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Health Psychology Review

ISSN: 1743-7199 (Print) 1743-7202 (Online) Journal homepage: www.tandfonline.com/journals/rhpr20

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To cite this article: Martina de Witte, Anouk Spruit, Susan van Hooren, Xavier Moonen & Geert-Jan Stams (2020) Effects of music interventions on stress-related outcomes: a systematic review and two meta-analyses, Health Psychology Review, 14:2, 294-324, DOI: 10.1080/17437199.2019.1627897

To link to this article: https://doi.org/10.1080/17437199.2019.1627897

HEALTH PSYCHOLOGY REVIEW
2020, VOL. 14, NO. 2, 294–324
https://doi.org/10.1080/17437199.2019.1627897

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Effects of music interventions on stress-related outcomes: a systematic review and two meta-analyses

Martina de Witte[a,b,c], Anouk Spruit[d], Susan van Hooren[c,e,f], Xavier Moonen[d,e] and Geert-Jan Stams[d]

[a]HAN University of Applied Sciences, Nijmegen, The Netherlands; [b]Stevig, Expert Treatment Centre for People with Mild Intellectual Disabilities and Psychiatric and Behavioral Disorders, Gennep, The Netherlands; [c]KenVaK, Research Centre for the Arts Therapies, Heerlen, The Netherlands; [d]Research Institute of Child Development and Education, University of Amsterdam, Amsterdam, The Netherlands; [e]Faculty of Healthcare, Zuyd University of Applied Sciences, Heerlen, The Netherlands; [f]Faculty of Psychology and Educational Sciences, Open University, Heerlen, The Netherlands

ABSTRACT

Music interventions are used for stress reduction in a variety of settings because of the positive effects of music listening on both physiological arousal (e.g., heart rate, blood pressure, and hormonal levels) and psychological stress experiences (e.g., restlessness, anxiety, and nervousness). To summarize the growing body of empirical research, two multilevel meta-analyses of 104 RCTs, containing 327 effect sizes and 9,617 participants, were performed to assess the strength of the effects of music interventions on both physiological and psychological stress-related outcomes, and to test the potential moderators of the intervention effects. Results showed that music interventions had an overall significant effect on stress reduction in both physiological ($d = .380$) and psychological ($d = .545$) outcomes. Further, moderator analyses showed that the type of outcome assessment moderated the effects of music interventions on stress-related outcomes. Larger effects were found on heart rate ($d = .456$), compared to blood pressure ($d = .343$) and hormone levels ($d = .349$). Implications for stress-reducing music interventions are discussed.

ARTICLE HISTORY
Received 18 September 2018
Accepted 3 June 2019

KEYWORDS
Music interventions; music therapy; arousal; stress; state anxiety; multilevel meta-analysis

Introduction

Stress is believed to be one of the major factors negatively affecting our health. High stress levels have shown to be strongly associated with many physical and emotional problems, such as cardiovascular disease, chronic pain, anxiety disorders, depression, burnout, and addictions (American Psychological Association [APA], 2017; Australian Psychological Society [APS], 2015; Casey, 2017; Howe, Chang, & Johnson, 2013; McEwen & Gianaros, 2010). Furthermore, there is a strong relationship between these stress-related health problems and higher absenteeism at work (UK Health and Safety Executive, 2016). To cope with stressors, millions of people around the world use tranquilising medication, which is associated with numerous contraindications and negative side effects (e.g., Bandelow et al., 2015; Olfson, King, & Schoenbaum, 2015; Puetz, Youngstedt, & Herring, 2015). Because of the difficulty of reducing or preventing stress without any professional support and the great demand for

CONTACT Martina de Witte martina.dewitte@han.nl
Supplemental data for this article can be accessed at https://doi.org/10.1080/17437199.2019.1627897.

nonpharmacological stress reduction interventions, the relevance of the development of cost-effective interventions for stress reduction is high (Casey, 2017; Holahan, Moos, Holahan, Brennan, & Schutte, 2005; Howe et al., 2013; McEwen & Gianaros, 2010; World Health Organization [WHO], 2010).

Music listening and music making have been associated with a broad range of positive outcomes in the domains of health and well-being (Juslin & Västfjäll, 2008; Koelsch, 2012, 2015; Thaut & Hoemberg, 2014; Zatorre, 2015). The most widely studied effects of music are the calming and stress reducing effects (Chanda & Levitin, 2013; Gillen, Biley, & Allen, 2008; Juslin & Västfjäll, 2008; Koelsch, 2015). For decades, music has been used as an intervention for stress reduction, such as music activities (like singing or music making), music listening for a certain patient group ('music as medicine'), and live music therapy offered by music therapists (Bradt, Dileo, & Shim, 2013b; Gold et al., 2011).

In order to integrate the available knowledge on the effects of music interventions on stress, the present study is a systematic review and meta-analysis of experimental studies testing the effects of music interventions on both physiological and psychological stress-related outcomes in clinical, medical and work- or study-related settings.

The stress system

The *stress system* can be considered as a highly important and preserved system in human beings. In physiology and medicine, the general definition of *stress* is introduced by Selye (1956): 'Stress is a general activation reaction to a stimulus that could mean both a challenge (in a positive way) and a threat (in a negative sense)' (p. 32). Aldwin (2007) emphasized the negative part and defined stress as the quality of an experience, produced through a person-environment transaction that, through either overarousal or underarousal, results in psychological or physiological distress (Aldwin, 2007; Riley & Park, 2015). The responses to stress can be categorised as *physiological arousal* and *emotional responses* (e.g., Aldwin, 2007; Li & Goldsmith, 2012; Pelletier, 2004). Together, the underlying systems of these responses regulate stress and affect each other during stress (e.g., Linnemann, Strahler, & Nater, 2017; McEwen & Gianaros, 2010).

The physiological response to stress implies the activation of the hypothalamic-pituitary adrenal (HPA) axis and, because of a release of adrenalin and noradrenalin, increased activity of the sympathetic nervous system resulting in increased physiological arousal, such as heartrate, blood pressure, and cardiac output (Bally, Campbell, Chesnick, & Tranmer, 2003; McCance,Forshee, & Shelby, 2006; Pfaff, Martin, & Ribeiro, 2007). In a parallel process, involving the hypothalamus and the adrenal glands, cortisol is released. The emotional response to stress can be described as emotional states of subjective worry, such as state anxiety, restlessness or nervousness (Akin & Iskender, 2011; Cohen, Kamarck, & Mermelstein, 1983; Pittman & Kridli, 2011; Pritchard, 2009). *State anxiety* has been defined as an emotional response to an individual's perception of a stressful experience (e.g., Hook, Songwathana, & Petpichetchian, 2008; Koelsch, Fuermetz, et al., 2011a; Ng et al., 2016; Zhang et al., 2014). Therefore, state anxiety was operationalised for several decades as one of the psychological stress-related outcomes (Koelsch, Fuermetz, et al., 2011a; Lazarus, 1966; Pelletier, 2004). It is assumed that both the physiological and the emotional responses of stress may be reduced by music (Bradt & Dileo, 2014; Dileo & Bradt, 2007; Pelletier, 2004).

Effects of music on stress

Recent neuroscientific studies provide insights into how music interventions may lead to stress reduction and increased well-being. Firstly, music seems to be able to decrease *physiological arousal*, which is increased during stress. Music listening, and music making/singing, have been associated with decreases of physiological arousal, shown by reduction of cortisol levels or decrease in heart rate and blood pressure (Hodges, 2011; Koelsch et al., 2016; Kreutz, Murcia, & Bongard, 2012; Leardi et al., 2007; Linnemann, Ditzen, Strahler, Doerr, & Nater, 2015; Nilsson, 2009; Sokhadze, 2007).

These three outcomes have been identified in neurobiology as distinct stress biomarkers (Cacioppo, Tassinary, & Berntson, 2007; Pfaff et al., 2007).

Music may also affect stress-related *emotional states*, such as subjective worry, anxiety, restlessness or nervousness (Akin & Iskender, 2011; Cohen et al., 1983; Pittman & Kridli, 2011; Pritchard, 2009). This is because music can modulate activity in brain structures that are known to be crucially involved in emotional processes. Recent neuroimaging studies on music and emotion showed that music may strongly influence the *amygdala*, a part of the limbic system, which is a section of the brain that plays a crucial role in the regulation of emotional processes by releasing endorphins. These neurotransmitters play an important role in enhancing a sense of well-being (Blood & Zatorre, 2001; Hodges, 2011; Koelsch, 2015; Koelsch, Siebel, & Fritz, 2011b; Levitin, 2009; Moore, 2013; Thaut & Wheeler, 2010; Uhlig, Jaschke, & Scherder, 2013; Zatorre, 2015).

The systematic review of Moore (2013) on the neurological effects of music on emotional processes indicated that musical improvisation and music listening could deactivate the amygdala, which may decrease the intensity of stress-related emotional states and psychophysiological arousal. This in turn has been shown to evoke feelings of pleasure and happiness (Blood & Zatorre, 2001; Koelsch et al., 2016; Koelsch, Offermanns, & Franzke, 2010; Limb & Braun, 2008). The (cognitive) behavioural framework is consistent with this and takes into account that music can serve as a distractor, diverting attention from a stressful event to something more pleasant, which reduces stress levels (Sendelbach, Halm, Doran, Miller, & Gaillard, 2006; Vaajoki, Kankkunen, Pietilä, & Vehviläinen-Julkunen, 2011).

