Nutrition 28 (2012) 1075–1080

Contents lists available at ScienceDirect

Nutrition

journal homepage: www.nutritionjrnl.com

Review

The impact of music on metabolism

Alisa Yamasaki B.A. [a], Abigail Booker B.A. [a,b], Varun Kapur M.D. [a], Alexandra Tilt B.A. [a,b], Hanno Niess M.D. [c], Keith D. Lillemoe M.D. [a], Andrew L. Warshaw M.D. [a], Claudius Conrad M.D., Ph.D. [a,*]

[a] *Massachusetts General Hospital, Department of Surgery, Harvard Medical School, Boston, MA, USA*
[b] *University of Virginia Medical School, Charlottesville, Virginia, USA*
[c] *Department of Surgery, University of Munich–Grosshadern, Munich, Germany*

ARTICLE INFO

Article history:
Received 26 January 2012
Accepted 26 January 2012

Keywords:
Music
Metabolism
Music therapy
Hypothalamic–pituitary axis
Sympathetic nervous system
Immune system
Stress
Pain management
Neonatal metabolism
Gastric physiology
Gastric myoelectrical activity
Exercise metabolism

ABSTRACT

The study of music and medicine is a rapidly growing field that in the past, has been largely focused on the use of music as a complementary therapy. Increasing interest has been centered on understanding the physiologic mechanisms underlying the effects of music and, more recently, the suggested role of music in modulating metabolic responses. Research has established a role for music in the regulation of the hypothalamic–pituitary axis, the sympathetic nervous system, and the immune system, which have key functions in the regulation of metabolism and energy balance. More recent findings have shown a role for music in the metabolic recovery from stress, the regulation of gastric and intestinal motility, the moderation of cancer-related gastrointestinal symptoms, and the increase of lipid metabolism and lactic acid clearance during exercise and postexercise recovery. The purpose of this article is to summarize the most current understanding of the mechanisms by which music affects the metabolic responses in the context of potential applications.

Introduction

The study of music and medicine is a rapidly growing field that in the past has been largely focused on the use of music as a complementary therapy. In clinical and non-clinical contexts, music has been shown to have a positive influence in wide-ranging fields such as stress reduction, relaxation, pain management, neural cognition, cardiac function, and more [1–5]. However, increasing interest has been centered on understanding the physiologic mechanisms underlying the effects of music and, more recently, the suggested role of music in modulating the metabolic responses. Research has established a role for music in the regulation of the hypothalamic–pituitary-adrenal (HPA) axis, the sympathetic nervous system (SNS), and the immune system, which have key functions in the regulation of metabolism and energy balance. More recent findings, as will be discussed, have shown a role for music in the metabolic recovery from stress, the regulation of gastric and intestinal motility, the moderation of cancer-related gastrointestinal symptoms, and the increase of lipid metabolism and lactic acid clearance during exercise and postexercise recovery.

The purpose of this review is to summarize the most current understanding of the mechanisms by which music affects the metabolic responses in the context of potential applications.

Established parameters: HPA axis, SNS, immune function

Recent studies have focused on a deeper understanding of the effect of music on the complex human stress response through the HPA axis, SNS, and immune system activity. Modulations in HPA axis activity have been measured by serum levels of cortisol, adrenocorticotropic hormone, growth hormone (GH), insulin-like growth factor, and oxytocin. Cortisol is released from the adrenal glands in response to increased adrenocorticotropic hormone from the anterior pituitary. Cortisol stimulates a metabolic response by inducing gluconeogenesis and glycogenesis in the liver and suppressing the immune system through a negative-feedback effect on cytokine production. This also

Ms. Yamasaki and Ms. Booker contributed equally to this work.

* Corresponding author. Tel.: +1-617-726-2000; fax: +1-617-582-6177.
E-mail address: cconrad1@partners.org (C. Conrad).

0899-9007/$ - see front matter © 2012 Elsevier Inc. All rights reserved.
doi:10.1016/j.nut.2012.01.020

promotes the general catabolic state through the metabolism of protein, fat, and carbohydrate in sites such as muscle, adipose tissue, connective tissue, and lymphoid tissue. Conversely, decreases in HPA activity attenuate the activation of these catabolic processes. Thus, HPA axis activity has an important role in regulating metabolic processes and energy balance.

