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Special Issue-
Medicine's Melodies: Adapting Music for Medical Settings








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Foreword

Practice does not make perfect – An overture to the special issue

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My piano teacher in college at Loyola University New Orleans told me that, "Practice does not make perfect, perfect practice makes perfect." What is perfect practice? And, if we had perfectly practiced the research and development resulting in the current alarmscape in the hospital, would we suffer from alarm fatigue, interrupted patient sleep quality, and clinician burnout? Alarm fatigue, while not operationally defined, is colloquially understood as fatigue resulting from the acoustic environment in the clinical space. Alarms have problems including, but not limited to: false alarms, loud alarms, difficult determining what is alarming, and inability to quiet an alarm – creating distractions and impeding patient care. Thinking of the constant battle to improve health, I am reminded of a passage from I Corinthians 14:8 KJV, "For if the trumpet give an uncertain sound, who shall prepare himself to the battle?"

This special issue was conceived from my own background in music and medicine, my formal training as a jazz pianist and current practice as a critical care anesthesiologist. It has been an uphill, yet fruitful, battle to conjoin these passions. But what is music and medicine? While there is much bickering in the fields of nomenclature of music therapy, music medicine and therapeutic music, my perhaps rosy-colored glasses view, is that I want the best for my patients. We all do. That is why, we must break down the barriers of our own egos and science to work together – easier said than done.

As a bit of a background, we must unpack music research. To other fields, it is dismissively viewed as music, what we listen to, and focused on aesthetics. While aesthetics are important, as listening to music is a pleasurable construct, music research is truly about acoustics and human perception and cognition. Roy Patterson and Judy Edworthy[1] understood this during the first iteration of the approach to alarm development in the 1970s. However, the focus of music as an aesthetic melodic construct, instead of acoustic features of sound, prevailed and the proposed melodic alarms of the International Electrotechnical Commission[2] were developed. We may have been our own worst enemy, we became siloed and narrow sighted, and this approach crashed and burned. Penelope Sanderson's[3] group showed how difficult these alarms are to learn (amongst other research groups: Cvach[4] et al, Edworthy[5,6] et al).

Poignantly, Frank Block wrote in his editorial[7] in *Anesthesia & Analgesia*, "This author would like to take this opportunity to apologize to the medical community for his role in derailing the Patterson alarm sounds nearly two decades ago. I now believe that the Patterson sounds were genius, and that they should have been adopted 10 or 20 years ago." If only the academic literature could contain vulnerability like Dr. Block has demonstrated. But sadly, an apology is not enough, we must show superiority of any further development of auditory alarms. We got ourselves into this problem by a group of arguably smart, yet biased researchers that express what the community wanted to hear. As musicians know, melody can be subjectively pleasing, but other aspects of the musical space serve to combat the alarm problems elucidated previously. We should explore harmony, rhythm, sharpness, roughness, attack, decay, amplitude envelope, and pitch center, to name a few. This does not just come from my own bias, but plenty of literature in the neuroscience and music perception and cognition research domains. As a call to action to work together, we must cross-publish in these domains and read the body of work. How many clinicians read music research? How many musicians read the medical literature? At my first International Association of Music and Medicine conference (the 3rd IAMM conference) in Beijing in 2012, I was asked, "Why are you here?" In a room of music therapists, I proved myself, and today I am pleased to be the lead editor of this special issue. It has been wonderful to witness and participate in the growth of our international music and medicine community. The integration of medical practitioners and music therapists has grown through this journal, but we still have more work to do.

In this issue, we go beyond auditory medical alarms. Medicine is a high-consequence industry, akin to nuclear power and transportation, mistakes can lead to death. Unlike aviation, my mistake will not lead to my own death, but everyday I come to work I have a non-zero chance of making an error that leads to a patient's harm and/or death. This is an awesome responsibility.

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When I set out to assemble my team of co-editors, I did not want to invite authors that would just write about my sphere of influence, or authors that would simply agree with my point of view. I want readers of this journal, and other journals, to start to use this research, reviews of the literature, and position pieces as a foundation and benchmark for the direction of the field. I am proud that contributors are experts in: audio branding, music perception and cognition, electronic music composition, sound design, psychology, neuroscience, clinical medicine, music theory and composition, nursing, law, and theology. This truly multidisciplinary approach, inclusive of everyone sitting at the table with a common goal to improve the integration of music research into clinical medicine will be the necessary future direction to advance the field of Music and Medicine.

The first edition features a piece by Daniel Levitin, *Music, Health and Well-Being,* in which he reviews the connection between music and medicine, including music therapy for both physical and psychological health, music for the management of pain, and musical interventions for dementia patients. Next, Charles Spence and Steve Keller discuss the role of the auditory environment in improving patient satisfaction and managing costs in the healthcare setting in his article *On the Costs & Benefits of Music, Soundscapes, & Noise in Healthcare Settings*. Barbara Salas looks into the role of music and the spiritual experience in terminal illness in her article *Crossing the River Styx: the Power of Music, Spirituality and Religion at the End of Life*. Alexander Chern and Iliza Butera discuss multidisciplinary perspectives on music perception and cognition for cochlear implant users, as well as methods to improve the cochlear implant experience in *Multidisciplinary Perspectives on Music Perception and Cognition for Cochlear Implant Users*. Fred Schwartz and Sophia Shirley describe years of experience as an anesthesiologist using music in medical practice, as well as relationships with various professionals in music medicine and music therapy in their article *Music Medicine and Music Therapy and an Anesthesiologist's Journey Along the Way*. Elif Ozcan, Lois Frankel and Jesse Stewart discuss some uncommon settings and roles for music and demonstrate how music can aid in the design and implementation of socially responsible healthcare products in their article *Uncommon Music Making: The Functional Roles of Music in Design for Healthcare*. Lastly, Jessica Klein and Kendall Burdick provide a literary metanalysis that defines interoperability and how it applies to music in medicine in their piece *Music Playing a Role in Medical Interoperability*.

