustic stimulation. Consequently, the findings suggest a differential impact of listening to music on the psychobiological stress system.

6.2 INTEGRATION OF CURRENT FINDINGS INTO THE THEORETICAL BACKGROUND

In the following section, the main findings of the two empirical studies that were presented in the current thesis will be embedded into the theoretical background (chapter 2).

Many previous studies have reported that listening to music may lead to short-term (e.g. Bulfone, Quattrin, Zanotti, Regattin, & Brusaferro, 2009; Roy, Peretz, & Rainville, 2007; Voss et al., 2004) and long-term (e.g. Angelucci, Ricci, Padua, Sabino, & Tonali, 2007; McKinney, Antoni, Kumar, Tims, & McCabe, 1997; Särkämö et al., 2008; Teng, Wong, & Zhang, 2007) beneficial effects. It was therefore assumed that habitual music-listening behavior is also associated with health indicators. However, we found no positive associations with any aspect of the habitual music-listening behavior and health indicators. Only negative associations between specific reasons for listening and health indicators were observed.

This finding does not appear to be in line with previous research (Mitchell, MacDonald, Knussen, & Serpell, 2007). Mitchell et al. reported repeated music listening and subjective importance of music to be associated with enhanced quality of life and reduced requirement of medical treatment. However, the discrepancy between our findings and those of Mitchell et al. may be primarily attributable to the different health status between these samples (healthy respondents and chronic pain sufferers, respectively). Moreover, our sample showed high mean ratings in subjective relevance of music with only few variations. Accordingly, it is assumed that due to a ceiling effect, possible interrelations between subjective importance of music and health indicators were masked. Differences in health status and related different lifestyles presumably lead to a different music-listening behavior and thus to different associations between various aspects of this behavior and health indicators. This interpretation is supported by the observation of a relatively low correspondence in the mean ratings for listening to music between our sample (healthy adults), the sample by Mitchell et al. (chronic pain sufferers), and another sample consisting of adolescents (North, Hargreaves, & O'Neill, 2000).

We documented negative associations between specific reasons for music listening, related to coping with or avoiding negative emotions (loneliness, aggression), and health indicators. Despite the fact that we did not assess these feelings per se, we might assume that those respondents who reported listening to music in order to reduce loneliness or aggression may also experience these feelings more often. Loneliness (and the related social isolation), as well as aggression have previously been associated with various health issues (e.g. Cacioppo & Hawkley, 2003; Cole, 2008; Hawkley, Thisted, & Cacioppo, 2009; Johnson, 1990; Lauder, Mummery, Jones, & Caperchione, 2006; Peel, McClure, & Bartlett, 2005; Raine, 2002; Reynolds & Kaplan, 1990). Our findings of negative associations between reasons for listening to 'reduce loneliness or aggression', as indirect indicators of loneliness and aggression, respectively, and health indicators are therefore in line with previous studies.

The finding of a direct negative association between the reasons for listening for 'arousing and intensifying specific feelings' and health indicators may only be interpreted when the mediating variables, i.e. distress-augmenting regulation and individual stress reactivity, are taken into account. Distress-augmenting regulation describes the disposition of an individual to intensify negative emotions (Mohiyeddini, 2005). Accordingly, it is assumed that individuals who have the disposition to intensify negative emotions also listen to music with the purpose of arousing or intensifying *negative* emotions. Individual stress reactivity describes the disposition of an individual to respond to stressors with immediate, strong, and long-term stress reactions (Schulz, Jansen, & Schlotz, 2005). Hence, we assume that respondents with this disposition also experience emotions associated with stress more often (such as anxiety or anger) and consequently preferentially listen to music with the purpose of arousing or intensifying these emotions. The prolonged experience of negative emotions as well as stress experience are associated with poor health (e.g. Esch, Stefano, Fricchione, &

Benson, 2002a; 2002b; 2002c; Frasure-Smith, Lespérance, & Talajic, 1995; Kubzansky & Kawachi, 2000; Watson & Pennebaker, 1989). Thus, the negative association between the reason for listening for 'arousing and intensifying specific feelings' and health indicators can be explained by the mediating influences of distress-augmenting emotion regulation and susceptibility to stress, and is thus in line with previous research.