Many studies on the effects of music considered *state anxiety* to be a stress-related emotional state, examining relationships between state anxiety outcomes and physiological stress-related outcomes (e.g., Hook et al., 2008; Koelsch, Fuermetz, et al., 2011a; Ng et al., 2016; Zhang et al., 2014). Although the terms *state anxiety* and *stress* are used interchangeably in the psychology literature, different self-reporting questionnaires are used. It is therefore necessary to examine whether music has the same effects on stress and state anxiety.

Music interventions

Music interventions can be regarded as purposeful musical exercises or methods in which music listening, music making, or singing is central. In both literature and practice there is a distinction between music interventions offered by a music therapist and music interventions offered by other healthcare professionals or without any support. First, music interventions can be defined as purposeful music activities if they concern listening to prerecorded music offered by medical or healthcare professionals, if the intervention is self-administered by the patient ('music as medicine'), or if it concerns music making or singing without the involvement of a music therapist or a therapeutic context (American Music Therapy Association, 2019). Second, music interventions as a part of *music therapy* are offered by trained music therapists and are characterised by the presence of a therapeutic process and the use of personal music experiences (Bradt & Dileo, 2014; Bradt et al., 2013b; Dileo, 2006; Gold et al., 2011; Kamioka et al., 2014). Music interventions in the practice of music therapy may concern music listening or music playing, but may also include composing, songwriting, or interacting with music (Leubner & Hinterberger, 2017).

It is assumed that specific characteristics of the music may have an impact on the stress-reducing effects of music interventions (e.g., Bradt & Dileo, 2014; Bradt, Dileo, & Potvin, 2013a; Pittman & Kridli, 2011). *Music tempo* can be considered as one of the most important moderators of music-related arousal and relaxation. Music with a slow tempo (60–80 bpm), for example meditative music, has often been associated with reductions in heart rate, resulting in greater relaxation (e.g., Bernardi, Porta, & Sleight, 2006; Bringman, Giesecke, Thörne, & Bringman, 2009; Chlan, 2000; Hilz et al., 2014; Nomura, Yoshimura, & Kurosawa, 2013). The use of *instrumental music*, instead of *music with lyrics*, would often lead to greater effects of music interventions on stress reduction. Several studies reported that music containing lyrics may be more distracting and activating instead of calming

(Good et al., 2000; Halpern & Savary, 1985). However, Koelsch et al. (2011a) reported that the use of music with lyrics may reinforce the positive effects of music interventions on stress reduction through the possible comforting effects of the lyrics. Another component of music interventions for stress reduction is the way the music is played (live music or prerecorded music). Music therapy consists mainly of live music interventions, which are assumed be more effective than 'music as medicine' interventions because music therapists individualise their interventions to meet patients' specific needs (Bradt & Dileo, 2014; Dileo, 1999, 2006). Notably, some studies measured differences in stress responses between participants receiving live music and those receiving prerecorded music, with live music appearing to be the most stress-reducing (e.g., Arnon et al., 2006; Bailey, 1983; Baker, 2001).

Many studies examining the effects of music interventions on stress-related outcomes in specific patient groups or settings have been published, such as cancer patients (Bradt, Dileo, Grocke, & Magill, 2011), coronary heart disease patients (Bradt et al., 2013a), and patients undergoing endoscopic procedures (Rudin, Kiss, Wetz, & Sottile, 2007). Several studies reported positive effects of music-listening on stress-related outcomes. In medical settings, listening to tranquilising music before, during, and after medical procedures has been reported to correlate with lower cortisol levels, associated with the reduction of stress and/or anxiety (e.g., Chanda & Levitin, 2013; Kamioka et al., 2014; Koelsch et al., 2016; Linnemann et al., 2015; Nilsson, 2008). However, the strength of the effect differs both within and between studies, and the particular impact of potential moderators – such as patient/client, setting, measurement and intervention characteristics – is largely unknown.

Rationale for the present study

The present study consists of two multilevel meta-analyses on the effects of music interventions on both physiological stress-related arousal (e.g., blood pressure, heart rate, hormone levels) and psychological stress-related experiences (e.g., state anxiety, restlessness or nervousness) in various populations and settings, and is a replication of the meta-analysis by Pelletier (2004), who reviewed 22 quantitative studies examining the effects of music interventions on stress reduction. Pelletier's (2004) meta-analysis showed that music alone and music-assisted relaxation significantly reduced stress-related arousal, with an overall medium-to-large effect size of $d = .67$, moderated by study characteristics, such as age, type of stress, musical preference and type of intervention. An important difference with the present study is that Pelletier included only studies in which the intervention consisted of listening to prerecorded music, often combined with relaxation techniques, whereas studies with live music interventions were excluded. Besides, studies examining *music therapy* for stress reduction were not included. The quality of the included studies was not assessed. Therefore, it is not clear whether the methodology of the studies did influence Pelletier's overall effects. In addition, we assume that the study quality of comparable studies has increased over the last 15 years.

In the last decade, music interventions were increasingly developed and used to reduce stress in a variety of settings (Chanda & Levitin, 2013; Heiderscheit, Chlan, & Donley, 2011; Koelsch, 2015; Uhlig et al., 2013), and to support physical and psychological health by creating an environment that stimulates relaxation and stress reduction (Bradt & Dileo, 2014; Kamioka et al., 2014; Koelsch & Stegemann, 2012; Nilsson, 2008). Therefore, it is timely to replicate the meta-analysis by Pelletier (2004) by using new multilevel meta-analytic techniques that enable moderator analyses of both within and between study differences in outcomes, thus preventing loss of information and increasing statistical power (Assink & Wibbelink, 2016).

The present meta-analytic study includes all *randomized controlled trials* (RCTs) on the effects of music interventions on stress-related outcomes in adults, who are not suffering from dementia, that have been published. The first aim of this study is to examine whether, and the degree to which, music interventions are effective in reducing stress. The second aim is to examine possible moderator effects of study, sample and intervention characteristics, which may influence the strength of the effects of music interventions on stress-related outcomes. The results of this meta-analysis may be used to increase the effects of music interventions on stress by examining the conditions under which music interventions have the largest effects on both physiological and psychosocial dimensions of coping and stress.

Methods

Inclusion criteria

For the current meta-analysis, multiple inclusion criteria were applied. Firstly, only RCTs that examined the effect of music interventions on the experience of stress and/or (state) anxiety were included. Outcome measures related to quality of life (QoL) or pain were excluded, because these outcomes can be a response to stress, but are not measuring the primary stress-related outcome measures, upon which the present study is focused. The physiological effects of stress had to be measured by heart rate, blood pressure and hormone levels. Psychological effects of stress had to be measured by self-report instruments aiming at 'stress' or 'state anxiety'. Secondly, studies including participants younger than 18 years of age or examining people with dementia were excluded. Although many studies reported cognitive and emotional benefits in dementia patients when they were singing or when they were listening to familiar songs (Särkämö et al., 2008, 2014), such findings are not directly related to 'stress reduction'. Moreover, the regular stress measurement instruments, which are also used in the included RCTs of the present study, are not used in studies in which people with dementia are being examined.

Selection of studies

We conducted a computer-based search of the psychological and medical electronic literature databases, including Medline, Academic Search Complete, Cochrane Library, Web of Science, Wiley Online Library, SpringerLink, PubMed, PiCarta, Academic Search Premier, ScienceDirect, PsychINFO and Google Scholar. Pelletier's meta-analysis (2004) can be seen as the starting point of current meta-analysis because Pelletier also included all kinds of settings and patient groups. All RCTs available until November 2017 that were in line with the inclusion criteria were included in this meta-analysis. The electronic databases were searched using the following English search string: (music*) AND (stress* OR anxiety* OR arousal) AND ('randomized controlled trial' OR 'randomised controlled trial' OR RCT). Furthermore, reference sections of review- and meta-analytic articles about the effect of music interventions on stress-related outcomes were inspected for qualifying studies. The initial search resulted in 2679 studies. Finally, 104 studies met all the inclusion criteria (Figure 1). An overview of the included studies and their main characteristics are presented in Table A1 (See Appendix 1).

Coding and moderators

The included studies were coded by the first author using a coding sheet according to the guidelines of Lipsey and Wilson (2001). *Stress* can be considered as the dependent variable and was coded into *physiological* or *psychological* stress-related outcomes, resulting in two meta-analyses. For each meta-analysis, various factors with a potential moderating effect on the relation between music interventions and stress were identified. These moderators were divided into outcome-, study-, sample-, and intervention characteristics.