Through the writing herein, it is my pleasure to introduce some of the most passionate researchers I know. We've enjoyed reading their writing, and sincerely hope you do as well. Thanks to our co-Editors of this, the first of two Special Issues: Christy J. Crockett, MD, Michael Schutz, PhD, Judy R. Edworthy, PhD, Kendall J. Burdick, BS, Jessica P. Klein and Barbara Salas, MD.

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Joseph J. Schlesinger, M.D. is an Associate Professor in the Department of Anesthesiology and Division of Critical Care Medicine at Vanderbilt University School of Medicine and Adjunct Professor of Electrical and Computer Engineering at McGill University in Montreal, Quebec, Canada. After earning his Bachelor of Arts in Music with a concentration in Jazz Piano Performance from Loyola University in New Orleans, Dr. Schlesinger earned his Doctor of Medicine degree from the University of Texas Health Science Center at Houston. He completed residency training in Anesthesiology followed by a fellowship in Critical Care Medicine at Vanderbilt University. While in training, Dr. Schlesinger became a B.H. Robbins scholar. Dr. Schlesinger's research interests include multisensory integration, human factors, aural perception, temporal precision, alarm development, patient monitoring, and medical education. This work led to the prestigious 2014 Education Specialty Award from the Society of Critical Care Medicine. Besides his publication history in high-impact scientific journals, Dr. Schlesinger is a patented inventor and has been featured on the podcast "99 percent invisible," CNN Health, and the New York Times.

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Full-Length Article

Medicine's Melodies: *On the Costs & Benefits of Music, Soundscapes, & Noise in Healthcare Settings*

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Abstract

A large and growing body of empirical research now demonstrates the positive impact that music and other auditory stimuli, such as nature soundscapes, can have across the entire spectrum of the healthcare ecosystem: From the point of entry and onward to the operating room, in the perioperative environment, patient wards, and medical waiting rooms, music affects those who hear it: Patients, their families, surgeons, caregivers, and hospital staff alike. In the age of the "experience economy," where patients are considered as both guests and consumers, private healthcare is increasingly starting to focus on customer satisfaction, and its impact on both financial performance and (not unrelated) health outcomes. In this review, we summarize the latest evidence concerning the impact of music, soundscapes, and noise, on medical outcomes and healthcare provision. We highlight the importance of the auditory (and, ultimately, the multisensory) environment on health and well-being. We also look at the role that music plays in improving patient satisfaction and potentially reducing the costs associated with healthcare provision

Keywords*: Music, Medicine, Atmospherics, Soundscapes*

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Introduction: Music, sound, noise, and health

The connection between music and medicine is an ancient one. According to Merriam [1], music and sound have been used in the healing practices of civilizations for centuries. Indeed, for the aboriginal cultures of Australia, the world was sounded into existence with the call of the didgeridoo, and chants, drums, bells, and shakers have been used by shamans and healers in every major civilization [2]. It may be no coincidence, then, that Apollo was embraced by the Greeks as the god of both music and medicine [3].

It seems as though the ancients were on to something: With the advent of new technologies and robust empirical investigation, a growing body of rigorous scientific research now demonstrates the profound ways in which music affects us whenever and wherever we hear it [4]. Music can help us to relax when we are stressed [5-7] and lift our spirits when we are depressed [8]. When we are incapacitated, such as when lying in a hospital bed, listening to music can distract us when we are bored, and change our perception of the passage of time [9]. There is even evidence to suggest that painful procedures can be made a little less unpleasant/painful by having the patient focus their attention on a pleasing tune or two [10-13].

It has been shown that some of our behaviors can be entrained to a musical beat [14-15]. Music and ambient soundscapes can also be used to help provide a blanket of privacy and/or to mask other sounds, such as the unpleasant noises associated with the operation of medical apparatus – think here only of the whining of the dentist's drill [16] or the cacophony of alarms in the intensive care unit [17-19]. While music is normally used in commercial settings and/or public spaces to attract people [20], there have also been occasions when it has been used deliberately to repel the gathering of certain groups of individuals [21]. For example, classical music acts as an effective deterrent to youths who might otherwise be tempted to congregate in public spaces [22-23].

Recognizing music's impact on our perception, behavior, and neurophysiology across a wide range of everyday situations, it stands to reason that it might play an especially important role in the world of healthcare and wellness. So can music, in any meaningful sense, be said to help in the healing of those who hear it? There has been a surprisingly large amount of research in this area, spread across a variety of contexts: Music in the operating room (for the surgeon and so-called 'support' staff); music in peri-operational care; music, and the problem of noise, in patient wards; music to help people who are grieving. In the sections that follow, we take a closer look at each of these in turn, before finally broadening out the discussion to a consideration of music as but one component of multisensory atmospherics – Atmospherics, being an area of marketing concerned with the

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creation of commercial spaces that elicit a particular atmosphere or mood, especially through the use of music.

