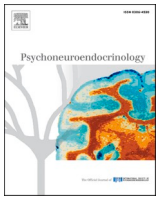
Psychoneuroendocrinology 158 (2023) 106381

Contents lists available at ScienceDirect

Psychoneuroendocrinology

journal homepage: www.elsevier.com/locate/psyneuen



Effects of participant-selected versus researcher-selected music on stress and mood – The role of gender

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ARTICLE INFO

Keywords:
Stress
Mood
Participant-selected music
Researcher-selected music
Emotions
Emotion regulation strategies

ABSTRACT

Objective: Previous research suggests differential effects of participant-selected (PS) vs. researcher-selected (RS) music on emotional responses to music listening. This study investigates whether such selection strategies, as well as gender, influence (1) stress and (2) mood responses. Additionally, we examine the role of (3) stimulus-induced emotions and (4) emotion regulation strategies.

Methods: Participants ($N = 61$) listened to auditory stimuli (PS music, RS music, sound of lapping water (LW); randomized) on three days and underwent a cold pressor test (CPT) while listening. Stress parameters (subjective acute stress, heart rate, parameter RMSSD, salivary alpha-amylase, salivary cortisol), mood dimensions (calmness, valence, energetic arousal), emotions, and emotion regulation strategies were measured. Multilevel and mediation analyses were conducted.

Results: (1) There were no direct effects of selection strategy or gender on stress responses, but interaction effects indicated that women showed the strongest subjective stress response and the longest HR recovery with PS music, while men showed the lowest HR response to the CPT with PS music. (2) No mood differences emerged between PS and RS music overall. Women showed stronger variability in calmness overall as well as perceived higher arousal when listening to PS music compared to men. (3) Higher stimulus-induced anger in men compared to women and with LW compared to PS was associated with lower calmness and valence, while no consistent pattern emerged for the stress responses. (4) Women scored higher on reappraisal, associated with a decrease in parasympathetic activity, whereas men scored higher on suppression, associated with an increase in endocrine activity.

Conclusions: Music selection and gender appear to have no direct impact on stress and mood responses overall, although men tend to benefit more from self-selected music than women. Our findings provide first indications that avoiding music stimuli that induce anger may facilitate mood management via music. Furthermore, finding alternative emotion regulation strategies to the strategy of suppression may be a helpful approach to improve music-based stress management.

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https://doi.org/10.1016/j.psyneuen.2023.106381
Received 14 February 2023; Received in revised form 21 July 2023; Accepted 3 September 2023
Available online 4 September 2023
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Konstanzer Online-Publikations-System (KOPS)
URL: http://nbn-resolving.de/urn:nbn:de:bsz:352-2-1ajfhi7qnlyff2

1. Introduction

Stress is a risk factor for various diseases (VanItallie, 2002), associated with psychosocial and economic costs (Kalia, 2002). Music listening as an easily applicable option for stress reduction (De Witte et al., 2020a) can affect both subjective stress and physiological systems (Chanda and Levitin, 2013). Psychobiological stress is associated with changes in mood[1] (Koelsch et al., 2016), and mood can also be influenced by music (Chanda and Levitin, 2013; Västfjäll, 2001). However, it is unclear which music-related characteristics are particularly beneficial for stress and mood management. Identifying these factors is essential to understand the mechanisms involved, which is necessary to develop interventions that can improve patient well-being in the long term.

1.1. Participant-selected (PS) versus researcher-selected (RS) music

PS music is suggested to yield stronger health benefits than RS music (Nilsson, 2008). A meta-analysis revealed that in clinical settings, PS music reduces pain and anxiety more than RS music, but no differences in parameters of the autonomic nervous system (ANS) were found (Vetter et al., 2015). However, as Linnemann et al. (2015) reported the strongest stress-reducing effects of PS music when participants selected relaxing music, specifically relaxing PS music might be especially effective for stress management. Accordingly, sedative music was shown to lower tension and physiological responses more than excitative music, and participants' preferred music lowered subjective tension (Iwanaga and Moroki, 1999). As participants showed highly different mood states in response to the same music (Carter et al., 1995), individualizing music also appears essential for mood improvement. Relaxing PS music may therefore also benefit mood management.

1.2. Music-induced emotions

Music listening affects emotions (Koelsch, 2020), which play a crucial role in music-based stress (De Witte et al., 2020a) and mood management (Van Kleef et al., 2011). Previous research by our team revealed stronger stimulus-induced joy for PS music compared to RS music and a control stimulus (Maidhof et al., submitted). Similarly, using music for emotion regulation has been shown to work best for individually preferred familiar music (Moore, 2013). As music-induced emotions can influence stress (De Witte et al., 2020a) and mood (Van Kleef et al., 2011), induced emotions might mediate the effects of music on stress and mood.

1.3. Gender

Women have shown stronger stress decreases than men in response to potentially less aversive music (Gupta and Gupta, 2016; McFarland and Kadish, 1991; Wuttke-Linnemann et al., 2019), but also increased stress sensitivity to aversive music (Nater et al., 2006). Considering the benefits of relaxing music for stress reduction (Linnemann et al., 2015) and the potential superiority of PS over RS music, women might experience stronger stress reduction than men when exposed to relaxing music, especially when they have selected it themselves. Similarly, in a study using uplifting PS songs to induce positive mood and depressing PS songs to induce negative mood, women showed stronger effects of music on mood compared to men (Sleigh and McElroy, 2012). Women might therefore also show stronger music-induced mood responses to relaxing music.

Despite some conflicting evidence (Robazza et al., 1994), gender differences in emotional responses to music are often observed (Hunter et al., 2011). Our aforementioned previous study revealed that women liked presented music more than men, reported lower arousal, less disturbance, higher concentration and less stimulus-induced anger (Maidhof et al., submitted). As music might lead to stronger affective responses (Gupta and Gupta, 2016; Sleigh and McElroy, 2012) and stress changes (Gupta and Gupta, 2016; McFarland and Kadish, 1991; Nater et al., 2006) in women compared to men, and assuming that music-induced emotional responses in turn influence stress (De Witte et al., 2020a) and mood (Van Kleef et al., 2011), we propose that women show stronger music-induced emotions than men, and that music-induced emotions mediate the effects of gender on mood and stress.