Regarding the stress-related outcomes, three different physiological outcome measures were coded: *heart rate, blood pressure* and *hormone levels*. These are three different biomarkers and each biomarker must be measured differently (Cacioppo et al., 2007; Pfaff et al., 2007). Regarding the psychological stress-related outcomes, it was coded whether the outcomes were assessed by

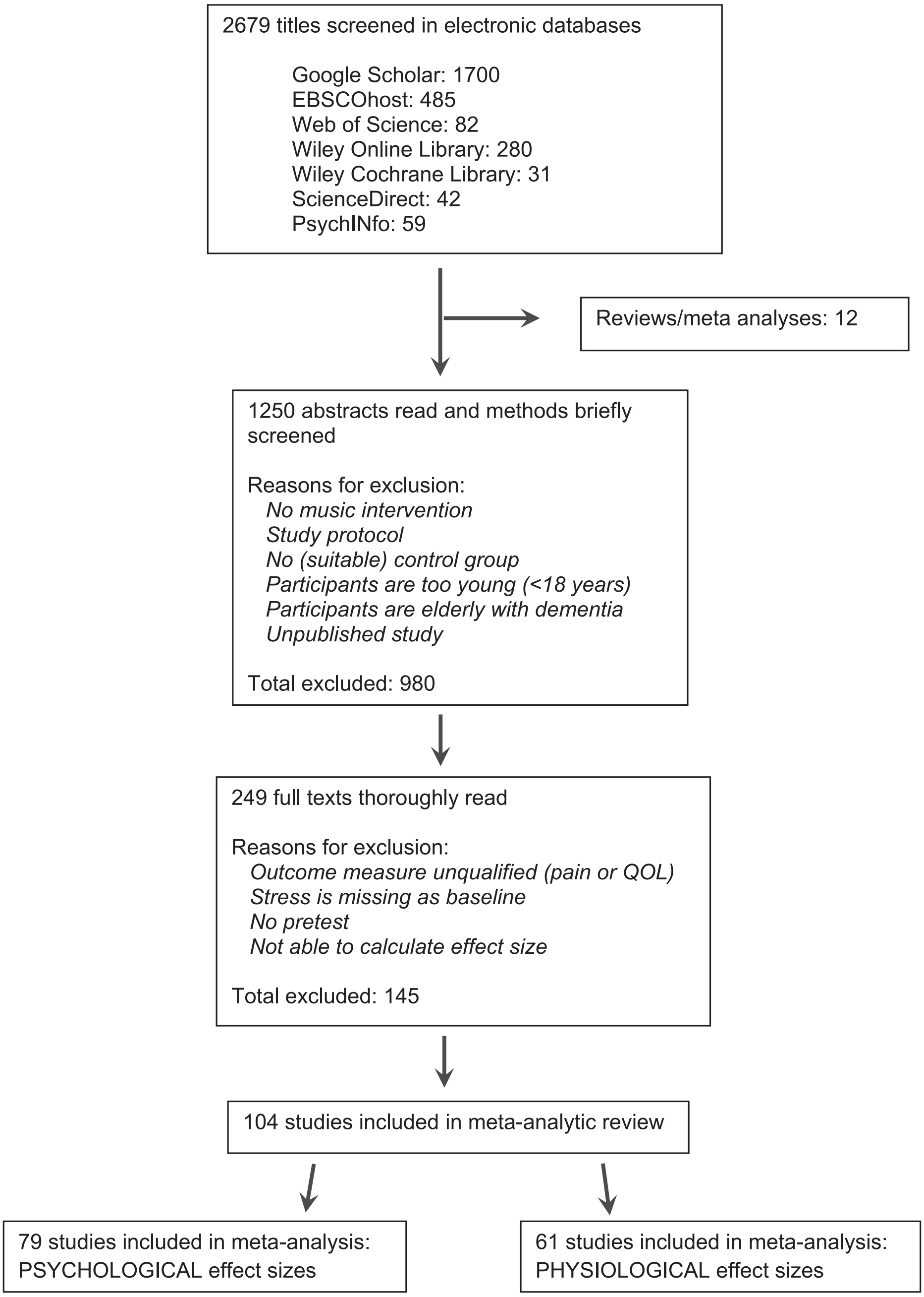

Figure 1. Flow chart of the search results.

means of questionnaires measuring *stress* or *state anxiety*. For measuring stress, the self-report questionnaires Perceived Stress Scale (PSS; Cohen et al., 1983) and the Visual Analogue Scale Stress (VAS-S) are widely used and 19% of the included studies measuring psychological stress-related outcomes have applied them. State anxiety is measured in multiple studies by the state version of the Spielberger State-Trait Anxiety Inventory (STAI-S; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), and is used in 59% of the included studies assessing psychological stress-related outcomes ($k = 76$). Notably, despite the positive psychometric features of the STAI-S, the measures have been criticised for their inability to adequately discriminate between the symptoms of anxiety and depression (Caci, Bayle, Dossios, Robert, & Boyer, 2003; Grös, Antony, Simms, & McCabe, 2007).

We coded whether the study quality was *strong, moderate* or *weak* with the 'Quality Assessment Tool for Quantitative Studies' (Effective Public Health Practice Project [EPHPP], 2009). This tool assesses the quality of a study by providing a comprehensive and structured assessment of the concept of study quality (Armijo-Olivo, Stiles, Hagen, Biondo, & Cummings, 2012). The EPHPP has been reported to have content and construct validity (Jackson & Waters, 2005; Thomas, Ciliska, Dobbins, & Micucci, 2004). Low-quality studies negatively affect the internal (causal conclusion) validity, which can lead to a biased estimation of the overall effect estimate (Higgins & Green, 2011; Zeng et al., 2015). Regarding the setting in which the study was conducted, we coded whether the study was conducted in a *polyclinic medical setting*, *pre-, during or after medical surgery*, or whether it was a so-called *nonmedical setting* (e.g., work-related settings, research among students at universities or musical activities to improve health in chronical patients). Further, we coded whether the study was conducted in a *Western* country (European countries, Australia, USA, Canada, New Zealand) or in a non-Western country (mainly Asiatic countries). The cultural environment has been shown to influence the way people respond to and cope with stress (Lonner, 2007; Tweed, White, & Lehman, 2004), which could influence the effect of music on stress. The type of control condition was coded as care as usual (CAU) or another intervention. Different control conditions can lead to different effect sizes and recognising this is crucial for drawing accurate conclusions about treatment efficacy (Finney, 2000; Karlsson & Bergmark, 2015).

Several sample characteristics were also coded, such as the percentage of men in each study. There are indications men and women tend to react differently to stress, both psychologically and physiologically, leading to substantiated gender differences in measured stress levels (Galanakis, Stalikas, Kallia, Karagianni, & Karela, 2009; Kajantie & Phillips, 2006; Verma, Balhara, & Gupta, 2011). We also coded the average age of the samples per study because research on occupational stress shows the existence of several significant differences in stress levels between different ages (Galanakis et al., 2009).

Finally, we coded six music intervention characteristics. First, according to Bradt and Dileo (2014), we coded whether the music intervention was offered in the context of *music therapy* by a trained music therapist, or whether the music intervention was offered by a healthcare professional, the researcher, or by the patient himself, as a *music activity* (Dileo, 2006; Dileo & Bradt, 2007; Kamioka et al., 2014; Leubner & Hinterberger, 2017). Second, we coded whether the music intervention involved *live music* or *prerecorded music*, because differences in effects on stress-related outcomes were found (e.g., Arnon et al., 2006; Bailey, 1983; Baker, 2001). Third, regarding the selection of music, it was coded whether the music was self-selected by the participants and based on *own preference* (bringing their own music) or whether the music was *pre-selected* by the researcher or the (music) therapist. Some researchers have advised to allow participants choose the music themselves, because this may have a greater stress reducing impact (Juslin, Liljeström, Västfjäll, Barradas, & Silva, 2008), but this does not always mean that participants could bring their own music. On the other hand, the pre-selected music (by the researchers) is mostly based on the musical characteristics related to classical and soothing music, which are assumed to positively affect relaxation and stress reduction (Burns et al., 2002; Labbé, Schmidt, Babin, & Pharr, 2007). Fourth, we coded whether the music intervention concerned the music tempo of 60–80 bpm, or whether no specific music tempo was mentioned in the study. Fifth, it was coded whether the music contained lyrics or whether the music was purely instrumental. Lastly, we coded the number of music intervention sessions. The number of interventions is positively correlated to improvements in many outcomes including the regulation of stress and anxiety (Cassileth, Vickers, & Magill, 2003; Gold, Solli, Krüger, & Lie, 2009; Robb, Carpenter, & Burns, 2011).

Calculation and analyses

Data analysis was performed by the first and second author. The effect sizes were transformed into Cohen's *d* by use of Wilson's (2013) calculator and Lipsey and Wilson's (2001) formulae. Negative effect sizes indicate that music interventions had a negative effect on stress-related outcomes. Most *d*-values were calculated based on reported means and standard deviations. To correct for pretreatment differences, pretest effects were subtracted from posttest effects. The effect size was coded as zero when a study mentioned that an effect was not significant without providing any statistics (Lipsey & Wilson, 2001). For both meta-analyses, the continuous moderators (age of the participants, gender of the participants, duration of the music intervention and frequency of the music intervention) were centred on their means. For categorical variables, dichotomous dummy variables were created. Extreme outliers in effect sizes were identified using box plots (Tabachnik & Fidell, 2013), and were winsorized (i.e., replaced by the highest or lowest acceptable score falling within the normal range) for both meta-analyses. Standard errors were estimated using Lipsey and Wilson's (2001) formulae.