Several studies have shown the role of music in decreasing cortisol levels in perioperative environments. Patients who were exposed to music after surgery exhibited significant decreases in cortisol levels compared with patients who were not exposed to music [6–8]. In a study by Nilsson et al. [7], day-surgery patients who received a postoperative music intervention exhibited a 206-mmol/L decrease in cortisol levels after 2 h in the postanesthesia care unit compared with 72 mmol/L in the control group. Similarly, Leardi et al. [6] reported decreases in cortisol levels in patients who received pre- and postoperative musical exposures. Statistically significant decreases in postoperative cortisol levels were exhibited in patients who were able to select the type of music used [6]. The hypermetabolic response is characterized by the release of catecholamines, cortisol, cytokines, and other neuroendocrine hormones that are modulated by the HPA axis and the SNS as a result of severe injury such as a burn. This intensely catabolic process is facilitated in part by hypercortisolemia through the promotion of glycogenolysis, lipolysis, and proteolysis. Through decreasing cortisol levels, it is conceivable that music has the ability to trigger decreases in energy catabolism, which is particularly detrimental in the pediatric burn population. Future research will demonstrate whether it is possible to consistently attenuate the hypermetabolic response to injury using music because conventional therapy is flawed by limited efficacy and significant side effects, especially in the pediatric patient population [9–12].

The probable first step in understanding music's ability to mediate stress relaxation is that music increases levels of GH, through which it directly affects the HPA axis [13]. Previously implicated in hypermetabolic pathology, GH is an anabolic hormone produced by the anterior pituitary that stimulates the breakdown of triacylglycerols, suppresses the uptake of circulating lipids, and mediates growth-stimulating effects in a wide variety of tissues by stimulating the secretion of insulin-like growth factor-1. In the early phases of injury, a state of GH resistance develops as part of the acute stress response [14]. Several studies have suggested that music may moderate this effect. This has been observed in critically ill patients who were shown to have significant increases in plasma concentrations of GH after exposure to defined relaxing music. Patients receiving music intervention also showed simultaneous decreases in levels of the inflammatory cytokine interleukin-6 (IL-6) and epinephrine in response to increased GH levels [13]. Mechanistically, this is explained by the ability of GH to bind IL-6 receptors on the surface of inflammatory cells, triggering a decrease in the inflammatory response. Studies have demonstrated an inverse correlation between the availability of the GH-releasing hormone and IL-6 release from peripheral blood mononuclear cells, which is mediated through a direct effect of GH on peripheral blood-derived mononuclear cells that secrete IL-6 [15]. A study by Okada et al. [16] confirmed similar trends, with significantly lowered levels of IL-6, epinephrine, and norepinephrine observed in patients with cerebrovascular disease and dementia receiving music therapy compared with patients who did not. Given the role of IL-6 and epinephrine in central nervous system–mediated immune modulation through the HPA axis and autonomic nervous system (ANS), respectively [17,18], these findings suggest a basis for the interaction between musical stimulation and neuroendocrine-immune pathways.

The alteration of ANS activity has implications for the regulation of cardiovascular responses in addition to the effects on neuroendocrine and immune system activity. The ANS response likely plays an important role in mediating the effects of music on immune and neurohormonal activity, particularly given the ability of music to induce emotional and mental activity that can modulate ANS function [19]. Studies investigating the impact of music on cardiovascular variables have found increased corticotropin-releasing hormone and adrenocorticotropic hormone levels in patients with chronic heart failure, suggesting dysfunctional feedback and increased signaling of the HPA axis in chronic heart failure [20]. Heart rate variability (HRV)—in addition to measurements of serum epinephrine and norepinephrine levels—is generally considered the standard method for assessing quantitative markers of cardiac autonomic activity. In patients with chronic heart failure, a higher HRV is linked to fewer life-threatening arrhythmias and a better prognosis, whereas a decrease in HRV is associated with worse outcomes. One of the simplest methods to determine HRV is through time–domain variables, which measure the instantaneous heart rate or the interval between successive normal complexes. Commonly used time–domain parameters include the square root of the mean squared differences of successive normal-to-normal intervals and the number of interval differences of consecutive normal-to-normal intervals that exceeds 50 ms. These two measurements, in addition to high-frequency activity, are indicative of parasympathetic HRV [21]. In two separate studies, it was found that music therapy led to a significant increase in HRV parameters such as the square root of the mean squared differences of successive normal-to-normal intervals, the number of interval differences of consecutive normal-to-normal intervals that exceeds 50 ms, and high-frequency activity in elderly patients with cerebrovascular disease and dementia, suggesting a music-induced activation of the parasympathetic nervous system [16,22]. At the same time, sympathetic tone was attenuated in patients undergoing music therapy because they had significantly lower levels of epinephrine and norepinephrine compared with control groups. Taken together, music therapy induced relaxation responses in the limbic and hypothalamic systems that also led to a lower frequency of acute heart failure events and congestive heart failure exacerbations compared with controls (10.9% versus 34.4%, $P < 0.05$). Similar observations were noted by Chuang et al. [23]; the measurement of HRV parameters in cancer survivors reflected increased parasympathetic nervous system activity and decreased SNS activity after 2 h of music therapy. In separate studies outside chronic heart failure, Chuang et al. [24] also showed that parasympathetic HRV parameters in patients with breast cancer were significantly increased with music exposure, although no concomitant change was seen in markers of sympathetic activity. In these ways, music has the potential to decrease HPA axis activity through ANS responses and provide measureable physiologic benefits that can be applicable to clinical settings.