1.4. Emotion regulation strategies

The link between stress and emotion regulation is well established, with effective emotion regulation aiding stress management and inadequate regulation enhancing stress (Wang and Saudino, 2011). The question therefore arises whether interindividual differences in emotion regulation strategies are accompanied by differences in stress and mood. Studies on gender differences in emotion regulation often concentrate on two common strategies: reappraisal and suppression. Reappraisal involves altering cognitive perception of emotion-eliciting situations, while suppression entails inhibiting emotional and behavioral responses (Gross and John, 2003; Masumoto et al., 2016). Research suggests that women tend to use reappraisal more than men (Spaapen et al., 2014), while men tend to use suppression more than women (Balzarotti et al., 2010; Gross and John, 2003; Spaapen et al., 2014). Trait reappraisal has been negatively associated with cortisol, heart rate, and state anxiety, and positively with euphoria (Carlson et al., 2012). Conversely, suppression has been linked to increased distress (Iwamitsu et al., 2005; Szentagotai, 2006), sympathetic arousal (Tamagawa et al., 2013), and mood disturbance (Iwamitsu et al., 2005). Carlson et al. (2012) found that trait suppression was positively correlated with state euphoria, but this correlation diminished when controlling, amongst others, for gender – which emphasizes the importance of gender for the effects of emotion regulation on mood. Considering that women use more often reappraisal than men and men use more often suppression, while at the same time reappraisal is negatively and suppression is positively associated with stress reactivity, we suggest that trait emotion regulation strategies may mediate the effects of gender on stress and mood.

1.5. Research aims

This study aims to investigate whether relaxing PS music reduces stress and enhances affective states to a greater extent than RS music and a control condition, and whether these effects are modulated by gender. Additionally, we investigate the role of stimulus-induced emotions and emotion regulation strategies. Detailed hypotheses are listed in Table 1. We assume that (1) music selection source and gender influence stress responses and (2) mood responses, (3) these effects are mediated by stimulus-induced emotions, and (4) emotion regulation strategies mediate the effects of gender on stress and mood.

2. Methods

2.1. Participants

Data for this study were collected as part of a broader project, which includes also a previous investigation on effects of music listening style on pain (Maidhof et al., submitted). On three days in the laboratory, participants listened to one of three auditory stimuli (PS music, RS music, sound of lapping water (LW)) in a randomized order, while undergoing a cold pressor test (CPT; see Fig. 1). The CPT was used to induce stress and pain, but pain was only investigated in our previous study (Maidhof et al., submitted). The laboratory investigations took

[1] In the current study, following the terminology by Västfjäll (2001), "mood" describes a state of general, low-intensity subjective feeling, while "emotion" describes a more intense, short-lived reaction to an event.

Table 1
Detailed hypotheses.

Research questions	Detailed hypotheses
1. Does relaxing PS music reduce stress to a greater extent than RS music and a control condition?	1. a) PS music reduces stress-induced psychobiological responses to a greater extent than RS music and a control stimulus. b) Music listening exerts stronger stress-reducing effects in women than in men, c) especially when listening to PS music.
2. Does relaxing PS music enhance affective states to a greater extent than RS music and a control condition?	2. a) PS music enhances mood responses to a greater extent than RS music and a control stimulus. b) Women show stronger music-induced mood responses than men, c) especially when listening to PS music.
3. What role do music-induced emotions play in the effects of music and gender on stress and mood?	3. a) Women show stronger music-induced emotions than men, and PS music induces stronger emotions than RS music and a control stimulus. The induced emotions mediate b) the effects of gender on stress and mood, and c) the effects of PS music, RS music and a control condition on stress and mood.
4. What role do emotion regulation strategies play in the effects of gender on stress and mood?	4. a) Men and women differ in their emotion regulation strategies, with men more frequently using the emotion regulation strategy of suppression and women more frequently using the emotion regulation strategy of reappraisal. b) The emotion regulation strategies mediate the effects of gender on stress and mood.

place between 11:30 and 18:00. The study was approved by the ethics committee of the University of Marburg (Department of Psychology, reference number 2014–25k) and was conducted in accordance with the Declaration of Helsinki. Participants were recruited through electronic mailing lists, internet platforms, and flyers.

The study included individuals with different music listening styles (Kreutz et al., 2008), categorized as showing either more emotional or more structural processing of music. Music listening styles were investigated in a previous study (Maidhof et al., submitted). Using the MEMS Inventory (Linnemann et al., 2018), 15 men and 16 women were selected to show rather emotional music processing, while 15 men and 15 women were selected to show rather structural music processing. In addition, the following inclusion criteria were applied: fluency in German, age 18 – 35 years, body mass index (BMI) of < 30, no chronic physical disease, no hearing or severe visual impairment, no current psychological disorder, no medication intake or treatment with psychophysiological impact (the use of oral contraceptives was monitored and not used as an exclusion criterion), smoking fewer than five cigarettes per week, no illegal drug consumption, no menstrual irregularities, no pregnancy, no breastfeeding, no profession associated with music. Participation was voluntary. All participants provided informed consent. As reimbursement, participants received 40 euros or course credit.

The sample size was set based on the main research questions of the broader project of which this study is a part. For the previous paper of the project (Maidhof et al., submitted), a sample size of 61 participants was required (see supplement – S1). For the analyses of the current paper, the following reasoning applied: Assuming a medium effect size of $f^2 = 0.15$ - based on meta-analyses showing medium effect sizes for the impact of music on stress parameters (De Witte et al., 2020b; Pelletier, 2004) -, a power of. 80, three predictors (condition, gender, time), an alpha level of. 05 and the statistical model of multilevel analyses, the minimum sample size was 56 subjects (Soper, 2012). The sample size that was used for the current analyses (61 participants due to the requirements of the previous paper) is also similar to previous studies on the effects of music on stress and mood (Linnemann et al., 2016; Thoma et al., 2013). However, it should be noted that investigating underlying mechanisms (music-induced emotions, emotion regulation strategies)