In almost all the studies it was possible to calculate more than one effect size as most studies reported on multiple stress-related outcome variables, multiple scales or measurement instruments. It is possible that the effect sizes from the same study are more alike than effect sizes from other studies. The assumption of independent effect sizes underlying traditional meta-analytic methods was therefore violated (Hox, 2010; Lipsey & Wilson, 2001). In line with recently conducted meta-analyses, we applied a multilevel approach in both meta-analyses in order to deal with the interdependency of effect sizes (Assink et al., 2015; Cheung, 2014; Houben, Van Den Noortgate, & Kuppens, 2015; Spruit, Assink, van Vugt, van der Put, & Stams, 2016; ter Beek et al., 2018).

A three-level meta-analytic model was used to calculate the combined effect sizes and to perform the moderator analyses. Three sources of variance were modelled, including the sampling variance for each effect sizes (level-one), the variance between effect sizes within studies (level-two), and the variance between studies (level-three) (Assink & Wibbelink, 2016). The meta-analysis was conducted in R (version 3.4.3) with the metafor package, employing a multilevel random effects model (Houben et al., 2015; Van den Bussche, Van den Noortgate, & Reynvoet, 2009; Viechtbauer, 2010). This model is adequate and often used for multilevel meta-analyses and is, in general, superior to the fixed-effects approaches used in traditional meta-analyses (Van Den Noortgate & Onghena, 2003). We used likelihood ratio tests to compare the deviance scores of the full model and the models without variance parameters on level two or three to determine if the level-two and -three variances were significant, indicating heterogeneity of effect sizes. A heterogeneous effect size distribution indicates that the effect sizes cannot be treated as estimates of a common overall effect size. In that case, we conducted moderator analyses, because the differences among effect sizes may be explained by outcome, study, sample, and/or intervention characteristics.

Publication bias

A common problem in conducting a meta-analysis is that studies with nonsignificant or negative results are less likely to be published than studies with positive and significant results. The studies included in this meta-analysis may therefore not be an adequate representation of all studies that have been conducted. This phenomenon is called the 'file drawer problem' (Rosenthal, 1995).

In order to check the presence of publication bias in the current meta-analysis, a trim and fill procedure was performed (Duval & Tweedie, 2000a, 2000b) by testing the asymmetry of the funnel plot according to Egger's method (Egger, Davey Smith, Schneider, & Minder, 1997). In case of publication bias, the funnel plot of the distribution of effect sizes is asymmetric, resulting in a significant Egger's test. If Egger's method indicates publication bias, a trim and fill procedure is required. We tested if effect sizes were missing on the left side of the distribution, since publication bias would only be likely to occur in the case of nonsignificant or unfavourable (i.e., negative) results. In case of left-sided funnel plot asymmetry, we imputed estimations of effect sizes of missing studies through trim and fill analyses, and subsequently computed an overall effect size that would take the influence of publication bias into account (Duval & Tweedie, 2000b), providing an estimate of the degree to which publication bias might have affected the overall mean effect size.

Results

This meta-analytic review included 104 RCTs (all non-overlapping samples) with a total of $N = 9.617$ participants of whom $n = 4.838$ participated in a music intervention group or music therapy group, and $n = 4.779$ constituting the comparison group. Table A1 shows an overview of the most important characteristics of the included studies (see Appendix 1). Table 1 shows the overall effects of music interventions on both physiological stress-related outcomes and psychological stress-related outcomes.

Effect of music interventions on physiological stress-related outcomes

The meta-analysis on the effect of music interventions on physiological stress-related outcomes contained 61 independent studies (*s*), from which 197 effect sizes (*k*) were denied, and a total sample of $N = 3.188$ participants, of which $n = 1.624$ participants in the music intervention groups, and $n = 1.564$ participants in the comparison groups.

Overall effect on physiological stress-related outcomes

A significant small-to-medium effect ($d = 0.380$, $p \leq .001$) of music interventions on physiological stress-related outcomes (heart rate, blood pressure, stress-related hormones) was found, indicating that music interventions reduced physiological stress symptoms. According to the trim-and-fill plot, the presence of publication bias was unlikely, as there were no imputed effect sizes on the left side of the funnel (see Figure A1, Appendix 2). The likelihood ratio test showed that significant variance was present at the between-study level (level 3) and the within studies level (level 2). In cases of heterogeneous effect size distributions, moderator analyses are advised to assess whether the variance between the effect sizes can be explained by moderators. Therefore, we conducted moderator analyses on type of outcome, study, sample, and music intervention characteristics to examine the effect of music intervention on physiological stress-related outcomes.

Results of moderator analyses on physiological stress-related outcomes

The moderator analyses of the physiological stress-related outcomes were justified by significant overall heterogeneity for all moderator variables, including the variables with missing values. The results of these moderator analyses are presented in Table 2.

Table 1. Overall effects of music interventions on physiological and psychological stress-related outcomes.

Outcome	*s*	*k*	Mean *d*	95% CI	*P*	σ^2_{level2}	σ^2_{level3}	% Var. level 1	% Var. level 2	% Var. level 3
Physiological outcomes	61	197	0.380	0.296–0.465	<.001***	0.024***	0.076***	32.44	16.09	51.47
Psychological outcomes	79	130	0.545	0.432–0.657	<.001***	0.119***	0.128***	15.38	40.76	43.87

Note: *s* = number of studies; *k* = number of effect sizes; CI = confidence interval; Mean *d* = mean effect size (*d*); CI = confidence interval; % Var = percentage of variance explained; σ^2_{level2} = variance between effect sizes within the same study; σ^2_{level3} = variance between studies.

Table 2. Moderator effects of music interventions on physiological stress-related outcomes.

Moderator variables	s	K	β_0 (mean d)	t_0	β_1	t_1	F(df1, df2)
Outcome characteristics	61	197					$F(2, 193) = 3.581$*
Bloodpressure (RC)	47	104	0.343	7.141***			
Hormones	13	22	0.349	3.949***	0.006	0.067	
Heart rate	53	70	0.456	8.944***	0.113	2.617	
Study characteristics							
Setting	61	197					$F(2, 194) = 1.099$
Surgery (RC)	27	110	0.393	6.370***			
Nonmedical	10	20	0.523	4.299***	0.130	0.953	
Polyclinical procedures	24	67	0.320	4.677***	−0.073	−0.794	
Continent	61	197					$F(1, 195) = 2.914$
Western (RC)	30	108	0.306	5.097***			
Non-Western	31	89	0.450	7.659***	0.143	1.707	
Study quality	61	197					$F(2, 194) = 0.586$
Strong (RC)	28	92	0.405	6.413***			
Moderate	20	52	0.313	4.052***	−0.093	−0.928	
Weak	13	53	0.426	4.596***	0.021	0.190	
Intervention characteristics							
Type of music intervention	61	197					$F(1, 195) = 0.094$
Music activity (RC)	54	183	0.379	8.346***			
Music therapy	7	14	0.423	2.931**	0.046	0.307	
Type of control condition	61	197					$F(1, 195) = 2.784$
CAU (RC)	46	130	0.417	8.641***			
Other intervention	18	67	0.284	3.948***	−0.133	−1.668	
Music selection	61	197					$F(1, 195) = 1.040$
Own preference (RC)	24	90	0.329	4.985***			
Selection by researcher/therapist	37	107	0.415	7.580***	0.087	1.020	
Music induction	61	197					$F(1, 195) = 1.065$
Prerecorded music (RC)	54	184	0.367	8.287***			
Live music	7	13	0.525	3.571***	0.159	1.032	
Music style	58	186					$F(1, 184) = 1.336$
Relaxation (RC)	46	152	0.393	8.689***			
Own choice	12	34	0.285	3.417***	−0.109	−1.156	
Music with lyrics	61	197					$F(2, 194) = 0.560$
No (RC)	47	143	0.372	7.488***			
Yes	2	6	0.189	0.789	−0.183	−0.747	
Both	12	48	0.446	4.604***	0.074	0.678	
Music tempo	61	197					$F(1, 195) = 0.304$
60–80 beats p/m (RC)	36	130	0.361	6.449***			
No specific tempo	25	67	0.409	6.029***	0.049	0.551	
Frequency	60	193					$F(1, 195) = 0.091$
One session (RC)	49	146	0.375	8.003***			
More sessions	11	47	0.402	4.845***	0.027	0.301	
Duration (continuous)	49	161	0.318	8.215***	0.003	1.479	$F(1, 159) = 2.187$
Sample characteristics							
Proportion of males (continuous)	55	181	0.366	7.871***	−0.094	−0.549	$F(1, 179) = 0.301$
Age (continuous)	55	182	0.386	8.228***	−0.001	−0.223	$F(1, 180) = 0.050$

Note: s = number of independent studies; k = number of effect sizes; β_0 = intercept/mean effect size (d); t_0 = difference in mean d with zero; β = estimated regression coefficient; t_1 = difference in mean d with reference category; $F(\text{df}_1, \text{df}_2)$ = omnibus test; (RC) = reference category. *$p < .05$, **$p < .01$, ***$p < .001$.