The purpose of the first study was to reveal associations between various aspects of music-listening behavior and health indicators in an exploratory manner, and thus fill the gap in the literature regarding what mediates the purported beneficial effect of music. Despite the fact that we found that listening to music is an essential part and parcel of the everyday lives of most respondents (indicated by the high mean values in the subjective significance of music and duration of listening (3.35 h / day)), associations between music and health are not as obvious as initially assumed. Music-listening behavior seems to be a complex behavior that might consist of various different components. Moreover, given the mediating effect of dispositions that are generally not associated with music-listening behavior, it might be assumed that other variables (e.g. personality factors (e.g. Chamorro-Premuzic, Swami, Furnham, & Maakip, 2009)) also influence this behavior and, thus, its association with health indicators. Furthermore, health indicators are also influenced by various other habitual behaviors, such as physical exercise or diet (e.g. Bucksch & Schlicht, 2006; Cordain et al., 2005; Lee & Buchner, 2008; Waddington, Malcolm, & Green, 1997). To conclude, the association between music and health is influenced by a multitude of different factors. Nonetheless, the fact that we found some associations might be an indicator that music listening might indeed have an impact on health.

This conclusion from the observed results, as well as the awareness gained of the mediating mechanisms obtained in the first study, were acknowledged and accordingly incorporated in the second, i.e. the main study of this thesis. In this study, the focus was shifted to physiological stress measures. By overcoming major methodological and conceptual shortcomings of previous studies, we conducted a study using a design that allowed us to give a comprehensive answer to the question of whether listening to music has a beneficial impact on the human stress response. Furthermore, it allowed us to elucidate underlying psychobiological mechanisms of the effectiveness of music interventions.

Our main finding of a relative increased stress-induced cortisol response in the music group, in comparison to both control groups, represents a novel finding that has not yet been reported in the previous literature. The only other study that examined the purported stress-reducing effect of music listening reported no particular influence of music on the subsequent endocrine activity (Knight & Rickard, 2001). However, due to several limitations of that study, such as the application of a non-valid stressor and the use of an inappropriate intervention setting (see Pelletier, 2004), possible changes due to music listening could not have been detected. Consequently, our findings confirm but also extend the findings by Knight and Rickard (2001) by showing that music listening prior to a stressor (in comparison to both control groups) does not attenuate the subsequent endocrine activity but actually increases it.

The differing influence of music and the sound of rippling water on stress-induced endocrine activity points toward the evidence that mechanisms other than a merely acoustic stimulation are responsible for these effects. The use of a control acoustic stimulus that is lacking the typical characteristics of music (see chapter 2.1.1) allowed us to draw specific conclusions on the underlying mechanisms of the effectiveness of music listening. It may be concluded that the effect of music is not due to a merely acoustic *distraction* effect, as was suggested by other investigators (e.g. Mitchell, MacDonald, & Brodie, 2006; Pothoulaki et al., 2008). Moreover, given the fact that both stimuli were comparably positively evaluated, it can be concluded that it was not the 'liking'-factor causing relaxation, as proposed by previous studies (e.g. Allen & Blascovich, 1994; Labbé, Schmidt, Babin, & Pharr, 2007; Siedliecki & Good, 2006; Stratton & Zalanowski, 1984). Furthermore, as both acoustic stimuli were perceived as relaxing, the differing effect on cortisol levels was not due to the effect of (self-reported) relaxation, as was recently proposed by Pothoulaki et al. (2008).