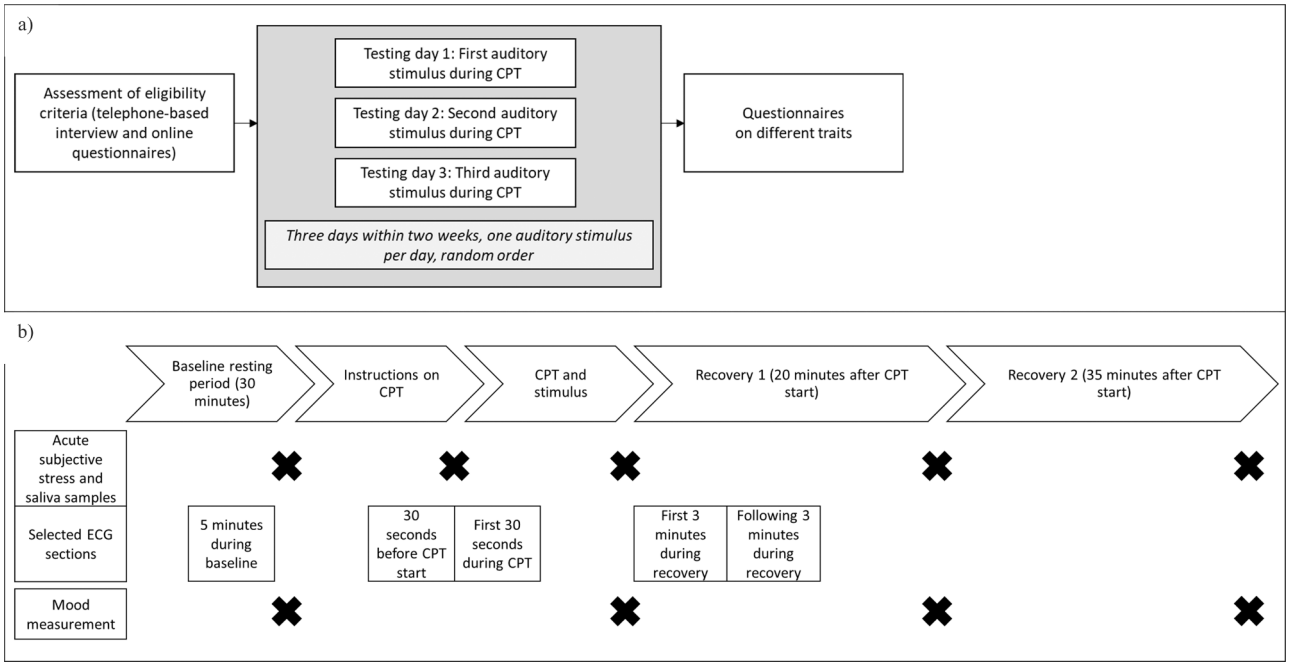

Fig. 1. Study procedure. Note. a) Overall study procedure. b) Procedure on one testing day. CPT = cold pressor test; ECG = electrocardiogram. The crosses represent the times at which acute subjective stress, saliva samples and mood parameters are measured. ECG parameters are examined during selected time periods. This basic procedure is the same during each of the three testing days. Only the auditory stimulus of the single conditions differs.

was not considered when determining the sample size (see also 4.5 Limitations).

2.2. Protocol

A two-step screening process was conducted: Participants were interviewed by phone to assess general eligibility (step 1), received an email with detailed study descriptions, and were instructed about the music to bring. The day before the first laboratory appointment, they completed online screening questionnaires, including the German Patient Health Questionnaire (PHQ-D; Löwe et al., 2002) to screen participants' mental health and eligibility criteria in detail (step 2).

In the laboratory, participants were not permitted to eat (for further instructions see supplement – S2). Electrocardiography (ECG) was measured using the programs Equivital™ EQ-02 (Hidalgo Limited, Cambridge, UK) and VivoSense for Windows (version 2.8; Vivonetics, San Diego, CA, USA). R waves and artefact regions (HR $>$ 220 or $<$ 30 bpm) were detected by algorithms. ECG sections were additionally manually corrected. Interpolations were performed for artifacts of a maximum of three R waves length. Investigated parameters were heart rate (HR), which is influenced by parasympathetic and sympathetic activity, and parameter RMSSD, which indicates parasympathetic activity (Kleiger et al., 1992). Five time slots were investigated: a baseline (BL) period (five minutes) during a 30 min resting phase, an anticipation period (30 s) before the CPT, the first 30 s during the CPT, and two successive time slots (three minutes each) during the recovery after the CPT.

Following the BL resting phase of 30 min, a saliva sample was taken using SaliCaps (IBL, Hamburg, Germany) for investigating salivary alpha-amylase (sAA) and salivary cortisol (sCort). The enzyme sAA, a viable biomarker for sympathetic activity (Nater and Rohleder, 2009), was later analysed using a kinetic colorimetric test (Roche Diagnostics, Mannheim, Germany). The parameter sCort, a marker of endocrine activity, was later analysed using an enzyme-linked immunosorbent assay (ELISA, IBL, Hamburg, Germany). Samples were collected by accumulating saliva in the mouth for two minutes without swallowing before transferring the collected saliva into a tube via a straw. Samples were stored at − 20 °C until analysis. Additionally, subjective stress and mood were measured directly after the 30 min BL period. Subjective stress was assessed using a visual analogue scale (VAS). Participants rated the item "I feel stressed" on a 10 cm scale ranging from 0 (not at all stressed) to 100 (maximally stressed). The VAS is a recommended tool for investigating subjective stress (Lesage et al., 2012). Mood was assessed using a short version of the German multidimensional mood questionnaire (MDBF; Wilhelm and Schoebi, 2007), which measures three mood dimensions (calmness, valence, energetic arousal).

Next, participants received instructions on the CPT. During the anticipation period prior to the CPT, a second saliva sample was taken and subjective stress was measured again.

In the CPT, participants were asked to submerge their dominant hand in the cold water (approximately 3 °C) for as long as possible, but were instructed to remove it from the water after three minutes for safety if it remained submerged for that duration. During the CPT, participants listened to one of the three acoustic stimuli. Participants brought their own relaxing song to use as the PS stimulus. The RS music stimulus was New World Music's "Carnelian" (for details on acoustic stimuli see supplement – S3). After the CPT, participants provided another saliva sample and rated their subjective stress, mood and stimulus-induced emotions. As such, a range of emotions was investigated on five-point Likert scales: joy, anger, sadness, relaxation, fear, nostalgia. The items were selected based on previous research (Fekete et al., 2022; Robazza et al., 1994).

During the recovery period, two further saliva samples were collected and participants rated their subjective stress and mood two more times (20 min (rec 1) and 35 min (rec 2) after the start of the CPT). After the last session, participants completed questionnaires on different traits, including the German Emotion Regulation Questionnaire (ERQ) for investigating habitual trait emotion regulation strategies (Abler and Kessler, 2009). Research distinguishes between the habitual use of trait emotion regulation strategies and the instructed situational use of specific emotion regulation strategies. Our study investigates habitual trait emotion regulation strategies to account for more general stable differences between individuals.

2.3. Statistical methods

Hypotheses 1a-c were investigated using multilevel analyses with the GAMLj module (Gallucci, 2019) in jamovi (The jamovi project, 2021), based on the program R (R Core Team, 2021). Stress parameters were included as dependent variables, and the interaction of *Condition* and *Time* (as within-subject factors) was investigated for hypothesis 1a, the interaction of (between-subject factor) *Gender* and (within-subject factor) *Time* for hypothesis 1b, and the interaction of *Condition*, *Gender* and *Time* for hypothesis 1c. The analyses were conducted following recommendations of Field (2013) and the program instructions (Gallucci, 2019). Model fit was calculated using REML. The module handles missing values by including all assessed data (Gallucci, 2019).

Hypotheses 2a-c were investigated similarly to hypotheses 1a-c, except that mood dimensions were investigated as dependent variables.