Outcome characteristics. We found a significant moderating effect ($p \leq .05$) on the different types of physiological stress-related outcomes (heart rate, blood pressure or stress-related hormones). The strongest effects of music interventions on the physiological stress-related outcomes were measured by heart rate ($d = 0.456$) compared to blood pressure ($d = 0.343$) and hormone levels ($d = 0.349$).

Study characteristics. No significant moderating effects of study characteristics were found. More specifically, the type of setting (nonmedical settings, pre- or postmedical surgery or during medical procedures), the continent where the study was conducted (Western or non-Western countries), and the quality of the study (weak, moderate or strong) showed no significant moderating effects. The continent where the study had been carried out showed a trend ($p = 0.089$), indicating that non-Western studies yielded larger effects on physiological stress-related outcomes than studies conducted in Western countries.

Sample characteristics. The age and gender of the samples did not have a moderating effect on the physiological stress symptoms.

Intervention characteristics. No significant moderating effect was found in the type of intervention (music therapy or music intervention), type of control condition (CAU or another intervention), music induction (prerecorded music or live music), music style (predetermined relaxing music or patient preferred music), music tempo (60–80 bpm or another tempo), or the use of music with lyrics in contrast to the use of purely instrumental music.

Effect of music interventions on psychological stress-related outcomes

The meta-analysis on the effect of music interventions on physiological stress-related outcomes contained 79 independent studies (*s*), from which 130 effect sizes (*k*) were denied, and a total sample of $N = 6.800$ participants, of which $n = 3.373$ participants in the music intervention groups and $n = 3.427$ participants in the comparison groups.

Overall effect on psychological stress-related outcomes

A significant medium-to-large effect ($d = 0.545$, $p \leq .001$) of music interventions on psychological stress-related outcomes was found, indicating that music interventions reduced psychological stress-related symptoms (state anxiety, nervousness, restlessness, and feelings of worry). The trim-and-fill plot did not show lack of effect sizes on the left side of the funnel (see Figure A2, Appendix 2), therefore publication bias was unlikely. The likelihood ratio test showed that significant variance was present at the between (level 3) and within (level 2) study level. Moderator analyses on type of outcome, study, sample, and music intervention characteristics were conducted to examine the effect of music intervention on psychological stress-related outcomes.

Results of moderator analyses on psychological stress-related outcomes

The moderator analyses of the psychological stress-related outcomes were justified by significant overall heterogeneity for all moderator variables, including the variables with missing values. The results of these moderator analyses are presented in Table 3.

Outcome characteristic. The type of psychological outcome (stress- or state anxiety) did not moderate the effect of music interventions on psychological stress-related outcomes.

Study characteristics. No significant moderating effects were found in the study characteristics. More specifically, the continent where the study was conducted, type of setting, and quality of the study, did not moderate the effect of the music intervention on physiological stress-related outcomes.

Sample characteristics. No moderating effects of the age and gender composition of the samples were found.

Intervention characteristics. We found no significant moderating effects of the intervention characteristics, which included the type of intervention (music therapy or music intervention), music induction (prerecorded music or live music), music style (predetermined relaxing music or self-selected music by the patient), and the use of music with lyrics in contrast to the use of purely instrumental music. The music tempo showed a trend ($p = .064$), indicating that music with 60–80 bpm yielded larger effects than music with another or unspecified tempo. Another trend concerned the type of

Table 3. Moderator effects of music interventions on psychological stress-related outcome.

Moderator variables	s	k	β_0 (mean d)	t_0	β_1	t_1	F(df1, df2)
Outcome characteristics	79	130					$F(1, 128) = 0.118$
State anxiety (RC)	70	101	0.553	9.008***			
Stress	19	29	0.512	4.592***	−0.041	−0.344	
Study characteristics							
Setting	79	130					$F(2, 127) = 2.353$
Surgery (RC)	23	51	0.669	6.808***			
Nonmedical	12	19	0.694	4.553***	0.025	0.137	
Polyclinic procedures	44	60	0.433	5.707***	−0.236	−1.897	
Continent	79	130					$F(1, 128) = 0.765$
Western (RC)	40	70	0.496	6.206***			
Non-Western	39	60	0.596	7.318***	0.100	0.874	
Study quality	79	130					$F(2, 127) = 1.573$
Strong (RC)	42	71	0.628	8.175***			
Moderate	21	28	0.387	3.423***	−0.240	−1.757	
Weak	16	31	0.518	4.142***	−0.110	−0.749	
Intervention characteristics							
Type of music intervention	79	130					$F(1, 128) = 0.013$
Music intervention (RC)	67	110	0.548	8.838***			
Music therapy	12	20	0.529	3.539***	−0.019	−0.115	
Type of control condition	79	130					$F(1, 128) = 2.795$
Other intervention (RC)	23	35	0.592	9.252***			
Care as usual	63	95	0.402	3.900***	−0.190	−1.672	
Music selection	79	130					$F(1, 128) = 0.953$
Own preference (RC)	30	62	0.611	6.911***			
Selection by researcher/therapist	49	68	0.498	6.709***	−0.113	−0.976	
Music induction	79	130					$F(1, 128) = 0.385$
Prerecorded music (RC)	66	109	0.560	8.991***			
Live music	13	21	0.464	3.269**	−0.096	−0.621	
Music style	71	120					$F(1, 118) = 0.512$
Own preference (RC)	34	47	0.521	5.655***			
Relaxation	37	73	0.609	7.296***	0.089	0.716	
Music with lyrics	79	130					$F(2, 127) = 0.872$
No (RC)	52	81	0.556	7.891***			
Yes	5	8	0.264	1.186	−0.292	−1.257	
Both	22	41	0.581	5.471***	0.026	0.201	
Music tempo	79	130					$F(1, 128) = 3.132$
60–80 beats p/m (RC)	49	82	0.625	8.789***			
No specific tempo	30	48	0.413	4.578***	−0.212	−1.871	$F(1, 128) = 3.156$
Frequency intervention	79	130					
One session (RC)	61	90	0.601	9.316***			
More than one session	18	40	0.379	3.487***	−0.222	−1.776	
Duration (continuous)	65	109	0.547	8.662***	0.001	0.547	$F(1, 107) = 0.299$
Sample characteristics							
Proportion of males (continuous)	78	129	0.549	9.480***	0.017	0.061	$F(1, 127) = 0.004$
Age (continuous)	73	123	0.537	9.023***	0.003	0.629	$F(1, 121) = 0.395$

Note: s = number of independent studies; k = number of effect sizes; β_0 = intercept/mean effect size (d); t_0 = difference in mean d with zero; β = estimated regression coefficient; t_1 = difference in mean d with reference category; $F(df_1, df_2)$ = omnibus test; (RC) = reference category. *$p < .05$, **$p < .01$, ***$p < .001$.

control condition ($p = .097$). If a non-established intervention aimed at stress reduction was used as a control condition, effects were somewhat larger than if the control condition concerned CAU (i.e., regular medical care). Finally, the number of interventions showed a trend ($p = .078$) indicating that one single session generated larger effects than two or more sessions.

Discussion

Overall effects

By conducting two separate multilevel meta-analyses, the current study aimed to assess the strength of the effect of music interventions on both physiological and psychological stress-related outcomes.

Furthermore, the study aimed to examine which outcome, study, sample or intervention characteristics moderated the strength of the effect on physiological and psychological stress-related outcomes. Overall, we found a significant small-to-medium effect of music interventions on physiological stress-related outcomes ($d = .380$) and a medium effect of music interventions on psychological stress-related outcomes ($d = .545$), indicating that music intervention groups benefited more than the comparison groups. We conclude that music interventions are effective in reducing physiological and psychological stress-related symptoms in different kinds of settings (mental healthcare, polyclinic medical settings, during medical surgery and in daily life situations). There were no indications of publication bias.

The overall findings of the current study are consistent with findings of previous meta-analyses (Bradt & Dileo, 2014; Bradt et al., 2013a; Bradt et al., 2013b; Bradt et al., 2011; Gillen et al., 2008; Kim, Evangelista, & Park, 2015; Pelletier, 2004; Rudin et al., 2007). There is a growing body of evidence that music interventions yield positive, moderate effects on stress reduction. Considering the demands of today's society, the need for stress reduction interventions are large. Millions of people around the world use tranquilising medications, such as tricyclic antidepressants and benzodiazepines, to cope with life stressors or anxiety (e.g., Bandelow et al., 2015; Olfson et al., 2015; Puetz et al., 2015). Not only do these types of medication have considerable negative side effects, including substance dependence and abuse, research also indicates that the effects of pharmacological treatment on stress-related problems are not much larger than the effects of music interventions found in the current meta-analytic study (Olfson et al., 2015). Besides, a common argument for starting pharmacological treatment instead of psychological treatment for stress reduction is that its effects occur immediately or faster (Bandelow et al., 2015; Fedoroff & Taylor, 2001). However, the results of this meta-analysis were based on mainly short-term music interventions, most of the time on a single occasion, having a direct stress reducing effect in various contexts. The current study therefore indicates the relevance of brief music interventions for stress reduction in all kinds of settings. Also, our search revealed that the effects of long-term music interventions have been seldom examined.