Finally, the fact that listening to music resulted in a relative increase of the endocrine activity, compared to the control groups, indicates that listening to music activates brain regions related to the activation of the HPA axis. Indeed, following brain systems, which are broadly interconnected, are recruited when listening to (pleasant) music: VTA, thalamus, hypothalamus, hippocampus, amygdala, prefrontal cortex, orbitofrontal cortex, midbrain/PAG, insula, and NAc (Blood & Zatorre, 2001; Blood, Zatorre, Bermudez, & Evans, 1999; Brown, Martinez, & Parsons, 2004; Menon & Levitin, 2005). This indicates that listening to music may activate similar brain regions to psychosocial stress, such as the hypothalamus, which exerts control over and regulates the hormonal release in the pituitary glands in response to stimulations to the sensory organs and cerebrum (for an extensive overview see Fukui & Yamashita, 2003). Accordingly, it might be argued that the relative increase in cortisol through listening to music, compared to both control groups, might be attributable to its activation of the hypothalamus and consequently the HPA axis. Listening to music prior to the induction of psychosocial stress might therefore add to, facilitate, or increase subsequent stress induction of HPA axis activation. However, as the increase was only of minor magnitude and well within the normal and healthy range, it might be interpreted as beneficial for the subjects. Through an increase in the activation of the neuroendocrine system, music listening might prepare an individual to cope with a stressor more efficiently. However, further research is warranted to determine whether this effect is specific to music listening or might also be obtained by other stimuli.

Moreover, it seems that depending on the time point of listening to music, i.e. before or after a stressor, the HPA axis is differentially affected. Listening to music (compared to silence) following a stressor was found to decrease cortisol levels faster, and thus may help to facilitate recovery of the organism (Khalfa, Bella, Roy, Peretz, & Lupien, 2003). However, the underlying mechanism for this differential effect on neuroendocrine activity due to the time point is unclear. Nevertheless, due to sex differences between the sample by Khalfa et al. (males) and our sample (females), it might be assumed that the difference is not due to the time point but may be better explained by the influence of sexual dimorphisms in the neuroendocrine system (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999; McFarland & Kadish, 1991; Nater, Abbruzzese, Krebs, & Ehlert, 2006; Standley, 1992; Stroud, Salovey, & Epel, 2002). Further studies should investigate the influence of music listening after a stressor also in female subjects so as to exclude sexual dimorphism as an alternative explanation.

The cortisol responsiveness in our sample was smaller in comparison to other samples (e.g. Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999). This may be explained by the following factors: 1) We examined female respondents in the follicular phase of the menstrual cycle. In comparison to men, or women in the luteal phase, women in the follicular phase of the menstrual cycle show lower cortisol reaction patterns (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999). 2) We modified the standardized stress protocol. In the Intro to the TSST, our subjects were not told about the nature of the upcoming speech, in order to avoid cognitive preparation for it. Otherwise, listening to music might have distracted our subjects in the cognitive anticipation phase and thus might have been perceived as stressful. Given the significant cortisol responses due to the stress test in all groups over time, the stress test was still successful in terms of cortisol responsiveness. 3) We applied a different immunoassay for the biochemical analysis for cortisol in comparison to Kirschbaum et al. (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999). It might be assumed that the smaller values in cortisol in our sample, in comparison to the female subjects in the follicular phase of Kirschbaum et al., were due to different applied immunoassays (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999).

The finding of a faster autonomic recovery in terms of sAA in the music group corresponds to previous investigations, which reported beneficial changes in various other autonomic parameters, such as heart rate, blood pressure, or respiration rate, due to music listening (e.g. Knight & Rickard, 2001; Miluk-Kolasa & Matejek, 1996; Nater, Abbruzzese, Krebs, & Ehlert, 2006; Sokhadze, 2007). No other previous study has investigated the influence of music listening on stress-induced sAA levels. However, our finding of a faster recovery in the music group represents only a statistical trend towards significance, which narrows its implications. Other investigations using ANS indicators derived from plasma, such as epinephrine and norepinephrine, did not find effects due to music listening either (e.g. Migneault et al., 2004; Wang, Kulkarni, Dolev, & Kain, 2002). Consequently, it might be assumed that different ANS parameters are differentially affected by effects of listening to music.