Hypothesis 3a was investigated using a MANOVA. Induced emotions were dependent variables, and *Gender* and *Condition* were factors. For each variable, only two out of 181 values were missing and were removed following recommendations of Farhangfar et al. (2007). Hypothesis 3b was investigated by mediation analyses using the jAMM module (Gallucci, 2020). Emotions were included as mediators, stress and mood parameters as dependent variables (difference between BL and CPT; for sCort: difference between BL and rec 1), and *Gender* as a factor. Hypothesis 3c was investigated similarly, except that *Condition* was included as a factor.

Hypothesis 4a was investigated using independent t-tests, with reappraisal and suppression as dependent variables, and *Gender* as the grouping variable. Regarding hypothesis 4b, mediation analysis was conducted, with emotion regulation strategies as mediators, stress and mood parameters as dependent variables (difference between BL and CPT), and *Gender* as a factor.

RMSSD, sCort and sAA were investigated following natural log transformation. For sCort and sAA, a constant of 10 was added, with reference to Linnemann et al. (2016). Outliers and extreme values were investigated using box-and-whisker plots and retained if not attributed to errors in data entry or recording. Test assumptions were investigated based on the recommendations of Field (2013), and p-values $<$ .05 were considered statistically significant.

3. Results

3.1. Study population

The study population was the same as that in our previous study (Maidhof et al., submitted). Due to specific eligibility criteria of the previous study regarding participants' music listening style, 3356 persons had to be screened in order to find 61 eligible participants (30 men, 31 women). None of participants dropped out over the course of the study. Fifty-seven participants completed the study within two weeks, and the remaining four participants within up to four weeks. Sample characteristics are presented in Table 2. On average, the men were older than the women (p = .01), and had a higher BMI (p = .001). When including age and BMI as covariates in the analyses of gender-specific effects, age and BMI showed no significant influence on stress reactivity, mood responses or emotion regulation strategies (p $>$ .05; see supplement – S4). On average, participants had 8.78% missing values, which were handled differently depending on the analysis (see 2.3 Statistical methods).

3.2. Stress responses

Detailed parameters of stepwise mixed models are shown in the supplement - Table 1-5. Stress parameters over time for different conditions and gender are depicted in Fig. 2 and Fig. 3.

3.2.1. Subjective stress

The interaction effect of *Condition* and *Time* was not significant ($F(8, 596.83) = .74$; $p = .66$). Only the main effect of *Time* was significant ($F(4, 91.73) = 9.48$; $p < .001$): Subjective stress increased from BL to anticipation and from anticipation to CPT, and decreased from CPT to rec 1 and from rec 1 to rec 2 (all: $p_b < .05$). The interaction effect of *Gender* and *Time* was not significant ($F(4, 92.06) = .26$; $p = .90$). The interaction effect of *Condition*, *Gender* and *Time* was significant ($F(22, 264.26) = 2.84$; $p < .001$), with women in the PS condition showing an increase in stress from BL to CPT ($p_b = .001$), a decrease from CPT to rec 1 ($p_b = .001$), and a decrease from CPT to rec 2 ($p_b < .001$). Moreover, men in the LW condition showed an increase in stress from BL to CPT ($p_b = .003$) and a decrease from CPT to rec 2 ($p_b = .004$). Other comparisons within or between groups were not significant ($p_b > .05$).

3.2.2. Heart rate (HR)

The interaction effect of *Condition* and *Time* was not significant ($F(8, 377.80) = 1.70$; $p = .10$). The main effect of *Time* was significant ($F(4, 66.38) = 27.22$; $p < .001$): HR increased from BL to anticipation and from anticipation to CPT, and decreased from CPT to rec 1 and from rec 1 to rec 2 (all: $p_b < .05$). The interaction effect of *Gender* and *Time* was significant ($F(4, 63.70) = 3.14$; $p = .02$), with men and women showing an increase in HR from BL to anticipation ($p_b < .001$) and from BL to CPT, and a decrease in HR from CPT to rec 1 and from CPT to rec 2 (all: $p_b < .05$). Only women showed an additional increase from anticipation to CPT ($p_b = .01$). The interaction of *Condition*, *Gender* and *Time* was significant ($F(22, 191.87) = 2.49$; $p < .001$). Specifically, in men, HR increased from BL to CPT when listening to RS music and LW, and decreased in all conditions from CPT to rec 1 and from CPT to rec 2 (all: $p_b < .05$). In contrast, in women, HR increased in all conditions from BL to CPT and decreased from CPT to rec 2. Only with RS music and the sound of LW did HR decrease from CPT to rec 1 (all: $p_b < .05$).

3.2.3. RMSSD

The interaction effect of *Condition* and *Time* was not significant ($F(8, 378.31) = .89$; $p = .53$). The main effect of *Time* was significant ($F(4, 63.07) = 12.63$; $p < .001$): RMSSD decreased from BL to CPT, and increased from CPT to rec 1, as well as from CPT to rec 2 (all: $p_b < .05$). No other significant changes between successive time points were found ($p_b > .05$). The interaction effects of *Gender* and *Time* ($F(4, 63.33) = 1.12$; $p = .35$), as well as of *Condition*, *Gender* and *Time* ($F(22, 209.79) = 1.38$; $p = .12$) were not significant.

3.2.4. Salivary alpha-amylase (sAA)

The interaction effect of *Condition* and *Time* was not significant ($F(8, 537.60) = .84$; $p = .57$). The main effect of *Time* was significant ($F(4, 81.05) = 5.12$; $p < .001$), with an increase in sAA from anticipation to CPT ($p_b = .003$), and no further time changes (all: $p_b > .05$). The interaction effects of *Gender* and *Time* ($F(4, 83.74) = 1.46$; $p = .30$), as well as of *Condition*, *Gender* and *Time* ($F(22, 254.00) = 1.35$; $p = .14$) were not significant.

3.2.5. Salivary cortisol (sCort)

The interaction effect of *Condition* and *Time* was not significant ($F(8,$

Table 2
Sample characteristics.