Psychological effects of music

Results of our meta-analysis show a medium effect of music interventions on psychological stress-related outcomes, including emotional states of subjective worry, state anxiety, restlessness and nervousness. Music not only reduces *physiological arousal*, but also affects *emotional states*. This may be attributed to the effect of music on brain areas, such as the amygdala, which are responsible for emotional processes. A related explanation for the positive effects of music interventions on psychological stress-related outcomes concerns the positive influence of listening to pleasant music on *emotional valence*, which can be explained by the degree of attraction that an individual feels towards a specific object or event (Jäncke, 2008; Juslin & Västfjäll, 2008). Music experienced as pleasant increases the intensity of emotional valence (the felt happiness), which has a stress-reducing effect (Jiang, Rickson, & Jiang, 2016; Rohner & Miller, 1980; Sandstrom & Russo, 2010; Witvliet & Vrana, 2007). An increased dopamine activity in the mesolimbic reward brain system has been shown to be associated with these feelings of happiness in response to high-valence music (e.g., Blood & Zatorre, 2001; Salimpoor et al., 2013; Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011; Zatorre, 2015).

Another explanation for the positive effect of music interventions on psychological stress-related outcomes may be that listening to music can provide 'distraction' from stress-increasing thoughts or feelings (Bernatzky, Presch, Anderson, & Panksepp, 2011; Chanda & Levitin, 2013). Indeed, the beneficial property of music to distract people from aversive states has been supported by short-term music interventions for acute stress reduction (Fancourt, Ockelford, & Belai, 2014; Linnemann et al., 2015). These findings are therefore in line with the current meta-analysis, which primarily included studies involving short-term music interventions.

Music listening in the presence of others may strengthen the stress-reducing effect of the music intervention, which is believed to be caused by increased emotional well-being (Juslin et al., 2008), and increased feelings of social cohesion (Boer & Abubakar, 2014; Linnemann, Strahler, & Nater, 2016; Pearce, Launay, & Dunbar, 2015). There is also empirical evidence showing that people synchronise in movement (auditory-motor synchronisation) with each other when engaging in music therapy group interventions, which evokes positive feelings of togetherness and bonding, and decreases stress levels (Linnemann et al., 2016; Tarr, Launay, & Dunbar, 2014). Group music-making or singing together may result in social bonding, which may be explained by the release of the neurotransmitters *endorphin* and *oxytocin* (e.g., Dunbar, Kaskatis, MacDonald, & Barra, 2012; Freeman, 2000; Tarr et al., 2014; Weinstein, Launay, Pearce, Dunbar, & Stewart, 2016). These neurotransmitters play a role in the defensive response to stress (Amir, Brown, & Amit, 1980; Dief, Sivukhina, & Jirikowski, 2018; Myint, Jayakumar, Hoe, Kanthimathi, & Lam, 2017). It should be noted that nearly all studies included in our meta-analysis examined participants listening to music alone (e.g., by using headphones), because most studies examined 'music as medicine' instead of music therapy, which is applied by a music therapist, and can be delivered both in a group and individual format.

Effect moderating variables

Results indicate that moderating variables may explain differences in the strength of the effect sizes. Significant stronger moderating effects were found in studies in which physiological arousal, as a result of stress, was measured by heart rate, compared to studies in which physiological arousal was measured by blood pressure or stress-related hormone levels. These results are consistent with the large body of knowledge concerning the immediate effects of psychological stress on the sympathetic responses in the autonomic nervous system, meaning increases of heart rate and decreases of heart rate variability (Chandola, Heraclides, & Kumari, 2010; Föhr et al., 2017). The results are also in line with the assumption that music with a slow steady rhythm provides stress reduction by altering inherent body rhythms, such as heart rate (Thaut & Hoemberg, 2014; Thaut, Kenyon, Schauer, & McIntosh, 1999).

None of the other possible moderators of interventions effects proved to be significant, but results showed some noteworthy trends of the intervention characteristics. First, the *music tempo* seemed to influence the strength of the effect of music interventions on the psychological stress-related outcomes. Larger effect sizes were found in music with a tempo of 60–80 bpm, where tempo represents slow and soothing music. This corresponds with previous research, which suggests that music with a slow tempo can be considered to be one of the most significant determinants of audio-related effects on stress reduction (Bernardi et al., 2006; Björkman, Karlsson, Lundberg, & Frisman, 2013; Iwanaga, Kobayashi, & Kawasaki, 2005; Jiang et al., 2016; Nilsson, 2008;). Second, the frequency of the music intervention sessions did moderate the effect of music interventions on the psychological stress-related outcomes, indicating that only one session is needed for achieving effects on stress reduction. This is in line with previous research, which implies that music has an immediate positive effect on stress reduction (e.g., Koelsch, 2015; Zatorre, 2015). However, Leubner and Hinterberger's (2017) review of the effectiveness of music interventions on depression showed that more than one session yielded larger effects (at least, within the first 6 weeks of treatment).

Contrary to our expectations, we did not find a significant moderating effect of some intervention characteristics. Firstly, type of intervention did not moderate the effects on physiological stress-related outcomes. Studies in which *music therapy* is offered (by a trained therapist) did not yield significantly larger effect sizes than studies in which music interventions were offered as so-called purposeful *music activities* (by the researcher, healthcare professionals or self-administered by the patient). However, Dileo (2006) stated that music therapy is more effective than 'music as medicine' interventions and attributed this difference to the fact that music therapists individualise their interventions to meet patients' specific needs (Bradt & Dileo, 2014; Dileo, 1999, 2006). A possible explanation for different findings of Dileo's review (2006) compared to the current meta-analytic review is that, in the past 14 years, the number of RCTs examining the effects of 'music as medicine' interventions has grown substantially, and with that, both the associated research methods and intervention protocols were improved. However, experimental research on the effects of *music therapy* is still in its infancy, while considerable diversity is evident in the interventions that have been examined so far. Secondly, results show that the way the music was selected did not influence the effect of music interventions on stress-related outcomes, while many previous studies report that self-selected music is the most effective in terms of stress reduction (e.g., Jiang et al., 2016; Jiang, Zhou, Rickson, & Jiang, 2013; Juslin et al., 2008). A possible explanation is that the term 'self-selected music' is used differently in studies included in this meta-analytic review. The term 'self-selected music' was both used when the patient brings their own favourite music *and* when the patient could choose the music from a pre-selected list of musical styles (e.g., Bradt & Dileo, 2014; Cepeda, Carr, Lau, & Alvarez, 2006; Helsing, Västfjäll, Bjälkebring, Juslin, & Hartig, 2016; Lee, Chung, Chan, & Chan, 2005; Nilsson, 2008). Notably, where self-selected music also means that patients have to choose their music from a preselected list, the researcher can preselect only music with specific characteristics (nonlyrical music with a tempo of 60–80 bpm and a sound intensity level of 60 dB) which contributes to a stronger effect on physiological stress-related outcomes (Bernardi et al., 2006; Björkman et al., 2013; Dileo, 2007; Gan, Lim, & Haw, 2016; Good et al., 2000). Besides, previous research shows that listening to soothing music, pre-selected by the researcher, lowers the stress-levels significantly in contrast to energetic up-tempo music (Iwanaga et al., 2005; Jiang et al., 2013; Sandstrom & Russo, 2010). This differs from the findings of many studies, which attribute these positive effects to the ability of participants to self-select music (Juslin et al., 2008). However, this often means that the participants can choose one of the researcher's pre-selected playlists instead of actually bringing their own music. Because of the uncertainty about what the effect actually causes, in the present study we coded 'own preference' when patients could bring their own music, and 'selection by researcher/therapist' when patients had to choose the music what was pre-selected by the researcher or therapist.

Results showed no moderating effect for the settings in which the music intervention was conducted (nonmedical, surgery, polyclinic procedures), which might indicate that the effects of music interventions do not depend on the type of setting. This is in line with the assumption that stress is a general activation response to any stimulus that could mean both a threat and a challenge, resulting in heightened arousal of the autonomic nervous system (Pfaff et al., 2007; Selye, 1976, 1973). Also, neurological evidence provides insight in to the positive effects of music on the stress response with respect to arousal regulation, and these effects appear to be independent of context or setting (e.g., Casey, 2017; Koelsch, 2015; Koelsch et al., 2016; Linnemann et al., 2015; Thaut & Hoemberg, 2014).