The ability of music to decrease stress has valid therapeutic uses that have been studied in various clinical environments. Perioperative acoustical stimulation has been shown to decrease the amount of sedative and analgesic medication needed in addition to decreasing perioperative anxiety and postoperative pain and improving overall postoperative recovery. Koelsch et al. [25] demonstrated that patients receiving musical stimulation before, during, and shortly after surgery required less sedative medication to achieve light sedation under regional anesthesia.

Patients exposed to music had approximately 15% lower consumption and target plasma concentration of propofol and nominally lower bispectral index scores compared with the control group, indicating deeper levels of sedation compared with controls [25]. Zhang et al. [26] reported significantly lower intraoperative propofol target concentrations, total propofol requirements, and time to induction of sedation in women undergoing hysterectomies with spinal–epidural anesthesia who received the music exposure of their choice compared with those who did not receive any music intervention. Similar findings were reported with patient-controlled, intravenous midazolam requirements in patients undergoing ambulatory or short-stay surgery with spinal anesthesia. The music intervention group required 1.2 mg of total midazolam for the entire perioperative period, which was significantly lower than the 2.5 mg required by the control group [8]. In patients undergoing open hernia repair, those receiving postoperative music also required a significantly lower total dose of intravenous morphine postoperatively (1.2 mg) compared with the control group (3.6 mg) [7]. Furthermore, a meta-analysis of six studies with 641 patients undergoing endoscopy showed that music therapy lowered analgesia requirements by 29% and procedure time by 21% [27]. Taken together, these studies demonstrate perioperative roles for the impact of music on stress reduction and metabolism, as indicated by lower analgesic requirements and enhancement of the sedative effects of analgesia.

Novel approaches: studies in neonates, gastric physiology, exercise metabolism

An increasing area of focus in music and metabolism involves the therapeutic role of music in promoting the anabolic responses necessary for recovery from injury or severe stress. In particular, studies in neonates have shown the efficacy of music as a developmental care intervention for preterm infants in the neonatal intensive care unit [28]. The review by Neal and Lindeke [28] highlighted several studies that observed decreased physiologic instability and increased physiologic functioning in preterm infants presented with music stimulation based on metrics such as fewer episodes of apnea and bradycardia, less observed pain, increased daily weight gain, larger formula intake, higher oxygen saturations, improved frequency and strength of non-nutritive sucking, and fewer days to discharge. More recently, Lubetzky et al. [29] showed that gavage-fed infants at postmenstrual 30 to 37 wk of age had a 10% to 13% decrease in their resting energy expenditure within 10 min of listening to the music of Mozart. Although the exact mechanisms are unclear, it is speculated that this decrease in energy expenditure correlates to an increased metabolic efficiency that thus improves weight gain. In contrast, an investigation in obese adults examined the use of stressful classical music to increase resting expenditure, though the study did not yield significant results [30]. Further research will be needed to elucidate the physiologic effects of music on resting metabolism.