	Total sample ($N = 61$)	Men ($n = 30$)	Women ($n = 31$)
Age [years, SD]	24.23 (3.85)	25.43 (4.03)	23.07 (3.34)
BMI [kg/m^2, SD]	22.31 (2.76)	23.51 (2.66)	21.14 (2.35)
Marital status	Unmarried: $n = 60$	Unmarried: $n = 29$	Unmarried: $n = 31$
	Married: $n = 1$	Married: $n = 1$	Married: $n = 0$
	Divorced/living apart/widowed: $n = 0$	Divorced/living apart/widowed: $n = 0$	Divorced/living apart/widowed: $n = 0$
Current partnership	Yes: $n = 26$	Yes: $n = 10$	Yes: $n = 16$
	No: $n = 35$	No: $n = 20$	No: $n = 15$
Highest school education	No graduation/general school: $n = 0$	No graduation/general school: $n = 0$	No graduation/general school: $n = 0$
	Institute of Applied Sciences: $n = 4$	Institute of Applied Sciences: $n = 2$	Institute of Applied Sciences: $n = 2$
	High school: $n = 55$	High school: $n = 27$	High school: $n = 28$
	Other: $n = 2$	Other: $n = 1$	Other: $n = 1$
	Dropouts: $n = 0$	Dropouts: $n = 0$	Dropouts: $n = 0$
Highest professional education	Apprenticeship/similar operational training: $n = 4$	Apprenticeship/similar operational training: $n = 4$	Apprenticeship/similar operational training: $n = 0$
	University/College: $n = 19$	University/College: $n = 7$	University/College: $n = 12$
	Still in professional education: $n = 22$	Still in professional education: $n = 13$	Still in professional education: $n = 9$
	Other: $n = 2$	Other: $n = 0$	Other: $n = 2$
	None: $n = 14$	None: $n = 6$	None: $n = 8$
Current employment (amount)	Full time: $n = 2$	Full time: $n = 0$	Full time: $n = 2$
	At least half time: $n = 4$	At least half time: $n = 4$	At least half time: $n = 0$
	Less than half time: $n = 13$	Less than half time: $n = 8$	Less than half time: $n = 5$
	In education: $n = 37$	In education: $n = 16$	In education: $n = 21$
	Unemployed: $n = 5$	Unemployed: $n = 2$	Unemployed: $n = 3$
	Other: $n = 0$	Other: $n = 0$	Other: $n = 0$
Professional position	Worker: $n = 1$	Worker: $n = 0$	Worker: $n = 1$
	Employee: $n = 9$	Employee: $n = 7$	Employee: $n = 2$
	Civil servant: $n = 0$	Civil servant: $n = 0$	Civil servant: $n = 0$
	Self-employed: $n = 2$	Self-employed: $n = 1$	Self-employed: $n = 1$
	Other: $n = 49$	Other: $n = 22$	Other: $n = 27$
Income	< 1250€: $n = 55$	< 1250€: $n = 26$	< 1250€: $n = 29$
	1250–1750€: $n = 3$	1250–1750€: $n = 3$	1250–1750€: $n = 0$
	2250–3000€: $n = 2$	2250–3000€: $n = 1$	2250–3000€: $n = 1$
	> 5000€: $n = 1$	> 5000€: $n = 0$	> 5000€: $n = 1$
	Other: $n = 0$	Other: $n = 0$	Other: $n = 0$

Note. BMI = Body Mass Index; Gender differed in age ($p = .01$) and BMI ($p = .001$).

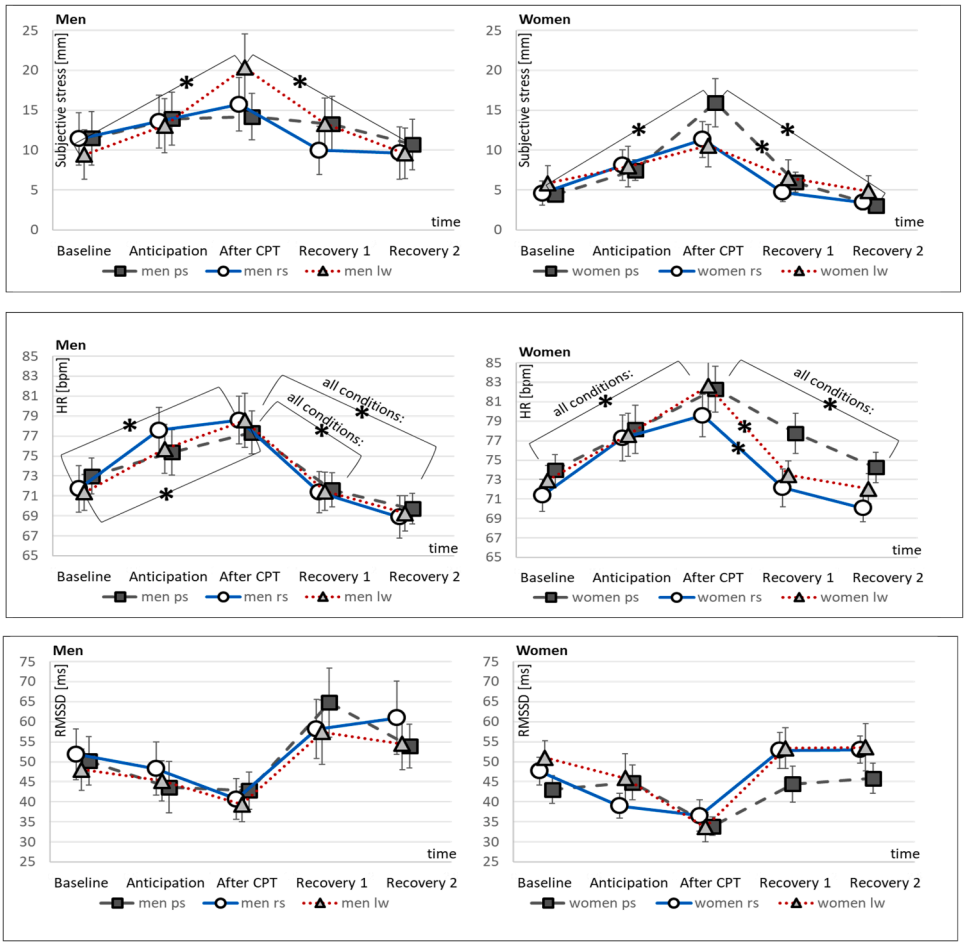

Fig. 2. Changes in subjective stress, heart rate (HR) and RMSSD over time for different conditions, separated by gender. Significant differences in significant three-way interaction effects of Condition, Gender and Time (for subjective stress and HR) are marked with * . Note. ps = participant-selected music; rs = researcher-selected music; lw = sound of lapping water; CPT = cold pressor test.