The 'experience economy' reaches healthcare

Kotler [24], in his classic paper on store atmospherics, not only discusses the importance of getting the multisensory attributes of the atmosphere right in prototypical commercial spaces, such as shops, restaurants, and travel agencies, but briefly discusses the notion of atmospherics in the psychiatrist's office as well. At the time, this foray into the healthcare ecosystem, broadly defined, perhaps seemed like something of an odd addition to a marketing paper. More recently, however, there has been a growing trend to think of patients as 'consumers' or 'guests', whose multisensory experience of healthcare (the consumer journey, in other words) needs to be carefully curated in order to meet (or possibly even to exceed) their expectations [25]. This emphasis on experience constitutes a potential point of differentiation, and is becoming ever more important in competitive healthcare environments, where hospitals with better patient-reported experience perform better financially [26] and produce more favorable clinical outcomes [27]. In a sense, one can think of this as a natural extension of the 'experience economy' mindset [28-29] applied to healthcare [30].

In this context, there is a growing recognition that music (and soundscapes) can functionally enhance the experience of patients, and thus improve patient outcomes [31-32]. One finds early mention of the effects of atmospherics on patient satisfaction in the work of Andrus [33], specifically in the context of dental surgery offices [34]. Some hospitals have gone further, even introducing live music in an attempt to improve the quality of life for both the patients and the staff employed to look after them. Consider the case of the patients and staff at The Adelaide and Meath Hospital in Dublin, Ireland (associated with the National Children's Hospital). They reported feeling more relaxed, happier and more positive after having listened to live music in the hospital setting. The patients' perception of the hospital itself was also positively affected by the sound of live music in the waiting areas [35]. Likewise, Mogos et al. [36] reported that patients gave higher ratings for care when live music was provided bedside, in contrast to those for whom music was not provided. That being said, one also needs to be aware of demand characteristics (not the least of which being scalability and cost for the provision of live music) and the fact that subjective feelings of well-being do not always correlate with more objective measures in healthcare situations [37].

More recently, at Sloan Kettering Hospital's Brooklyn Infusion Center in New York, some of the treatment pods have been equipped with custom chemotherapy chairs allowing the patients the opportunity to check their e-mail, shop online, listen to Pandora internet radio (note that Pandora is a large North American music streaming service; see www.pandora.com), and even control the lighting (in the pod). Consider too, the findings of Zhou et al. [38], where post-mastectomy women had significantly lower depression scores (and shorter hospital stays) if they were part of a music listening group that was given access to a music library that had been specifically curated for the study. Indeed, a number of interesting interventions have been executed in this space over the last decade or so [39-41]. At the same time, however, it is important to remember that there is likely going to be some cost implication associated with offering live or pre-recorded music to those in healthcare settings. Crucially, in order for a successful sonic strategy to remain in place in the long-term, any costs associated with the playing of music will need to be well-justified. For unless a sound business case (if you'll excuse the pun) can be made in terms of the benefits of introducing music and/or soundscapes into healthcare, such an approach is unlikely to stick in the long-term due to the all too frequent cost-cutting by accountants [42].

At the same time, however, one also finds a growing awareness of the negative consequences produced by seemingly ever-increasing levels of background noise, not only in the intensive care unit (ICU) but also in the public wards and neonatal units [43-53]. It certainly feels like we are a long way from the time, a little over half a century ago, when the sound levels in hospitals were recorded at no more than 50-68 dB [54].

The professional's perspective

Music in the operating room

Much like chefs slaving away in the kitchen [55-56], surgeons often like to have music playing in the background while operating on their patients [57-58]. Intriguingly, when Pennsylvanian surgeon Evan Kane first wrote a brief note to the *JAMA,* as cited by Bosanquet et al. [59], in which he declared himself a keen supporter of the "benefic [sic] effects of the phonograph within the operating room," his concern was primarily with "calming and distracting the patient from the horror of their situation," rather than distracting/relaxing the surgeon and or his/her team in the operating room [59]. Granted, improvements in anesthesia presumably mean that patients today often have less awareness of what is going on than would have been the case over a century ago when Kane wrote his letter. However, it is important to stress that while the focus amongst researchers has typically been on the desires of the surgeon in this regard, they are certainly not the only ones who want music to be played in the operating room. Indeed, according to a 2014 study [60], music, most often of the classical variety [61], is played in the operating room somewhere between 62-72% of the time [62]. Given the literature suggesting that people walk, shop, eat, drink, and even drive faster while listening to loud music with a fast beat [63-64], one might legitimately want to know what listening to music does to a surgeon's operating performance. A number of simulation studies have demonstrated that music aids task completion while, at the same time, lowering stress and muscle fatigue. The good (reassuring, one might say) news here is that the presence of background music in the operating room has been shown to improve both the speed and quality of surgical closures, at least in the context of plastic surgery, thus suggesting that it might indeed improve the surgeon's efficiency, hence potentially translating into healthcare cost savings [65] (for reference, consider that 14 years ago, hospital operation room fees averaged out at $62 per minute [66] – thus time saved could be considered cost saved). Furthermore, in an often-cited early study, Allen and Blascovich [67] reported that autonomic (specifically cardiovascular) reactivity was reduced while mental task performance was enhanced in surgeons listening to music of their own choice as compared to no music, or a generic stress reduction music condition. While these studies are promising, it should be noted that in the previously cited surgical closers study, the music played was the preferred music of the individual doing the stitching, and the simple wound closure was actually carried out on pigs' feet rather than a human patient, and in the case related to cardiovascular reactivity, all of the participants were music enthusiasts, the study was conducted in a soundproof laboratory, and the task was an arithmetic exercise. Future research in more ecologically valid settings is needed to truly understand the cost benefit.