Recent research has suggested a role for auditory stimuli in the regulation of gastric myoelectrical activity. In animal studies, acoustic stress has been shown to have a negative impact on gastric and intestinal motility. A study in dogs subjected to postprandial acoustic stress showed a delay in the recovery of the migrating motor complex pattern, a slowing of gastric emptying, and an increase in the feeding-induced release of gastrin, pancreatic polypeptide, and somatostatin [31]. A similar study in mice revealed an increase in gastric emptying associated with increased levels of corticotropin-releasing factor when subjected to acoustic stress [32]. In contrast, human studies have indicated that listening to enjoyable music increases the amplitude of gastric myoelectrical activity in healthy human adults, which can promote increased gastric motility and stimulate gastric emptying [33]. The same study also showed that the effect of music on gastric contractility was much lower in patients who deemed the music to be unenjoyable. Interestingly, the impact of music on gastric activity is age dependent, because adolescents in the fasting state are much more susceptible to audio stress than adults in the fasting state. Although classical music and noise impaired gastric slow-wave frequency in adolescents, classical music increased gastric slow wave rhythmicity in adults [34]. In these ways, music therapy may play a part in improving gastric motility and stimulating gastric emptying. Overall, these data provide growing support for the ability of music to facilitate normalizing intestinal motility. In clinical contexts, these findings are particularly relevant in environments such as the intensive care unit, where patients could achieve significant benefit from improved gastrointestinal motility through a decreased need for parenteral support, the promotion of early enteral nutrition, and a lessened risk of long-term adverse sequelae from intestinal non-use.

Music therapy may also prevent or attenuate gastrointestinal symptoms such as nausea and vomiting in cancer therapy. In a study of bone marrow transplant recipients undergoing high-dose emetogenic treatment, patients receiving musical stimulation in combination with antiemetics reported significantly less nausea and vomiting than those taking antiemetics alone [35]. This finding was corroborated by Madson and Silverman [36] when the qualitative impact of music interventions on pain and nausea was studied in transplant recipients. After receiving weekly music therapy sessions of 15 to 35 min, transplant recipients reported significant improvements in relaxation, anxiety, pain, and nausea. Ongoing research may continue to define a clinical role for music as a complementary therapy in moderating cancer-related gastrointestinal symptoms.

During exercise, music is commonly used for motivational purposes, to counterbalance emotional and physical fatigue, and to improve performance. Recent research has implied physiologic evidence for the role of music in increasing exercise performance, improving the lipid profile, and facilitating postexercise recovery. An early study by Brownley et al. [37] investigated the physiologic impact of listening to no music, fast-paced music, and sedative music for trained and untrained runners during exercise of varying intensities. Under conditions of high-intensity exercise, runners listening to fast music had higher plasma cortisol levels [37]. Given the role of cortisol in promoting the catabolism of energy substrates in muscle, adipose, and connective tissues, this suggests a potential metabolic benefit for the use of upbeat music during exercise. Interestingly, music had a differential psychological effect depending on training level; untrained runners reported a more positive psychological affect from fast music during high- and low-intensity exercise compared with trained runners who experienced their most negative feelings while listening to fast music [37]. Achieving the maximal benefits of music during exercise may therefore require calibration of the type of music used and a consideration of the fitness level of the individual. Music may also have a role in re-enforcing the effect of exercise in improving the lipid profile. In a study of resistance training in obese women, subjects who participated in resistance training with music showed a significant increase in high-density lipoprotein and significant decreases in total cholesterol, low-density lipoprotein, and total body fat percentages, whereas decreases in total

Table 1
Summary of key references and established impact of music and novel approaches