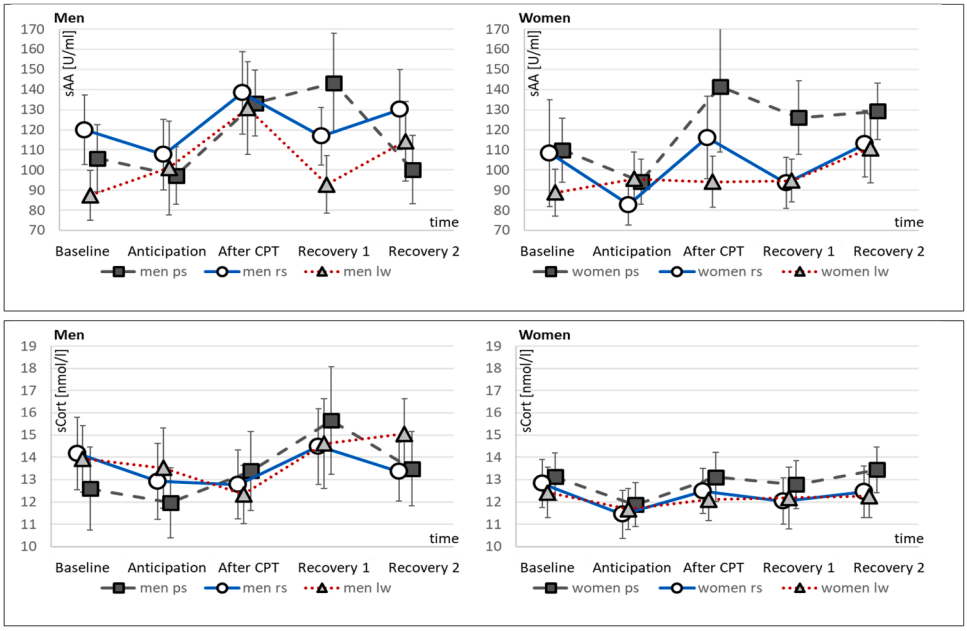

Fig. 3. Changes in salivary alpha-amylase (sAA) and salivary cortisol (sCort) over time for different conditions and gender. Note. ps = participant-selected music; rs = researcher-selected music; lw = sound of lapping water; CPT = cold pressor test.

597.94) = .98; p = .45). A significant main effect of *Time* (F(4, 101.19) = 3.69; p = .01) revealed that sCort decreased from BL to anticipation (p_b =.02) and increased from anticipation to rec 2 (p_b =.046). The interaction effects of *Gender* and *Time* (F(4, 100.22) = 2.05; p = .09), as well as of *Condition*, *Gender* and *Time* (F(22, 242.04) = 1.18; p = .26) were not significant.

3.3. Mood responses

Detailed parameters of stepwise mixed models are shown in the supplement - tables 6–8. Mood parameters over time for different conditions and gender are depicted in Fig. 4. In the following, there will be a detailed description of the results for the three mood dimensions "Calmness", "Valence" and "Arousal".

3.3.1. Calmness

The interaction effect of *Condition* and *Time* was not significant (F(6, 381.01) = 2.07; p = .06). A significant main effect of *Time* (F(3, 74.78) = 10.01; p < .001) revealed that calmness decreased from BL to CPT (p_b <.001) and increased from CPT to rec 1 (p_b =.045). No change was found from rec 1 to rec 2 (p_b =.19). The interaction effect of *Gender* and *Time* was significant (F(3, 72.76) = 3.09; p = .03). Specifically, in women, calmness decreased from BL to CPT (p_b <.001) and increased from CPT to rec 1 (p_b =.047), while no change occurred from rec 1 to rec 2. No significant changes in calmness were found in men (p_b >.05). The interaction effect of *Condition*, *Gender* and *Time* was not significant (F (17, 249.14) = 1.49; p = .10).

3.3.2. Valence

For valence, the interaction effect of *Condition* and *Time* was significant (F(6, 384.24) = 3.42; p = .003). Specifically, participants showed higher valence in response to the CPT with PS music than with the sound of LW (p_b =.004) and higher valence with RS music than with the sound of LW (p_b =.045). With the sound of LW, valence decreased from BL to CPT (p_b <.001) and increased from CPT to rec 1 (p_b =.02). A significant main effect of time (F(3, 76.62) = 5.50; p = .002) revealed that valence decreased from BL to CPT (p_b =.01) and increased from CPT to rec 1 (p_b =.02), while no change was found from rec 1 to rec 2 (p_b >.99). The interaction effects of *Gender* and *Time* (F(3, 75.80) = .75; p = .53), as well as of *Condition*, *Gender* and *Time* (F(17, 232.38) = 1.48; p = .10) were not significant.

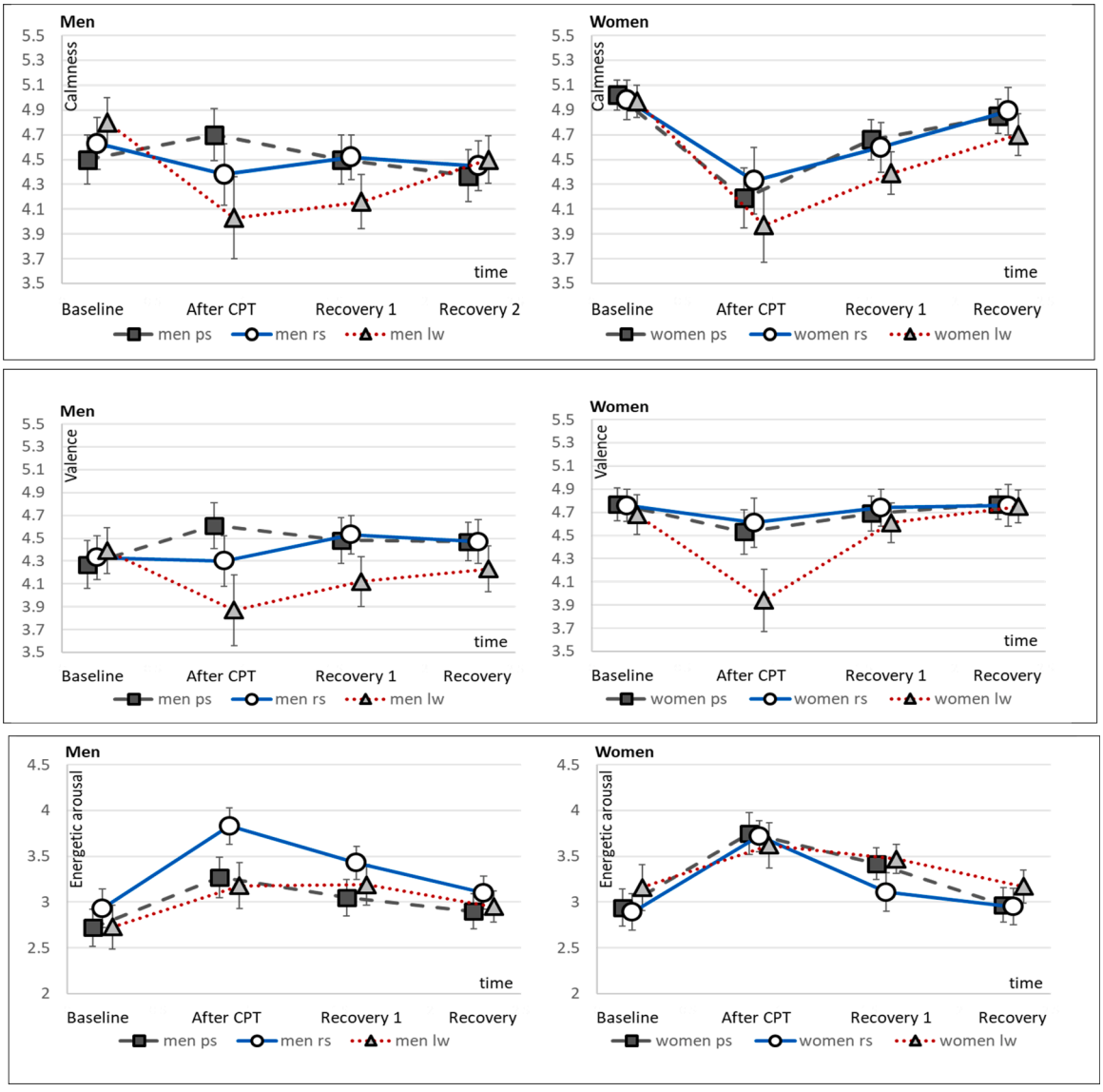

Fig. 4. Changes in mood parameters over time for different conditions, separated by gender. Note. ps = participant-selected music; rs = researcher-selected music; lw = sound of lapping water; CPT = cold pressor test.