It can further be imagined how the opportunity to listen to background music likely becomes all the more important as the duration of the operation increases. In fact, over the years, a number of studies have considered the role/influence of music in the operating room, along with potential tensions that might be triggered in this unique environment – e.g., between the different healthcare individuals working in the same space who might, it can all too easily be imagined, have somewhat different musical preferences [68]. In one light-hearted yet nevertheless interesting study, rock music was shown to impair the performance of men (but not women) when attempting multi-organ resection in the board game "Operation" [69].

Classical music has been shown to improve the performance of expert surgeons performing a laparoscopic task [70]. By contrast, in another study, the task performance of novice surgeons undertaking virtual laparoscopic interventions was found to be impaired by particularly aggressive or upbeat background music, as compared to soothing music or silence [71]. Meanwhile, Siu et al. [72] reported that trainee surgeons (N = 10) with limited experience performed various robot-assisted laparoscopic surgical tasks significantly faster when highly rhythmic music (e.g., Jamaican music or hip-hop) was playing in the background rather than jazz, classical, or else when the tasks were performed without any music. It should, however, be noted that no patients were operated on in this particular study. Notice too that when quizzed, anesthesiologists in another study rated reggae and pop music as the two most disturbing types of music that might be played in the operating room [73], though it is unclear what role expertise plays in the different results reported here.

In spite of the potential benefits, the impact of music on the so-called 'noise floor' (the measure of the signal created from the sum of all the noise sources and unwanted signals within a system) is a concern. It has been estimated that music can add 87 dBA or more to these already noisy conditions in the operating room [74]. According to Kracht et al. [75], peak noise levels in operating rooms during orthopaedic and neurosurgical procedures exceed 100 dB for extended periods of time (i.e., > 40% of the time), a fact that is particularly troubling when one considers that the negative impact of loud noise is related to the duration for which people are exposed to it. Alarms, 'suckers', 'intercoms', etc. [76] all contribute to noise levels in this space [77-80]. Across a range of surgeries, average equivalent sound levels (also known as the time average sound level or LAT) of 62-66 dB (A) are common. Somewhat worryingly, the highest peak levels routinely documented during surgery exceed 120 dB [61]. Indeed, the peak noise levels in orthopaedic surgery are such that there is very real concern about long-term consequences (i.e., hearing loss) amongst orthopaedic staff [81-82]. Note here that the anaesthetized patients may also be at risk of hearing damage due to the fact that anaesthesia paralyses the stapedius muscle that normally protects the ears by attenuating the response to loud noise [83-84]. According to Liu et al. [85], many patients have reported finding the noise levels around surgery too loud.

MacDonald and Schlesinger [86] attempted to address music-related noise floor issues by creating a device that functions as a semi-automated music volume controller. The idea here is that the device would control music in the operating room and integrate it with vital sign data from the anesthesia monitor. A slowing heart rate, diminishing blood pressure, or declining oxygen saturation might then all be deemed salient events that necessitate a quieter operating environment in which the surgical team can communicate and concentrate on the patient in hand. Hence the idea is that the device would automatically lower the volume of the music at the relevant point(s). Note that a similar solution has also been considered for use in the interior of cars, where natural music levels of 130 dB have been reported [87].

The choice of music to play in the operating room is not an insignificant consideration. The head surgeon is typically given the choice, but his/her selection must then be listened to by the rest of the operating staff, and perhaps even by the unlucky patients themselves [88]. While music might help those working in the operating room to maintain their focus and avoid boredom when performing more intricate operations, some researchers/commentators have highlighted a number of possible problems with the use of music during operations [89]. Here, it is perhaps also worth considering whether levels of boredom might not be higher in routine operations, rather than more intricate ones. That said, we are not aware of any information on this particular issue. Hawksworth et al. [73] surveyed 200 consultant anesthetists (senior doctors) in the UK to determine the prevalence of music playing in the operating room and anesthetists' attitudes toward it. Of the 72% of those who responded, an equivalent percentage (N = 104) worked in an operating room where the playing of music was a regular feature. Roughly one quarter of the sample thought that music reduced their vigilance and impaired their communication with other staff with a little over 10% being concerned that music might distract their attention from alarms. A little over half felt that music was distracting when a problem was encountered during the operation. That said, a subsequent study by the same research group failed to identify any adverse effects of self-selected or classical music on psychomotor task performance (testing numeric vigilance, tracking, and RT) by residents (i.e., trainee doctors) in anesthesiology [90].

Ultimately, the effect/impact of music (either positive or negative) may differ depending on an individual's role in the operating room [91], and given that the choice typically resides with the lead surgeon [62], whether or not the music is liked [73]. The loudness level is presumably also a relevant issue that is worthy of further consideration. Nevertheless, the evidence does support the suggestion that music can be a helpful adjunct, assuming its use is carefully managed.

Music for the staff

A number of studies have shown that music and ambient soundscapes can have a positive effect on employees in a working environment, including its role in helping to reduce fatigue [92], improve visual recognition [93], and increase productivity [94]. The implications of this research might be especially important when applied to healthcare providers, as any drop-in staff well-being and associated burnout has been shown to significantly impact patient safety [95-96]. Unfortunately, beyond a number of studies looking at the negative effects of noise on healthcare workers [46, 97-99], research into the specific effects of music and sound on healthcare practitioners, while promising, is currently quite limited [100-101]. Due to the critical nature of the work performed by many healthcare professionals, it's imperative that we understand how sonic interventions that have been designed to improve the patient experience might also affect professionals, as they will likely be living with the consequences for longer.