Article	Summary
Music and healing	
Conrad C. Music for healing: from magic to medicine. Lancet 2010;376(9757):1980–1	Provides a historical and philosophical account of the evolving use of music in healing and medicine. Explores future avenues for research to better characterize the impact of music on the stress response and its future therapeutic applications.
Established impact on anxiolysis and sedation	
Koelsch S, Fuermetz J, Sack U, Bauer K, Hohenadel M, Wiegel M, et al. Effects of music listening on cortisol levels and propofol consumption during spinal anesthesia. Front Psychol 2011;2:58	Examines the impact of instrumental music on hormone levels, the immune system, and sedative requirements during spinal anesthesia. Demonstrates the stress-decreasing effect of music and the clinical relevance of music in decreasing sedative requirements to achieve light sedation under regional anesthesia.
Conrad C, Niess H, Jauch K-W, Bruns CJ, Hartl WH, Welker L. Overture for growth hormone: requiem for IL-6? Crit Care Med 2007;35(12):2709–13	Investigates the biological basis of music's anxiolytic effect in humans and describes a significant role for centrally expressed growth hormone and peripheral interluekin-6 conduction in hemodynamics.
McCraty R, Barrios-Choplin B, Atkinson M, Tomasino D. The effects of music on mood, tension, and mental clarity. Altern Ther Health Med 1998;4(1):75–84	Studies the effect of grunge rock, classical, New Age, and designer music on the mood, tension, and mental clarity of individuals. Provides initial groundwork for more detailed investigation of the variable impact of different musical genres on autonomic nervous system, cardiovascular, neuroendocrine, and immune system functions.
Neonatal and pediatric populations	
Lubetzky R, Mimouni FB, Dollberg S, Reifen R, Ashbel G, Mandel D. Effect of music by Mozart on energy expenditure in growing preterm infants. Pediatrics 2010;125(1):e24–8	Presents a role for music therapy in neonatal and pediatric populations. Suggests resting energy expenditure is decreased in preterm infants who were exposed to music of Mozart, although continued work is needed to elucidate the specific mechanisms of this effect.
Neal DO, Lindeke LL. Music as a nursing intervention for preterm infants in the NICU. Neonatal Netw 2008;27(5):319–27	Reviews the current literature surrounding the use of music in neonatal intensive care unit settings and outlines guidelines for the effective use of music for preterm infants.
Gastric activity	
Chen DD, Xu X, Zhao Q, Yin J, Sallam H, Chen JD. Effects of audio stimulation on gastric myoelectrical activity and sympathovagal balance in healthy adolescents and adults. J Gastroenterol Hepatol 2008;23(1):141–9	Demonstrates differential impact of classical music and noise on gastric myoelectric activity and sympathovagal balance in adolescents versus adults. Establishes potential utility of music therapy in stimulating gastric motility.
Exercise physiology and recovery	
Eliakim M, Bodner E, Eliakim A, Nemet D, Meckel Y. Effect of motivational music on lactate levels during recovery from intense exercise. J Strength Cond Res 2012;26(1):80–6	Explores ability of music to facilitate postexercise recovery after intense physical training, based on measurements of blood lactate concentration and self-perceived exhaustion. Represents area for continued research to understand underlying physiology of music's impact on exercise recovery.

cholesterol, low-density lipoprotein, and total body fat percentage were not observed in the control group [38]. However, further studies are needed to characterize the isolated impact of music and to define the mechanisms through which music may alter lipid metabolism during exercise. After conditions of intense exercise, music may also facilitate postexercise recovery. In a study of trained college-age men, listening to dance-style remixes of Western pop music resulted in significant increases in voluntary activity after sessions of intense running compared with those who did not listen to music. Subsequently, the music group showed significant decreases in blood lactate concentration and the rate of perceived exhaustion within the first 15 min of postexercise recovery compared with controls [39]. Although these studies provide a foundation for describing the role of music in exercise-related performance and metabolism, this represents an area for continued future study.

Conclusion and future recommendations

Current research has defined a role for musical stimulation in the regulation of metabolism and energy balance through the regulation of HPA activity. Studies have shown that music decreases HPA axis stimulation by decreases in serum levels of cortisol, increases in GH, and moderate decreases in IL-6 and epinephrine levels. Music also affects ANS responses, which can have resultant effects on immune system activity, neuroendocrine stimulation, and cardiovascular measurements. The therapeutic value of these findings have translated into advantages in clinical settings, particularly in perioperative environments in which acoustic stimulation led to decreased requirements for sedative and analgesic medications. More novel studies have focused on understanding the applicability of music in promoting metabolic efficiency during injury recovery, improving gastric myoelectric activity and gastric motility, curbing cancer-related gastrointestinal symptoms, and increasing exercise-related metabolic benefits (Table 1).

Several new areas of research have also emerged that represent promising topics for continued future inquiry. The impact of different types of music on specific metabolic responses is a question that has not been extensively pursued, although existing work has examined the effect of different musical genres on aspects of the stress response. Several studies have observed the relaxing effect of classical music, whereas genres such as hip hop, techno music, and heavy metal [40] (see Table 2 for definitions) are commonly associated with physiologic arousal [41]. More specifically, a study by Gerra et al. [42] found that listening to techno music led to significant increases in heart rate and norepinephrine, cortisol, and adrenocorticotropic hormone levels. Research has suggested that a listener's personal music preferences increase the ability of a specific type of music to attenuate an individual's stress levels. Labbé et al. [43] found that healthy volunteers who listened to self-selected or classical music after exposure to a stressor showed significant decreases in self-rated anxiety, whereas those exposed to heavy metal or silence did not. In addition, self-selected music and silence led to the greatest decreases in anger. Musical genres also had variable effects on respiratory and heart rates; the respiratory rate was significantly lowered in volunteers listening to classical and