3.3.3. Energetic arousal

The interaction effects of *Condition* and *Time* ($F(6, 372.55) = .99$; $p = .43$), as well as of *Gender* and *Time* ($F(3, 74.50) = .63$; $p = .60$) were not significant. The interaction effect of *Condition*, *Gender* and *Time* was significant ($F(17, 211.32) = 1.72$; $p = .04$). Specifically, in both genders, energetic arousal increased with RS music from BL to CPT and decreased from CPT to rec 2 (for all: $p_b < .05$). In contrast, with PS music, arousal increased from BL to CPT and decreased from CPT to rec 2 only in women (for all: $p_b < .05$), while the tests were not significant for men (for all: $p_b > .05$).

3.4. Music-induced emotions

Multivariate tests of MANOVA revealed significant effects of condition ($F(12, 342) = 5.29$; $p < .001$) and gender ($F(6, 170) = 2.75$; $p = .01$). Univariate tests revealed differences in music-induced joy ($p < .001$), sadness ($p = .04$), relaxation ($p < .001$), and nostalgia ($p < .001$) between conditions: PS music induced stronger joy and nostalgia than the other conditions ($p_b < .001$), and partly stronger relaxation and sadness. According to univariate tests, men showed higher music-induced sadness than women ($p < .05$), and, as already demonstrated in our previous investigation (Maidhof et al., submitted), also higher music-induced anger ($p < .05$).

Stimulus-induced anger mediated the effects of gender on subjective stress (indirect effect: $\beta = -.05$, $z = -2.12$, $p = .03$) and sAA (indirect effect: $\beta = .07$, $z = 2.62$, $p = .01$): Men showed higher anger than women, which was in turn associated with a stronger increase in subjective stress and a lower increase in sAA from BL to CPT. Moreover, anger mediated the effects of gender on calmness (indirect effect: $\beta = .10$, $z = 2.45$, $p = .01$) and valence (indirect effect: $\beta = .10$, $z = 2.42$, $p = .02$): Men showed higher anger than women, which in turn was associated with lower calmness and lower valence.

Stimulus-induced anger also mediated the effects of condition on calmness (indirect effect: $\beta = .08$, $z = -2.07$, $p = .04$) and valence (indirect effect: $\beta = -.08$, $z = -2.13$, $p = .03$): Anger was higher with LW than with PS music, which was in turn associated with lower calmness and lower valence. Stimulus-induced joy mediated the effects of condition on RMSSD: Joy was higher for PS music compared to RS music (indirect effect: $\beta = -.09$, $z = -2.43$, $p = .01$) and the sound of LW (indirect effect: $\beta = -.09$, $z = -2.48$, $p = .01$), which in turn was associated with a stronger decrease in RMSSD from BL to CPT. Other indirect effects were not significant ($p > .05$; for details see supplement – S5).

3.5. Emotion regulation strategies

Independent t-tests were significant for both reappraisal ($p = .02$, $d = -.60$) and suppression ($p = .03$, $d = .56$), with women scoring higher on reappraisal compared to men, and men scoring higher on suppression compared to women. Reappraisal mediated effects of gender on RMSSD (indirect effect: $\beta = .05$, $z = 2.13$, $p = .03$): Women scored higher on reappraisal than men, and higher reappraisal was in turn associated with a stronger decrease in RMSSD from BL to CPT. Moreover, suppression mediated effects of gender on sCort (indirect effect: $\beta = .07$, $z = 2.69$, $p = .01$): Men scored higher on suppression than women, which was in turn associated with a stronger increase in sCort from BL to rec 1. ER strategies did not mediate changes in other stress or mood parameters (for details see supplement – S6).

4. Discussion

Using an experimental design, we investigated whether men and women differ in psychobiological stress and mood responses to PS music, RS music and a control stimulus. Furthermore, we examined the roles of stimulus-induced emotions and emotion regulation strategies. Our findings revealed that music selection and gender – while only partly showing direct effects on the outcome variables – influence stress and mood responses via induced emotions and emotion regulation strategies.

4.1. The roles of music selection and gender regarding stress

Our findings indicate that relaxing PS music has no advantages over relaxing RS music in terms of overall stress reduction. This contradicts our hypothesis and previous recommendations favoring PS over RS music for health benefits (Nilsson, 2008). The limited impact of the CPT on stress measures may explain the lack of variation in stress responses between conditions. Another possible explanation is that PS and RS music induced similar levels of relaxation, potentially minimizing differences between conditions in stress outcomes. Although our findings do not indicate that relaxing PS music reduces stress more than relaxing RS music, it should be noted that the CPT also elicited pain, and previous research based on the same data set showed that pain tolerance was longest with PS music (Maidhof et al., submitted). Although the longest pain was endured with PS music, stress responses were not stronger than in the other conditions. This aligns with a meta-analysis indicating that in clinical settings, PS music reduces pain more than RS music, but does not affect ANS activity (Vetter et al., 2015).

Similarly, our findings suggest that, except for HR, gender does not influence stress responses directly. This contradicts previous research on gender differences in stress systems when listening to music (Gupta and Gupta, 2016; McFarland and Kadish, 1991; Nater et al., 2006; Wuttke-Linnemann et al., 2019). This discrepancy may be attributed to having kept the music listening styles of men and women constant. Gender differences in music listening styles are associated with emotional and cognitive processes (Kreutz et al., 2008), which could have weakened psychobiological differences between men and women in our study compared to studies that did not control for music listening styles. However, we found in women stronger increases in HR in response to the CPT than in men, indicating that music may not reduce stress in women as effectively as in men in terms of HR.

We found in women the strongest subjective stress response and the longest HR recovery with PS music, while men showed lower HR responses to the CPT with PS music. Potentially, the emotional and cognitive activation associated with the favorite song, along with the stressful event, led rather to arousal than relaxation in women, resulting in higher or prolonged stress. Therefore, despite the minor direct influence of music selection and gender on stress, PS and RS music seem to influence stress responses of men and women differently to some extent. Our findings imply that less personally relevant or less relaxing PS music may be more stress-reducing for women, whereas men may benefit most from PS relaxing music.