The patient's perspective

Detrimental effect of noise: Too much noise in wards

Florence Nightingale was right when, back in 1859, she wrote that "Unnecessary noise is the most cruel absence of care which can be inflicted either on sick or on well," as cited by Katz [79]. As anyone who has been in a hospital ward or ICU knows only too well, hospitals tend to be exceptionally noisy places [43, 47-48]. While the World Health Organization (WHO) recommends that noise levels inside hospital wards should not exceed 30 dBA at night [102], recent measurements show that the peak noise levels in some hospitals can rival that of a chainsaw, reaching more than 80 dBA [103]. Such loud noise on the wards undoubtedly affect the patient's ability to sleep, and hence must presumably deleteriously affect their recovery. Besides proving detrimental to rest, loud background noise also results in a number of other negative effects, including the suppression of the immune response to infection, increased pituitary and adrenal gland stimulation, and increased cardiovascular stimulation [104-106]. Poor sound absorption (due to the need for hard, cleanable, floors and surfaces), coupled with the plethora of warning signals, alerts, and bleeps, can all too easily create a cacophony of sound that is further complicated by noise from carts, intercoms, staff conversations and visitors. We have already touched on the problematic design of most effective alerts and warning signals for use in the operating room, or elsewhere [107]. "Effective" here being something of a euphemism for attention-capturing, which often translates into "disturbing" for anyone who is not interested in noticing it. Notice here how oftentimes those who are not interested in the alert are nevertheless aware of its presence.

A number of researchers and practitioners have been attempting to address the problem of alarm noise and fatigue [108-109]. Tactile alerts (e.g., warning signals or notifications that are delivered with the skin surface) offer another potential solution and much more personalized (and less distracting to those who are not interested in them) [110], but their uptake has unfortunately been (s)low in this sector, particularly when compared to other sectors, like automotive [63]. At the same time, it is worth noting that alternative solutions to the problem of noise in hospitals may come from outside the medical sector, with musicians occasionally leading the way. One such example is Yoko K. Sen, a Washington, D.C., based composer and performance artist. Sen has collaborated with medical and design professionals at Sibley Innovation Hum, Stanford Medicine X, IDEO, and Medtronics to develop alarm sounds and hospital soundscapes designed to sonically improve the patient experience, while still adhering to standard alarm protocol [111]. The use of tactile alerts and enhanced sound alert design just two of the ways in which people are trying to limit the problem of noise in hospitals.

Music in perioperative care

Certainly, the use of music is not limited to the operating room. There is also a rich literature base on the impact of music and music therapy instituted for a broad range of medical populations, from neonates through the elderly in painful procedures and perioperative care [112-117]. Perioperative care is defined as the *care* that is given before and after surgery; Note that it commonly includes ward admission, anesthesia, surgery, and recovery. Feelings of anxiety and apprehension are understandably common amongst patients during the various phases of their surgical procedure or healthcare encounter. While there are undoubtedly a growing number of pharmacological agents that are available to ease their anxiety and pain, music can be seen as providing an alternative that is both cheap and effective [42, 118]. What is more, it can be used in combination with, or even on occasion, to replace anxiety-reducing medications [119-121]. For example, Bringman et al. [120] reported on a randomized trial of 372 patients undergoing elective surgery, in which relaxing melodies (60-80 bpm, coincidentally mimicking the resting heart rate) were found to be significantly more effective than midazolam as a pre-anesthetic anxiolytic. Music has also been shown to improve patient comfort and satisfaction during local anesthesia [12, 122-123]. Music may play an important role in keeping patients relaxed and "sonically isolated" from noise and conversations during the administration of general anesthesia.

The postoperative use of music has also been shown to be effective in reducing anxiety, distress, pain, and medication consumption, while at the same time also improving patient satisfaction [124-130]. In one frequently cited study, Conrad et al. [131] found that the presence of music resulted in a significant decrease in the dosage of sedative needed to achieve a desired level (of sedation). Other studies have also alluded to the potential power of music as a sedative [132-135]. Here, allowing the patient to choose the music (i.e., rather than the surgeon in the case of the music playing in the operating room) may lead to the best results [124].

In summary, then, the widely-held belief is that music plays an important role in helping to relax/calm those individuals who may be about to undergo an operation and/or any other stressful healthcare encounter [136-139]. At the same time, a positive role for music has also been reported in those undergoing mechanical ventilation [140-142]. In conclusion, therefore, from intake to anesthesia, surgery, and recovery, it is clear that music can play a valuable role in perioperative practice for a variety of patients. Indeed, perioperative care may be one of the most important places where music can be used to enhance the healthcare encounter from the patient's perspective.

Music to aid recovery

While noise can have a negative impact on patients, some sonic interventions can be beneficial to patients and treatment outcomes. It is not enough simply to reduce noise; Adding soundscapes to healthcare settings is the other part of the equation. Indeed, it has been suggested that the introduction of intentionally-designed soundscapes can enhance the patient experience [143]. Positive soundscapes (operationally defined as those soundscapes that were rated positively by listeners) have been associated with faster cardiovascular stress-recovery in laboratory research [144], as well as with better self-reported health conditions in large-scale surveys (e.g., how often survey participants reported experiencing/feeling irritated, headaches, stomach discomfort, depression, etc.). Aletta et al. [145] have provided a systemic review of the associations between positive health-related effects and soundscapes. Additionally, the use of music has been shown to help reduce the postoperative pain suffered by children [146-147]. Särkämö et al. [148-149] found that the verbal memory and focused attention of recovering stroke patients improved when listening to music for a couple hours a day. The researchers suggested that listening to music may help recovery via three distinct neural mechanisms: 1) Stimulation of the damaged brain areas; 2) stimulation of general mechanisms related to brain plasticity (i.e., the ability of the brain to repair/renew neural networks); and 3) stimulation of the dopaminergic mesocorticolimbic system (i.e., the part of the nervous system associated with memory, motivation, reward and arousal).