Limitations of the present study

The current study has some limitations that need to be mentioned. Firstly, we operationalised the concept of stress in terms of physiological and psychological outcomes, which resulted in two meta-analyses. Because the moderator analyses were performed on both psychological and physiological data, the impression can be that it concerns two independent outcomes, while the outcomes always affect and strengthen each other during stress. This is because the underlying systems of the physiological and psychological responses are both, and mostly at the same time, responsible for the experience of stress (e.g., Linnemann et al., 2017; McEwen & Gianaros, 2010). Secondly, some categories of relevant variables included in the moderator analyses contained only a few effect sizes, which reduces statistical power and sets limits to the generalizability of the study findings. This especially may be the case for the moderators *music induction* (prerecorded music vs. live music) and *music style* (relaxation vs. own choice) in the meta-analysis of the physiological stress-related outcomes and the moderators *music tempo* (60–80 bpm vs. another tempo), and the *frequency* of the intervention (a single session vs. more than one session) in the meta-analysis of the psychological stress-related outcomes.

Implications for research and practice

Despite the limitations, this study has important implications for future research and the practical use of music interventions in stress reduction. First and foremost, this meta-analytic study indicates that music interventions can be effective in the reduction of stress. Many people suffer from stress-related symptoms, both in their daily lives and in specific settings (e.g., medical settings, mental health care settings, work-related settings). Considering the fact that music interventions are very easy and inexpensive to integrate in both daily lives and in medical settings, it is important to recognise the effects of music interventions. Another implication is that future research should focus on the specific characteristics of the music intervention on stress reduction, for example, the music tempo, the style of the music, the use of live music or prerecorded music, the way the music is selected, or the frequency of the music intervention sessions.

The vast body of neurological evidence regarding the influence of music on arousal, stress and emotional processes is still growing, but the specific practical implications have not yet been sufficiently investigated. In included RCTs, music interventions are still considered like one and the same, while the specific characteristics of music show different effects, such as the music tempo (60–80 bpm). To identify the most effective music intervention for stress reduction, it is important that the possible moderators of the music interventions be better tested. Therefore, it is recommended for future trials to describe all aspects of the music intervention, with both the specific characteristics involved in these two meta-analyses as well as the musical characteristics, such as timbre, melodic and harmonic aspects, and rhythmic accentuation. These characteristics were not reported in the included RCTs, but can nonetheless moderate the effects of music interventions on stress reduction (e.g., Leubner & Hinterberger, 2017; Moore, 2013; Thaut & Hoemberg, 2014). There are many RCTs examining the effect of *music as medicine interventions*, but there is definitely a lack of RCTs examining the effect of *music therapy interventions* on stress-related outcomes, and it is therefore impossible to establish at this time whether these interventions are more effective than the 'music as medicine' interventions. Although the use of prerecorded music may be preferred by researchers as a standardised stimulus, it is recommended to also develop specific *music therapy* protocols that will adhere to the research standards of RCTs.

The relationship between the frequency/duration of the music intervention and the effects on stress reduction is unclear. Future research should examine this topic, because apart from the musical characteristics, such as the music style and music tempo, these general characteristics of the music intervention may also moderate the effects on stress reduction. It seems that the influence of the music selection method on the effects of the music intervention is interpreted differently. In new trials, we strongly recommend reporting clearly if the researcher/therapist did choose the music of the intervention, or if the participants had to choose one of the researchers' or therapists' pre-selected music playlists, or if the participants brought their own music. Finally, it is recommended to compare the effects of music (therapy) interventions on stress-related outcomes with pharmacological treatment, but also with other experiential interventions, such as yoga or mindfulness.

Summary

The current meta-analytic review provides high-level evidence that music interventions can be effective in reducing stress and provides justification for the increasing use of music interventions for stress reduction in both medical and mental health care practice. Considering the low costs and lack of side effects of music interventions, the moderate tranquilising effects of music are very significant for the prevention and treatment of stress-related problems. However, the development of music (therapy) intervention protocols are necessary to set up more robust research into the effects of music interventions, and to gain more insight into the effect moderating characteristics of music intervention for stress reduction.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Nederlandse Organisatie voor Wetenschappelijk Onderzoek: [grant number 023.007.068].

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Appendices

Appendix 1

Table A1. Characteristics of included studies.

Authors	Year	*N*	Impact factor	Study quality	Type of measures	Type of outcome (s)	Physiological measure	Type setting	Intervention
Aba et al.	2017	186	1.379	Strong	psych	Anxiety	–	Med-proc	MA
Allen et al.	2000	40	4.58	Strong	phys	Stress	BP, HR	Surgery	MA
Ames et al.	2017	41	–	Strong	psych	Anxiety	–	Surgery	MA
Angioli et al.	2014	372	1.283	Moderate	phys, psych	Stress, Anxiety	BP, HR	Med-proc	MA
Bally et al.	2003	107	1.326	Strong	psych	Anxiety	–	Med-proc	MA
Bauer et al.	2010	80	2.05	Strong	psych	Stress	–	Med-proc	MT
Beck et al.	2015	20	0.8	Weak	phys, psych	Stress	Horm	Non-med	MT
Bekiroglu et al.	2013	60	1.935	Moderate	phys	Stress	BP	Med-proc	MA
Bringman et al.	2009	326	2.322	Moderate	phys, psych	Stress, Anxiety	BP, HR	Surgery	MA
Buffum et al.	2006	170	0.524	Weak	phys, psych	Stress, Anxiety	BP, HR	Surgery	MA
Bulfone et al.	2009	60	0.659	Moderate	psych	Anxiety	–	Med-proc	MA
Camara et al.	2008	203	1.17	Weak	phys	Stress	BP, HR	Surgery	MA
Cassileth et al.	2003	62	6.072	Moderate	psych	Anxiety	–	Med-proc	MT

(*Continued*)

Table A1. Continued.

Authors	Year	*N*	Impact factor	Study quality	Type of measures	Type of outcome (s)	Physiological measure	Type setting	Intervention
Chan et al.	2006	43	1.197	Weak	phys	Stress	BP, HR	Med-proc	MA
Chen et al.	2012	73	1.754	Strong	psych	Anxiety	–	Med-proc	MA
Cutshall et al.	2011	100	1.243	Weak	phys, psych	Stress	BP, HR	Surgery	MA
Chang et al.	2015	76	1.426	Weak	phys	Stress	BP, HR	Med-proc	MA
Chang Yu, Chen & Chen	2015	296	1.545	Strong	psych	Stress	–	Med-proc	MA
Chang et al.	2008	236	1.255	Strong	psych	Stress	–	Med-proc	MA
De la Torre-Luque et al.	2017a	21	1.296	Strong	phys, psych	Stress, Anxiety	HR	Non-med	MA
De la Torre-Luque et al.	2017b	58	1.394	Strong	phys, psych	Stress, Anxiety	HR	Non-med	MA
DeMarco et al.	2012	26	–	Moderate	phys, psych	Stress, Anxiety	BP, HR	Surgery	MA
Di Nasso et al.	2016	100	2.807	Moderate	phys	Stress	BP, HR	Med-proc	MA
Doğan & Şenturan	2012	200	–	Strong	psych	Anxiety	–	Med-proc	MA
Doro et al.	2016	100	2.698	Moderate	psych	Anxiety	–	Med-proc	MT
Drzymalski et al.	2017	99	3.14	Moderate	phys	Stress	BP, HR	Med-proc	MA
El-Hassan et al.	2009	180	5.727	Weak	psych	Anxiety	–	Med-proc	MA
Elliott	1994	38	1.657	Strong	phys, psych	Stress, Anxiety	BP, HR	Med-proc	MA
Ghetti	2013	23	1.185	Moderate	phys, psych	Stress, Anxiety	BP, HR	Med-proc	MT
Ghezeljeh et al.	2017	92	0.801	Strong	psych	Anxiety	–	Med-proc	MA
Gomez-Urquiza et al.	2016	120	1.998	Moderate	phys, psych	Stress, Anxiety	BP, HR	Surgery	MA
Graversen & Sommer	2013	75	2.232	Weak	phys	Stress	Horm	Surgery	MA
Groener et al.	2015	35	1.555	Moderate	psych	Stress	–	Med-proc	MA
Gupta & Gupta	2015	60	1.9	Strong	phys, psych	Stress, Anxiety	BP, HR	Non-med	MA
Guzetta	1989	53	1.657	Strong	phys	Stress	HR	Med-proc	MA
Hamel	2001	101	1.326	Strong	phys, psych	Stress, Anxiety	BP, HR	Med-proc	MA
Hammer	1996	16	1	Strong	psych	Anxiety	–	Non-med	MT
Hamidi & Ozturk	2017	100	2.27	Strong	phys, psych	Stress, Anxiety	BP, HR	Med-proc	MA
Han et al.	2010	137	1.255	Strong	phys, psych	Stress, Anxiety	BP, HR	Surgery	MA
Horne-Thomson & Grocke	2008	25	2.023	Moderate	phys	Stress	HR	Non-med	MT
Hook et al.	2008	110	–	Strong	psych	Anxiety	–	Surgery	MA
Hsu et al.	2016	70	2.056	Moderate	psych	Anxiety	–	Med-proc	MA
Hayes et al.	2003	198	0.671	Weak	psych	Anxiety	–	Med-proc	MA

(*Continued*)

Table A1. Continued.