4.2. The roles of music selection and gender regarding mood responses

Contradicting our hypothesis, we found that valence did not differ between music conditions, indicating that relaxing PS and RS music are similarly effective in improving mood. Similarly, individuals responded with similar levels of calmness and arousal to PS and RS music. Therefore, although mood responses to music can vary greatly between individuals (Carter et al., 1995), the instructions for selecting the music and its relaxing properties or associated audio features may have a stronger impact on mood than who selects the music. Moreover, responses of energetic arousal and calmness did not differ between any of the conditions. Our findings indicate that relaxing music improves

valence, while other relaxing auditory stimuli can similarly influence calmness and arousal.

Regarding gender, we found that calmness decreased more in women than in men in response to the CPT, and this effect was consistent across conditions. Therefore, women may generally exhibit a stronger decrease in calmness when faced with stressful events. Similarly, Plante et al. (2003) reported that after physical exercise, women showed a decrease in calmness whereas men did not. Alternatively, the presence of another person, such as the experimenter, may have reduced calmness more in women than in men. Relatedly, Plante et al. (2007) found that women were calmer when exercising alone than when exercising with another person. Furthermore, we found similar levels of valence and arousal in men and women overall. However, men reported lower arousal with PS music compared to women, corresponding to our finding that women show stronger specific stress responses with PS music. Our findings imply that PS relaxing music appears to be more advantageous for men than for women regarding the management of arousal.

4.3. The role of music-induced emotions

We found that men exhibited stronger stimulus-induced sadness and anger than women. One explanation might be the greater use of suppression in men compared to women, which has been found to be associated with increased negative emotions (Masumoto et al., 2016). Our previous study (Maidhof et al., submitted) and additional analyses (see supplement – S7) demonstrated that stimulus-induced emotions in men varied across conditions, with PS music inducing less anger than the other conditions, stronger joy and nostalgia, and partly higher sadness and relaxation.

Moreover, we found that higher stimulus-induced anger in men compared to women, and with LW compared to PS, was associated with lower calmness and valence. As studying mechanisms was not considered in the sample size calculation, it can only cautiously be concluded that it seems advisable to avoid inducing anger in music-based mood management, particularly for men and when selecting auditory stimuli. Regarding the mediating role of anger for stress responses, a rather complex picture emerged, thus we would not draw early conclusions and would advise investigating the role of emotions in stress responses more specifically in future studies. Additionally, we found that stronger joy in PS music led to stronger decreases in parasympathetic activity. Previous research has also shown that self-selected music induces stronger joy than prescribed music and affects stress-responsive systems (Lynar et al., 2017). For selecting music for health programs, our finding implies that it seems important to consider that music-induced joy may come with physiological arousal.

4.4. The role of emotion regulation strategies

Consistent with our hypothesis and the existing literature (Balzarotti et al., 2010; Gross and John, 2003; Spaapen et al., 2014), we found that men more frequently use the strategy of suppression compared to women, who are more likely to use reappraisal. Moreover, higher reappraisal in women was associated with a decrease in parasympathetic activity, whereas suppression in men was associated with an increase in endocrine activity. Engaging actively with emotion-triggering situations through reappraisal may naturally lead to a less relaxed state and thus a reduction in parasympathetic activity. This strategy, however, may protect against an increase in endocrine activity, which appears to occur in men using the suppression strategy. While interpreting the results with caution due to the omission of mechanisms in sample size calculations, it can tentatively be concluded that reducing suppression in men may be beneficial for stress management.

4.5. Limitations

The sample size was determined based on the main research questions, and a larger sample size would appear more suitable for investigating psychological mechanisms (music-induced emotions, emotion regulation strategies). The results regarding the mechanisms should be only cautiously interpreted as first insights into processes that have been neglected by previous research.

Another limitation is the absence of pre-registration. While the research questions and procedures were well-defined before conducting the study, pre-registration was not a common practice at the time and location of the study. In hindsight, we would have pre-registered the study.

While the recommended approach to control for biomarker variability and within-subject changes is a repeated measures design (Polli et al., 2022), it also carries the risk of habituation effects. To address this, we followed previous research (Skoluda et al., 2015), performing the different CPTs on separate days for each participant and randomizing the order of conditions.

To comprehensively investigate stress and mood, we examined various psychobiological stress responses and different mood dimensions. This approach offers nuanced insights into psychobiological stress responses (Skoluda et al., 2015) and mood (Wilhelm and Schoebi, 2007). However, presenting results from these multifaceted constructs poses a challenge and may be seen as a potential limitation compared to focusing on one or two outcome variables.

4.6. Future directions

Future research should examine different patient groups with varying stress or mood responses, as well as different contexts, such as daily life and clinical contexts. As our stressor showed a relatively weak impact on the outcome variables and additionally elicited pain, future studies may investigate other types of stressors, such as the TSST, which is known to elicit higher stress responses than the CPT (Skoluda et al., 2015).

Further investigation is necessary to understand the role of music-induced emotions, particularly anger and joy. Additionally, the potential of managing emotion regulation strategies, specifically suppression, as an additional tool for music-based stress and mood management should be further investigated.

Our investigation of habitual emotion regulation strategies allows to investigate stable differences between individuals. However, to gain information about the actual use of emotion regulation strategies during the CPT, future studies should incorporate additional questionnaires and include situational instructions for regulating emotions.

Finally, the role of audio features, such as tempo, should be further examined, as potential health-beneficial impacts of audio features remain under-researched.

4.7. Conclusions

Music selection and gender appear to have no direct impact on stress and mood responses overall, although men tend to benefit more from self-selected music than women. Our findings provide first indications that avoiding music stimuli that induce anger may facilitate mood management via music. Furthermore, finding alternative emotion regulation strategies to the strategy of suppression may be a helpful approach to improve music-based stress management.

CRediT authorship contribution statement

Rosa M. Maidhof: Data curation, Formal analysis, Funding acquisition, Methodology, Software, Visualization, Writing – original draft. **Mattes B. Kappert:** Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Writing – review & editing. **Alexandra Wuttke:** Conceptualization, Data curation, Investigation, Methodology, Project administration, Software, Writing – review & editing. **Andreas R. Schwerdtfeger**: Methodology, Software, Validation, Writing – review & editing. **Gunter Kreutz:** Conceptualization, Methodology, Validation, Writing – review & editing. **Urs M. Nat:** Conceptualization, Funding acquisition, Methodology, Resources, Supervision, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors gratefully acknowledge that this research was partly funded by a completion grant of the Vienna Doctoral School in Cognition, Behavior and Neuroscience (VDS CoBeNe).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.psyneuen.2023.106381.

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