When considering music as part of the "recovery soundscape", it should be noted that the type of music used makes a difference to the outcomes that are observed. Trappe [150] reported that vocal and orchestral music had a significant impact on correlations between cardiovascular and respiratory signals, whereas classical and meditative music were reported to produce the most beneficial effects on health for intensive care patients. By contrast, it has been suggested that heavy metal music or techno may not only be ineffective, but could actually lead to stress and life-threatening arrhythmias, giving a rather macabre twist to the genre known as 'death metal' (see also Bosanquet et al. [59] for a playful take on good and bad playlists during surgery).

Finally, the use of music and soundscapes away from the healthcare setting can also prove effective as a component of treatment. Salivary cortisol is often used as a biomarker for stress [151]. Khalfa et al. [152] have reported that relaxing music has a beneficial effect after the induction of psychological stress, while Thoma et al. [153] found that listening to music had a positive impact on the psychobiological stress system.

Music interventions in the face of death and dying

While composers have been writing music especially for those who are grieving for millennia [154], research into the use of music as it relates to the experience of death and dying has been limited. However, in the instances where research is available, the results are promising. One example is found in "music vigils" offered to terminally ill and/or actively-dying patients and their families, where it was found to improve patients' breathing, relaxation, comfort, and ability to sleep [155]. Relevant here, Bernardi et al. [156] assessed cardiovascular and respiratory variables while their participants (both musicians and non-musicians, N = 12 in each group) listened to different kinds of music with differing rhythmic, harmonic, and melodic structures. As one might have predicted, fast tempo music was found to be arousing [157], whereas slow or meditative music was reported to be more relaxing instead. It may be worth noting that, though there has been little discussion to date regarding cross-cultural differences in music, there may well be a cultural component to the music that people deem appropriate to listen to in healthcare settings [158].

Meanwhile, Holm et al. [159] conducted a focus group study examining the impact of music during care for family members and the deceased (i.e., after-death care). The study, which consisted of a series of interviews with ICU nurses, concluded that there were positive outcomes when music was part of the caregiving process. In addition to positive feedback shared with the caregivers by the bereaved (e.g., creating a more peaceful atmosphere, helping distract from other disturbing sounds in the environment, adding a sense of reverence), there was also a noticeable increase in the amount of time the grieving would spend with the deceased when music was playing. While the researched did not indicate if this increase in time spent was a positive or negative result, it is assumed that the caregivers saw this as a benefit to those grieving. What was also notable in this study was the self-reported impact of music on the caregivers themselves: There were, for instance, reports of music providing more dignity during the preparation of the body of the deceased, leading to feelings of peacefulness and increased focus and mindfulness on the part of the nurses to the task at hand. Caring for those grieving after the loss of a loved one is understandably stressful. The suggestion here is that music may be used strategically in after-death care in order to help reduce anxiety, stress, and fear for both caregivers and those needing the care [160-161].

By extension, one might also think about the important role that music often play at funerals or memorial services. Here it is worth noting that different types of music (e.g., classical, heavy metal, and personally curated playlists) have been shown to have differential effects on people's ability to deal with stress [153, 162]. At the same time, it should be recognized that the extended period over which grieving normally takes place means that it is obviously not an easy subject for empirical research on the impact of music. It is also worth noting that music may help temper other kinds of loss-related grief, including end-of-life care [163-165].

Finally, when it comes to practical applications in this space, once again we find artists and composers willing to lend their talents. In 2013, composer/musician Brian Eno made a foray into creating music especially for the hospital setting [166], creating an ambient soundscape specifically for the "meditation room" at Montefiore Hospital in Sussex. We are not aware of any empirical research specifically designed to assess the effect of this particular soundscape on people's response to grief, but the question arises as to whether music/soundscapes specially developed for healthcare situations would be more beneficial than music that may have been created for a variety of other purposes, including entertainment [167-169].

Music at mealtimes

Long-term exposure to noise has been shown to have a detrimental effect on people's health no matter where they happen to be – either hospital or home [170]. As has been noted earlier, public hospital wards tend to be exceptionally noisy places [171]. The research demonstrates that loud background noise also adversely affects people's ability to taste food and drink [172-173]. All that noise is likely to impair the patients' ability, if not to enjoy, at least to experience the food as acceptable, resulting in potentially adverse effects on maintaining a nutritionally-balanced diet. Indeed, it has often been commented on that continuing care patients experience particular problems at mealtimes [174]. It is great to see that some hospitals have been focusing on the provision of food [175, 176]. But can sound really be used to improve the patient experience and outcomes as they relate to food enjoyment and nutrition? As it happens, there is an extensive literature on the effects of music while dining [177]. As such, one might want to ask about similar applications in the hospital setting [178].

Certainly, music and soundscapes can be used to help calm agitated patients [179]. Courtright et al. [180] studied the effects of relaxing music on disruptive and violent aggressive behaviors during dinner amongst more than 100 psychiatric inpatients. The idea here was that music would buffer the general noise level that is typically found in dining rooms, so exerting a calming influence, and thus perhaps reducing the incidence of disruptive behaviors. In fact, according to the authors, playing the sound of sea gulls led to a drastic reduction in the incidence of aggressive behaviors. This is particularly interesting in the context of the use of sea gull sounds in a dish called the 'Sound of the Sea' [180-182], served in world-leading The Fat Duck three Michelin-starred restaurant.