In contrast to many previous studies (e.g. Labbé, Schmidt, Babin, & Pharr, 2007; Voss et al., 2004; Wang, Kulkarni, Dolev, & Kain, 2002), we did not observe an anxiety-reducing effect of music in our participants. Because the anxiolytic effect of music represents the most consistent finding concerning the effectiveness of music listening in previous literature, our finding remains to be explained. It is proposed that our stress test (TSST) was too strong. Music listening might only be effective in decreasing anxiety levels due to mild stressors, such as minor surgeries or cognitive stress tests (in laboratory) (e.g. Knight & Rickard, 2001; MacDonald et al., 2003). Evans (2002) found in his review that music listening was effective for the reduction of anxiety during normal care delivery (mild stressor), but not for patients undergoing invasive or unpleasant procedures (strong stressor).

Another possible explanation for our result is provided by the findings of Chikahisa et al. (Chikahisa, Sano, Kitaoka, Miyamoto, & Sei, 2007), who reported that the anxiety-reducing effects of the exposure to music are mediated by progesterone in female mice (Chikahisa, Sano, Kitaoka, Miyamoto, & Sei, 2007). The authors consequently suggested anxiolytic treatment with music in the luteal phase of the menstrual cycle in women (high progesterone levels). As we investigated women in the follicular phase (low progesterone levels), the reason why we did not find an anxiety-reducing effect through listening to music may also be due to low progesterone levels. Further research should investigate the anxiolytic effect of music listening in women, both in the follicular and luteal phase of the menstrual cycle so as to exclude low progesterone levels as the explanation of the missing effect of listening to music on anxiety.

Finally, psychological measures in terms of cognitive appraisal processes, and subjective perception of stress, did not significantly differ between groups during the experiment. Previous data on the beneficial effect of music listening on stress-induced cognitive components is limited and inconsistent. Whereas some studies found positive effects on cognitive parameters (e.g. Allen et al., 2001; Burns et al., 2002), others did not (e.g. Scheufele, 2000). Consistent with previous work, we found that physiological and psychological measures do not correspond with each other (Davis & Thaut, 1989; Scheufele, 2000). We found that the emotional and cognitive experiences of individuals were less affected by listening to music than their physiological arousal. One might conclude that physiological stress responses may not be mediated by cognitive or emotional processes, but may reflect more fundamental biological processes.

6.3 METHODOLOGICAL CONSIDERATIONS

6.3.1 Methodological limitations of the empirical study I

In the first study, we applied a web-based data collection methodology, which entails many advantages, such as anonymity and convenience for the respondents, as well as a fast and cost-efficient access to a broad and homogenous population. However, this method also brings with it several shortcomings, such as self-selection bias and low response rates. Furthermore, due to the limited representativeness of our sample (young academic adults), generalizations beyond this sample are restricted. Furthermore, given the fact that our study is based on a cross-sectional design, we were only able to reveal associations between the variables of interest and were unable to draw any conclusions on causal interpretations of the present results.

6.3.2 Methodological limitations of the empirical study II

The second study was based on more restrictive selection criteria. The exclusion and control of probable confounding variables improves the internal validity, but at the expense of external validity. The current findings describe the psychobiological stress response of healthy young female participants, who were non-smokers, did not take any hormonal contraceptives, and were in the follicular phase of the menstrual cycle. Whether our results can be generalized beyond this particular sample, e.g. to the female population as a whole, to men or older subjects, needs to be subject to further investigation. Additionally, the use of a different stressor may have led to different results, since the type of stress essentially modulates the psychobiological stress reaction (Kudielka, Hellhammer, & Wüst, 2009).