Table 2
Definitions of musical genres

Musical genre	Description
Designer music	Created with the intention of eliciting a specific physiologic or psychological response in the listener. Examples include Medical Resonance Therapy Music by Peter Hübner, which is designed to stimulate the brain by strengthening the body's natural regenerative capabilities [19].
Grunge	Form of rock music dominated by recurrent guitar riffs that became widely used with the emergence of Nirvana in the early 1990s.
Heavy metal	Music genre that emerged in the 1960s that is dominated by a traditional guitar, bass, and drum lineup with an accent on technique. It is usually accompanied by stylized singing of generally simplistic lyrics and is often interchangeable with "hard rock." Examples of early heavy metal include Cream, Jimi Hendrix, Black Oak Arkansas, Grand Funk Railroad, and Led Zeppelin.
Hip hop	Style of music that uses rap (spoken rhyme) over a rhythmic background that is mainly characterized by the manipulation of pre-existing recordings.
New Age	Contemporary musical genre that features Asian and Western musical instruments and styles with roots in New Age ideology that invokes alternative healing and the connection between music, meditation, and the mind. The term was first introduced in 1976 with Will Ackerman's release of acoustic guitar solos, *In Search of the Turtle's Navel*.
Techno	A form of 20th century electronic dance club music that is relatively simple in structure and tempo and characterized by a pounding bass–drum effect.

Definitions are from the *Encyclopedia of Popular Music* [40] unless otherwise noted

heavy metal, whereas heart rate was significantly decreased in those listening to self-selected music [43]. Such trends have been used by the music industry with the emergence of "designer music," a novel genre created to deliberately elicit a specific affect in the listener. A study of grunge rock, classical, New Age, and designer music showed that designer music had the most significant effect on improving self-scored positive scales of caring, relaxation, mental clarity, and vigor and decreasing negative scales of tension, hostility, fatigue, and sadness, although New Age and classical music showed similar but less drastic trends in inducing positive and negative mental states [19]. Although such studies have provided the groundwork for analyzing the psychophysiologic effects of different types of music, further research is needed to understand the potential for specific types of music to elicit changes in metabolic activity. Even within musical genres, there is a need for greater analysis of the variable impact of compositional motifs, rhythm, tempo, and musicality in addition to the artist. Elucidating the differential impact of various types of music has important implications in determining the future therapeutic potential of targeted musical interventions.

Gender-specific responses to music are another topic that merits further evaluation. Research has suggested the tendency for women to be more stress reactive compared with men. A study by Nater et al. [41] showed different reactivity patterns in men and women. When presented with heavy metal music, women exhibited a greater increase in the SNS response than did men according to finger temperature and skin conductance measurements. Interestingly, men exhibited an exaggerated autonomic response after heavy metal exposure as indicated by an increased secretion of salivary amylase, which is induced by sympathetic and parasympathetic nerve stimulations [41]. Basic science has suggested that sex-based differences in psychophysiologic responses to music could have a hormonal basis [44–47]. Compared with male sex hormones, female sex hormones tend to elicit a heightened stress response that favors music anxiolysis, which may have potential implications for the sex-based differences in the efficacy of music therapy in critical illness [48]. Despite such findings, little is known regarding the differences in music-induced metabolic responses in men and women. Achieving a better understanding for the sex-based variations in the metabolic response to music has important implications for the nuanced use of music therapy in distinct patient populations.

The field of music and medicine is making exciting strides toward a deeper appreciation of music and the physiologic mechanisms through which music has its effect. In the continuing investigation of the potential of music to induce and restore metabolic responses, there is much to be understood to create a path for the effective use of musical interventions in clinical practice.