Noise-cancelling headphones might provide another solution to the extremely loud noise in wards. In fact, the noise in wards is, in many cases, louder than the intolerable levels one increasingly finds in restaurants [172]. The key point to note here is that all that noise is likely to impair the patients' ability to, if not enjoy, at least to experience the food as acceptable and hence to achieve a nutritionally-balanced diet. In addition, noise-cancelling headphones might help not only with the reduction of ambient noise, but also provide for the addition of music and/or soundscapes to the dining experience [56, 173]. While the use of headphones in some instances might be beneficial, it should be noted that their use obviously reduces the opportunity for socialization at mealtimes, when socialization is something that many older patients desperately want/need [183].

Looking to the future, there may also be the potential to use 'sonic seasoning' – defined as the use of specific pieces of music or soundscapes in order to season the food [184] - to help address poor nutrition, and possibly also taste disorders amongst various patient groups. One relevant example here comes from the Xin café in Beijing [185], where 'sweet' music (that is, high-pitched sounds, etc.; see Knöferle et al. [186] for a summary of the sonic parameters associated with 'sweet' music) is played so that less sugar can be added to a customer's drink, while not having to compromise on taste (as the "sweet" music creates a perception of sweetness that might otherwise be missing). While this particular intervention smacks more of a marketing-led story than a genuine attempt by those concerned to nudge the populace towards better health, the idea is still definitely one worth exploring. It is striking how little thought is often given to the provision of healthy food options elsewhere within the hospital, particularly when one considers the foods available from vending machines and outlets which, typically, tend to be of very low nutritional content [171].

One could potentially also use music to enhance the perceived authenticity of food amongst patients [187-189]. In fact, the results of several studies have shown that the perceived authenticity of a dish can be enhanced simply by matching the music to the region where foods are thought to come from in order to [190]. Similarly, playing classical music has been shown to enhance perceived quality of food and drink [188]. To the extent that the food in the hospital is perceived as better, either because it is rated as more authentic, or because it appears to be of higher quality, this may improve health outcomes by enhancing the likelihood of the patients receiving somewhat better nutrition. There could also be an important role for music and food in triggering nostalgia, especially for those older patients who may be suffering from memory loss [191]. Consider the French palliative care hospital where proper meals are served by staff dressed as waitresses rather than as nurses [192], or the effect of nostalgia triggered by sound on flavor perception/meal experience [193]. One might, for example, think of playing the music of Vera Lynn for those octogenarians wasting away in the UK healthcare system. As yet, though, we have not seen anyone taking a systematic approach to applying this research in the hospital setting. The key point remains that in order to deliver meaningful food provision in the care sector, one needs to go beyond the current focus on the food itself, and think about the total experience – sonic elements play a key role here.

The multisensory perspective

Music and soundscapes (i.e., a sound or combination of sounds that are part of an immersive auditory environment) undoubtedly have an important role to play for both patients and the staff who look after/treat them. However, it is important to remember that the auditory environment (or atmosphere) constitutes but one element of the total multisensory experience [194-195]. Consider the research on the impact of olfactory cues both in helping to mask unpleasant, and/or stress-inducing odors, while at the same time potentially aiding relaxation [196-201]. What is more, the tactile elements of design, including the feel of materials and surfaces [202] as well as the interpersonal tactile elements of interaction in the hospital setting [203], are coming to be recognized as increasingly important, especially given the growing awareness of the so-called "touch hunger" facing so many in society today [204]. "Touch hunger" can be defined operationally as the need for tactile stimulation that most people have, and which is evidenced by the typically positive health outcomes associated with increased tactile stimulation. Petting dogs and weighted blankets [37, 205] are both popular interventions in this space, not to mention the therapeutic use that massage therapy might play. The visual aspects too, can impact healthcare experiences and outcomes [206-207]. Everything from providing a view of nature through the patient's bedroom window [208] to the restorative effects of viewing art [209-212]. There has been some consideration of the role of lighting and use of color as well [213-214].

Given these considerations, an informed approach to music/soundscape provision in the various stages of the healthcare encounter must recognize that, no matter the situation, we never just listen to sound in isolation (i.e., as a unisensory experience). Rather, we must consider the auditory environment in the context of the total multisensory experience [195].

There are a number of uses of often relatively unstructured multisensory stimulation designed for its therapeutic value, as in psychiatric care [215-217]. Those working with the 'Snoezelen' concept try to develop multisensory environments that encourage both relaxation and sensory exploration (the term itself is derived from the Dutch verbs 'to explore' and 'to relax'). The Snoezelen company has been supplying multisensory environments for various healthcare applications for a number of years now [218-219]. While such environments often involve visual and olfactory stimulation, the auditory component (often consisting of relatively unstructured sound, i.e., without any vocal or explicitly musical components) is also important. Indeed, according to one anthropologist, hearing becomes more pronounced in the hospital environment from the patient's perspective, precisely because the visual environment is typically dull/boring [220]. This kind of controlled multisensory stimulation (e.g., in the Snoezelen) has been shown to have beneficial effects in the control of chronic pain [221], as well as helping those with dementia [222-224] or severe brain damage [225].

Ultimately, though, a considered multisensory approach is likely going to deliver the biggest benefits for all of the interested parties. Indeed, if the impact of the various sensory manipulations are not coordinated, one may be in danger of delivering sensory incongruency [196, 226-227], or else perhaps even sensory overload [228]. Sensory incongruency is bad not only because it lacks processing fluency, but also because the end result might be confusion, with the various components actually counteracting one another [229]. Unpacking these terms, 'sensory incongruency' refers to when the senses do not match, while 'processing fluency' refers to the subjective ease of information processing. Incongruency is typically not processed fluently. Especially relevant here is research by Fenko and Loock [196] demonstrating that while music or ambient (i.e., environmental) scent (both chosen to be pleasant and minimally arousing) could be used to reduce stress in a plastic surgeon's waiting room in Germany (N = 117 patients), combining these two sensory interventions did not actually result in a significant reduction in patients' self-reported anxiety over the no sensory intervention baseline condition. However, it may be worthwhile to consider whether the study had sufficient power to detect an effect had there been one.