The choice regarding the music stimulus was essential in this investigation. There is some controversy concerning the choice of music stimuli; should stimuli be selected based on previous research or should participants be allowed to bring their own music (i.e. self-preferred)? Depending on the choice, this might affect the psychological and physiological response of the individual. As we were conducting a laboratory-based study, with a focus on the underlying mechanisms of the *pure* effect of music on stress parameters, we decided to use a standardized music stimulus (Nater, Abbruzzese, Krebs, & Ehlert, 2006), for several reasons. First, standardized music stimuli have been shown to display more influence on stress reduction (Pelletier, 2004). Second, we wanted to exclude confounding influences such as associations and memories elicited by self-selected music, as listening to music has been found to be linked to memory systems (e.g. Särkämö et al., 2008). It might be assumed that listening to music is efficient because it is a commonly used means to elicit pleasant memories and associations, and thus increases positive emotions and mood. It can be argued, though, that we might have excluded an important aspect of general music-listening behavior and thus of its effectiveness on psychological and physiological parameters in individuals. Although a study by Labbé et al. reported no differences in the effects of experimenter-provided and self-selected music (Labbé, Schmidt, Babin, & Pharr, 2007), more rigorously controlled laboratory-based studies should compare differently selected stimuli and their effectiveness.

Finally, it might be argued that our control acoustic stimulus, i.e. the sound of rippling water, does not constitute a ‘neutral’ control stimulus, such as white or pink noise. However, give the fact that white noise has been shown to induce stress in rats (e.g. Rex, Voigt, & Fink, 2005), it was assumed that listening for ten minutes to white noise would also induce stress in humans. To control for effects that were due to a merely acoustic stimulation, we decided to use a non-music stimulus that can be presented for extended periods of time. However, this might have come at the cost of the ‘neutrality’ of the control stimulus.

6.4 IMPLICATIONS AND DIRECTIONS FOR FUTURE STUDIES

These are the first studies to investigate the association between music listening and health indicators under consideration of predicted mediating mechanisms in a first step and, in a second step, the assumed stress-reducing effect of listening to relaxing music in a rigorously controlled experiment in a laboratory setting. The present data suggest that associations between music and health are not obviously connected and additionally, mediated by dispositions that are commonly not associated with music-listening behavior. Further, our findings indicate that listening to music differentially impacts the psychobiological stress system.

The detection of mediating variables in the association between music and health is a novel finding. With this, we have identified essential mechanisms that have been neglected in past studies. In order to achieve a better understanding of the exact mechanisms responsible for the lack of positive associations between music and health in the current study, further studies are needed to also investigate other dispositions or traits that might also be relevant in mediating music listening and health, such as personality traits (Chamorro-Premuzic, Swami, Furnham, & Maakip, 2009). Probably, only a broadly constructed prospective study design, i.e. a longitudinal correlational study, which controls for a multitude of influencing variables, might give a comprehensive answer to the question of whether listening to music does have a positive impact on health.

Furthermore, the implications of the small increase in HPA axis activation, indexed by salivary cortisol and the faster recovery in SNS, in terms of sAA, through listening relaxing music as an assumed beneficial effect should be further studied.

Moreover, studies are needed to reveal the relevance of listening to the sound of rippling water. Given the observation of a small attenuation of neuroendocrine stress response through listening to the sound of rippling water, in comparison to the control group with no acoustic stimulation, it is assumed that brain areas or specific neuronal mechanisms are activated that might be related to attenuating or inhibiting HPA axis activation. Consequently, functional brain imaging studies are warranted to reveal the neuronal processing of the sound of rippling water.

To compare possible sex-specific physiological and psychological reaction patterns following listening to music, studies including both men and women are necessary. Ideally, these studies should also examine women in the luteal phase of the menstrual cycle to reveal whether progesterone and its metabolites might indeed be relevant in mediating the anxiolytic effect of music exposure, as proposed by Chikahisa et al. (Chikahisa, Sano, Kitaoka, Miyamoto, & Sei, 2007).

Finally, although the decision to use a standardized music stimulus was based on conceptual and empirical implications in the current study, future studies should replicate our results by using a different music stimulus. This would reject the argument that our findings are exclusive to the particular music stimulus we were applying and consequently not generalizable. It might be assumed that listening to self-selected, i.e. individually preferred music would exert different effects on stress-induced physiological and psychological parameters. However, this hypothesis remains to be tested.

The results of the studies presented may help to elucidate the underlying mechanisms of the effectiveness of music interventions and thus may be more systematically used in therapeutic settings to consequently enhance their clinical relevance.

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