Authors	Year	*N*	Impact factor	Study quality	Type of measures	Type of outcome (s)	Physiological measure	Type setting	Intervention
Jeppesen et al.	2016	143	–	Moderate	psych	Anxiety	–	Surgery	MA
Jiménez-Jiménez et al.	2013	40	0.211	Strong	phys	Stress	BP, HR, Horm	Surgery	MA
Johnson et al.	2012	119	0.662	Strong	psych	Anxiety	–	Surgery	MA
Kar et al.	2015	34	–	Moderate	phys	Stress	Horm	Surgery	MA
Ko et al.	2017	138	1.252	Weak	psych	Anxiety	–	Med-proc	MA
Kunikullaya et al.	2015	88	0.922	Strong	phys, psych	Stress, Anxiety	BP, HR, Horm	Med-proc	MA
Kushnir et al.	2012	60	1.264	Strong	phys	Stress	BP, HR	Surgery	MA
Lai & Li	2011	54	1.741	Strong	phys, psych	Stress	BP, HR, Horm	Non-med	MA
Lai et al.	2008	44	1.255	Strong	phys, psych	Stress, Anxiety	BP, HR	Med-proc	MA
Lai et al.	2013	60	1.814	Strong	phys	Stress	BP, HR	Non-med	MA
Latha et al.	2014	80	–	Moderate	phys	Stress	BP, HR	Non-med	MA
Leardi et al.	2007	60	5.596	Moderate	phys	Stress	Horm	Med-proc	MA
Lee et al.	2016	64	1.585	Moderate	phys, psych	Stress	BP	Non-med	MA
Lee et al.	2012	140	1.427	Strong	phys, psych	Stress, Anxiety	HR, HRV	Surgery	MA
Lee, Lai, Sung et al.	2017	85	2.344	Strong	phys, psych	Stress, Anxiety	BP, HR	Med-proc	MA
Lee, Lee, Hsu et al.	2017	85	1.549	Strong	phys, psych	Stress, Anxiety	BP, HR	Surgery	MA
Lee, Wu, Lee et al.	2017	100	2.013	Weak	phys, psych	Stress, Anxiety	BP, HR	Surgery	MA
Lin et al.	2011	98	1.384	Strong	psych	Anxiety	–	Med-proc	MA
Lin et al.	2012	88	1.604	Moderate	phys, psych	Stress	BP, HR	Med-proc	MA
López-Cepero Andrada	2004	118	2.253	Moderate	psych	Anxiety	–	Med-proc	MA
Mahdipour et al.	2012	150	–	Moderate	psych	Stress, Anxiety	–	Surgery	MA
Mandel et al.	2007	68	0.8	Weak	phys, psych	Stress, Anxiety	BP	Surgery	MT
Menegazzi et al.	1991	38	4.58	Weak	phys	Stress	BP, HR	Med-proc	MA
Ng et al.	2016	197	3.64	Strong	psych	Anxiety	–	Med-proc	MA
Miyata et al.	2016	42	–	Strong	phys, psych	Stress, Anxiety	HR	Med-proc	MA
Ni et al.	2011	172	1.384	Weak	phys, psych	Anxiety	BP, HR	Surgery	MA
Nilsson	2009	58	1.332	Strong	phys	Stress	BP, HR, Horm	Surgery	MA
Nilsson et al.	2005	75	3.634	Strong	phys	Stress, Anxiety	BP, HR, Horm	Surgery	MA
O'Callaghan et al.	2012	97	1.182	Moderate	psych	Anxiety	–	Med-proc	MA
Padam et al.	2017	132	0.81	Strong	phys, psych	Stress, Anxiety	BP, HR	Med-proc	MA
Pothoulaki et al.	2008	60	1.748	Weak	psych	Anxiety	–	Med-proc	MA
Radstaak et al.	2014	123	3.473	Strong	psych	Stress	–	Non-med	MA
Romito et al.	2013	62	0.769	Strong	psych	Stress, Anxiety	–	Med-proc	MT

(*Continued*)

Table A1. Continued.

Authors	Year	*N*	Impact factor	Study quality	Type of measures	Type of outcome (s)	Physiological measure	Type setting	Intervention
Ripley et al.	2014	70	0.824	Moderate	phys	Stress	BP, HR	Med-proc	MA
Salehi et al.	2016	166	0.972	Strong	psych	Anxiety	–	Med-proc	MA
Sanal & Gorsev	2014	70	0.647	Weak	psych	Anxiety	–	Non-med	MA
Sendelbach et al.	2006	86	2.172	Moderate	phys, psych	Stress, Anxiety	–	Surgery	MA
Shabanloei et al.	2010	100	0.24	Moderate	psych	Anxiety	BP, HR	Med-proc	MA
Shin & Kim	2011	233	0.849	Moderate	psych	Stress, Anxiety	–	Med-proc	MA
Simavli et al.	2014	141	3.57	Moderate	psych	Anxiety	–	Med-proc	MA
Smith	2008	80	–	Weak	psych	Anxiety	–	Non-med	MT
Solomon & Ridgeway	2016	66	3.56	Moderate	psych	Anxiety	–	Med-proc	MA
Soo et al.	2016	80	2.993	Strong	psych	Anxiety	–	Med-proc	MA
Stein et al.	2010	56	0.622	Weak	psych	Stress, Anxiety	–	Surgery	MA
Su et al.	2013	28	1.917	Moderate	phys	Stress	–	Surgery	MA
Tabrizi et al.	2012	90	1.292	Weak	phys	Stress	BP, HR, Horm	Surgery	MA
Tan et al.	2015	100	1.158	Moderate	phys	Stress	BP, HR	Med-proc	MA
Thoma et al.	2015	92	2.13	Weak	psych	Anxiety	–	Med-proc	MA
Toker & Kömürcü	2017	70	2.013	Moderate	psych	Anxiety	–	Med-proc	MA
Triller et al.	2006	200	2.651	Moderate	phys	Stress	BP, HR	Med-proc	MA
Uedo et al.	2004	29	0.93	Moderate	phys	Stress	Horm	Med-proc	MA
Vachiramon et al.	2013	100	1.936	Strong	psych	Anxiety	–	Surgery	MA
Voss et al.	2004	61	5.836	Strong	psych	Stress, Anxiety	–	Surgery	MA
Wang et al.	2015	60	1.395	Strong	phys, psych	Stress, Anxiety	BP, HR	Surgery	MT
Warth et al.	2016	84	2.649	Strong	phys, psych	Stress	HRV	Med-proc	MT
White	1992	40	0.766	Strong	phys, psych	Anxiety	BP, HR	Surgery	MA
Wiwatwongwana et al.	2016	91	2.275	Strong	phys, psych	Stress, Anxiety	BP, HR	Surgery	MA
Yeo et al.	2008	70	1.71	Weak	phys	Stress	BP, HR	Med-proc	MA
Zengin et al.	2013	100	1.935	Weak	phys	Stress	BP, HR, Horm	Med-proc	MA
Zhang et al.	2014	124	0.68	Strong	psych	Anxiety	–	Med-proc	MA

Note: psych = psychological stress-related outcomes; phys = physiological stress-related outcomes; BP = blood pressure; HR = heart rate; Horm = hormone levels; HRV = heart rate variability; MA = music activity; MT = music therapy.

Appendix 2

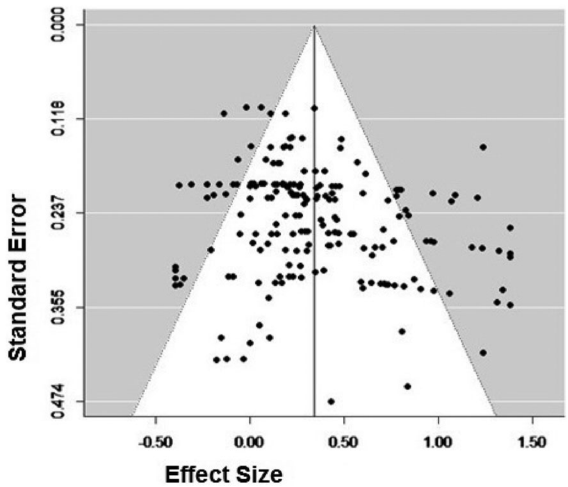

Figure A1. Trim-and-fill plot of the effects of music interventions on physiological stress-related outcomes.

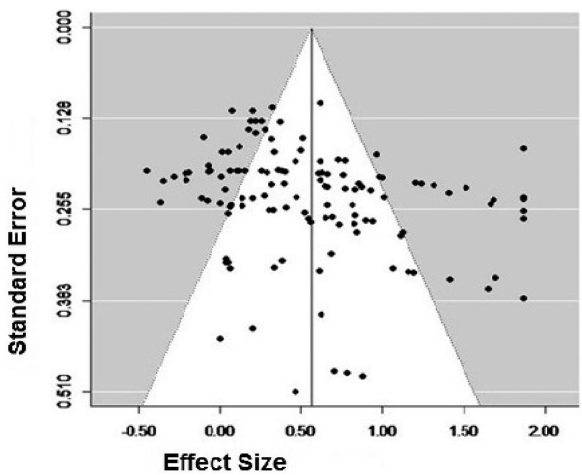

Figure A2. Trim-and-fill plot for the effects of music interventions on psychological stress-related outcomes.