References

[1] Yehuda N. Music and stress. J Adult Dev 2011;18:85–94.
[2] Thaut M. The future of music in therapy and medicine. Ann N Y Acad Sci 2005;1060:303–8.
[3] Nilsson U. The anxiety- and pain-reducing effects of music interventions: a systematic review. AORN J 2008;87:780–807.
[4] Bernatzy G, Presch M, Anderson M, Panksepp J. Emotional foundations of music as a non-pharmacological pain management tool in modern medicine. Neurosci Biobehav Rev 2011;35:1989–99.
[5] Cervelllin G, Lippi G. From music-beat to heart-beat: a journey in the complex interactions between music, brain, and heart. Eur J Med 2011;22:371–4.
[6] Leardi S, Pietroletti R, Angeloni G, Necozione S, Renalletta G, Del Gusto B. Randomized clinical trial examining the effect of music therapy in stress response to day surgery. Br J Surg 2007;94:943–7.
[7] Nilsson U, Unosson M, Rawal N. Stress reduction and analgesia in patients exposed to calming music postoperatively: a randomized controlled trial. Eur J Anaesthesiol 2005;22:96–102.
[8] Lepage C, Drolet P, Girard M, Grenier Y, DeGagné R. Music decreases sedative requirements during spinal anesthesia. Anesth Analg 2001;93:912–6.
[9] Weissman C. The metabolic response to stress: an overview and update. Anaesthesiology 1990;73:308–27.
[10] Buckingham JC. Hypothalamo-pituitary responses to trauma. Br Med Bull 1985;41:203–11.
[11] Brillon DJ, Zheng B, Campbell RG, Matthews DE. Effect of cortisol on energy expenditure and amino acid metabolism in humans. Am J Physiol Endocrinol Metab 1995;268(3 Pt 1):E501–13.
[12] Bessey PQ, Watters JM, Aoki TT, Wilmore DW. Combined hormonal infusion stimulates the metabolic response to injury. Ann Surg 1984;200:264–81.
[13] Conrad C, Niess H, Jauch K-W, Bruns CJ, Hartl WH, Welker L. Overture for growth hormone: requiem for IL-6? Crit Care Med 2007;35:2709–13.
[14] Defalque D, Brandt N, Ketelslegers JM, Thissen JP. GH insensitivity induced by endotoxin injection is associated with decreased liver GH receptors. Am J Physiol Endocrinol Metab 1999;276(3 Pt 1):E565–72.
[15] Siejka A, Stepien T, Lawnicka H, Krupinski R, Komorowski J, Stepien H. Effect of the growth hormone-releasing hormone [GHRH(1–44)NH2] on IL-6 and IL-8 secretion from human peripheral blood mononuclear cells in vitro. Endocr Regul 2005;39:7–11.
[16] Okada K, Kurita A, Takase B, Otsuka T, Kodani E, Kusama Y, et al. Effects of music therapy on autonomic nervous system activity, incidence of heart failure events, and plasma cytokine and catecholamines in elderly patients with cerebrovascular disease and dementia. Int Heart J 2009;50:95–110.
[17] Bethin KE, Vogt SK, Muglia LJ. Interleukin-6 is an essential, corticotropin-releasing hormone-independent stimulator of the adrenal axis during immune system activation. Proc Natl Acad Sci U S A 2000;97:9317–22.
[18] Eskandari F, Webster JI, Sternberg EM. Neural immune pathways and their connection to inflammatory diseases. Arthritis Res Ther 2003;5:251–65.
[19] McCraty R, Barrios-Choplin B, Atkinson M, Tomasino D. The effects of music on mood, tension, and mental clarity. Altern Ther Health Med 1998;4:75–84.
[20] Sivukhina EV, Poskrebysheva AS, Smurova IuV, Dolzhikov AA, Morozov IuE, Jirikowski GF, Grinevich V. Altered hypothalamic–pituitary–adrenal axis

activity in patients with chronic heart failure. Horm Metab Res 2009;41:778–84.
[21] Task Force of the European Society of Cardiology and North American Society of Pacing Electrophysiology. Heart rate variability: standards of measurement, physiological interpretation, and clinical use. Circulation 1996;93:1043–65.
[22] Kurita A, Takase B, Okada K, Horiguchi Y, Abe S, Kusama Y, Atarashi H. Effect of music therapy on heart rate variability in elderly patients with cerebral vascular disease and dementia. J Arrhythmia 2006; 22:161–6.
[23] Chuang CY, Han WR, Li PC, Young ST. Effects of music therapy on subjective sensations and heart rate variability in treated cancer survivors: a pilot study. Complement Ther Med 2010;18:224–6.
[24] Chuang CY, Han WR, Li PC, Song MY, Young ST. Effect of long-term music therapy intervention on autonomic function in anthracycline-treated breast cancer patients. Integr Cancer Ther 2011;10:312–6.
[25] Koelsch S, Fuermetz J, Sack U, Bauer K, Hohenadel M, Wiegel M, et al. Effects of music listening on cortisol levels and propofol consumption during spinal anesthesia. Front Psychol 2011;2:58.
[26] Zhang XW, Fan Y, Manyande A, Tien YK, Yin P. Effects of music on target-controlled infusion of propofol requirements during combined spinal-epidural anaesthesia. Anaesthesia 2005;60:990–4.
[27] Rudin D, Kiss A, Wetz RV, Sottile VM. Music in the endoscopy suite: a meta-analysis of randomized controlled studies. Endoscopy 2007;39: 507–10.
[28] Neal DO, Lindeke LL. Music as a nursing intervention for preterm infants in the NICU. Neonatal Netw 2008;27:319–27.
[29] Lubetzky R, Mimouni FB, Dollberg S, Reifen R, Ashbel G, Mandel D. Effect of music by mozart on energy expenditure in growing preterm infants. Pediatrics 2010;125:e24–8.
[30] Carlsson E, Helgegren H, Slinde F. Resting energy expenditure is not influenced by classical music. J Neg Results Biomed 2005;4:6.
[31] Gué M, Peeters T, Depoortere I, Vantrappen G, Bueno L. Stress-induced changes in gastric emptying, postprandial motility, and plasma gut hormone levels in dogs. Gastroenterology 1989;97:1101–7.
[32] Bueno L, Gué M. Evidence for the involvement of corticotropin-releasing factor in the gastrointestinal disturbances induced by acoustic and cold stress in mice. Brain Res 1988;441:1–4.
[33] Lin HH, Chang WK, Chu HC, Huang TY, Chao YC, Hsieh TY. Effects of music on gastric myoelectrical activity in healthy humans. Int J Clin Pract 2007;61:1126–30.
[34] Chen DD, Xu X, Zhao Q, Yin J, Sallam H, Chen JD. Effects of audio stimulation on gastric myoelectrical activity and sympathovagal balance in healthy adolescents and adults. J Gastroenterol Hepatol 2008;23:141–9.
[35] Vickers AJ, Cassileth BR. Unconventional therapies for cancer and cancer-related symptoms. Lancet Oncol 2001;2:226–32.
[36] Madson AT, Silverman MJ. The effect of music therapy on relaxation, anxiety, pain perception, and nausea in adult solid organ transplant patients. J Music Ther 2010;47:220–32.
[37] Brownley KA, McMurray RG, Hackney AC. Effects of music on physiological and affective responses to graded treadmill exercise in trained and untrained runners. Int J Psychophysiol 1995;19:193–201.
[38] Costa RR, Lima Alberton C, Tagliari M, Martins Kruel LF. Effects of resistance training on the lipid profile in obese women. J Sports Med Phys Fitness 2011;51:169–77.
[39] Eliakim M, Bodner E, Eliakim A, Nemet D, Meckel Y. Effect of motivational music on lactate levels during recovery from intense exercise. J Strength Cond Res 2012;26:80–6.
[40] Larkin C, editor. Encyclopedia of popular music. 4th ed. Oxford Music Online. Available at: http://www.oxfordmusiconline.com.ezp-prod1.hul.harvard.edu/subscriber/book/omo_epm. Accessed January 2012.
[41] Nater UM, Abbruzzese E, Krebs M, Ehlert U. Sex differences in emotional and psychophysiological responses to musical stimuli. Int J Psychophysiol 2006;62:300–8.
[42] Gerra G, Zaimovic A, Franchini D, Palladino M, Guicastro G, Reali N, et al. Neuroendocrine responses of healthy volunteers to ‘techno music’: relationships with personality traits and emotional state. Int J Psychophysiol 1998;28:99–111.
[43] Labbé E, Schmidt N, Babin J, Pharr B. Coping with stress: the effectiveness of different types of music. Appl Psychophysiol Biofeedback 2007;32:163–8.
[44] Mlcak RP, Jeschke MG, Barrow RE, Herndon DN. The influence of age and gender on resting energy expenditure in severely burned children. Ann Surg 2006;244:121–30.
[45] Palanza P. Animal models of anxiety and depression: how are females different? Neurosci Biobehav Rev 2001;25:219–33.
[46] Palanza P, Gioiosa L, Parmigiani S. Social stress in mice: gender differences and effects of estrous cycle and social dominance. Physiol Behav 2001;73:411–20.
[47] Chikahisa S, Sano A, Kitaoka K. Anxiolytic effect of music depends on ovarian steroid in female mice. Behav Brain Res 2007;179:50–9.
[48] Conrad C. Music for healing: from magic to medicine. Lancet 2010;376: 1980–1.