Beyond Fenko and Loock's study [196], the multisensory design of the waiting room environment is undoubtedly important, given that people may end-up spending a lot of time here, experiencing elevated levels of anxiety and/or stress [206, 230]. While the environment might well be designed to reduce stress/anxiety, another role for sensory design here could, of course, be used to help reduce the perceived duration of the wait too [231], though Fenko and Loock [196] found no influence of their environmental manipulations on this particular aspect of their participants' ratings.

Given that these various sensory interventions have been shown to interact it is important to consider noise/music as but one albeit important element of the sensory milieu [232]. Ultimately, as desirable as music may be in many different healthcare settings, it needs to be cost-effective, financially-speaking, in order to confirm its legitimacy. And, beyond the technical delivery of calming multisensory environments there is, of course, also the long tradition of the healing garden in healthcare facilities in many countries, from The United States and Canada to Europe and the UK [233-235]. As yet, it is unclear what aspect of the salutogenic nature inputs are key here. The term 'salutogenic', coined by Aaron Antonovsky [236], refers to an approach to medical practice that focuses on those factors that support human health and well-being, rather than on the factors that are responsible for causing disease (pathogenesis). However, it is likely to be that the sound of nature is not unimportant, especially if, as has been shown repeatedly, the sight and sound of nature can be offset, say, by distracting traffic noise [237-239]. The key point here, then, being one of how the beneficial effects of nature's influence us – is seeing nature sufficient, or being in it, hearing nature, or perhaps feeling it [240-242].

Conclusions

As this review of the literature makes clear, there is more to the topic of music and medicine than meets the eye (or more literally, "the ear"). There is a growing body of robust empirical research demonstrating the therapeutic role that music can play in a variety of contexts and for a variety of players [243], though as we have seen, there are undoubtedly also tensions [244]. It would seem that damping noise, aiding distraction, and delivering a bit of nature sonically might be most beneficial [245]. Key questions in this area include who gets to choose what music is listened to (and by whom), what type of music will be played, and at what volume. Looking to the future, we can imagine how better outcomes might be achieved by the use of music or soundscapes that have been especially composed for the various stages of healthcare provision, rather than simply picking music that was composed for some other primary purpose (and hence presumably not ideally suited to the constraints of the healthcare situation). The beneficial effects in this case being backed-up by a number of Randomised Control Trials (RCTs; in many ways, the gold standard), along with multiple Cochrane Systematic reviews assessing the impact of music at various stages of the consumer's/patient's healthcare journey [246-248].

Music's ability to distract our attention can be good for the patient who is undergoing a painful medical procedure (e.g., wound dressing), while at the same time being bad for those who need to monitor safety critical machinery [249]. It is important to consider that multiple mechanisms may be in play simultaneously when trying to help explain the impact of music, soundscapes, and noise on the various players in the healthcare scenario. One important question for future research is the extent to which people need to attend to/be aware of the sensory cues, be they auditory or olfactory, in order for them to influence people's cognitive, affective, or physiological state [196].

Although the auditory aspects of the healthcare environment are undoubtedly important, it is imperative that we consider them within the broader context of the salutogenic properties of the built environment as a whole [32, 41, 250-255]. As we have seen time-and-again throughout this review, music's influence is likely moderated by not only the type of music (and possibly the volume at which it is played) but also by the hedonic response to the music of those who hear it.

The weight of the evidence summarized here makes it difficult to argue against the integration of sonic interventions into the regular practice and delivery of healthcare provision/services. The positive impact on patient health and wellness, not to mention on healthcare providers themselves, should be reason enough to explore a more intentional approach to the use of music and soundscapes in healthcare settings. Perhaps a further motivation can be found in taking a cue from retail and service marketing, where customer satisfaction and care can make all the difference between business success or failure [30]. Indeed, positive patient experiences have been associated with increased profitability, while a negative patient experience can lead to the opposite outcome [256]. The use of music and sound may be good not only for the health and wellbeing of patients and staff, but for the health and wellbeing of the healthcare business, too. Taking such a view may offer greater justification for management to devote more time and resources to "medicine's melodies." It's certainly worth a look – and a listen.

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Full-Length Article

Crossing the River Styx: *the Power of Music, Spirituality and Religion at the End of Life.*

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Abstract

Dying from a terminal illness involves a period of transition throughout which the person deals with multiple losses, including the loss of one's own life. The awareness of death makes the individual confront spiritual questions that touch the very nature of existence, and music can help intensify that spiritual experience bringing new meaning to the end of life. The reasons why spirituality, religion and music can facilitate the existential quest for meaning and provide an overall improvement of the quality of life at the end of life will be explored. It will be suggested that a humanist approach to end-of-life care in which alleviation of suffering and consideration of the specific needs of the patient, including spiritual care and therapy with music, would be desirable to help patients during the dying process.

Keywords*: terminal care, music, religion, spirituality.* multilingual abstract | **mmd.iammonline.com**

Introduction

According to Greek mythology, Orpheus was the greatest of all musicians. After the death of his beloved Eurydice, he decided to go to the land of the dead in an attempt to bring her back to life. But to do that, he had to cross the River Styx. The river separated the realm of the living from the realm of the dead, and it was closely guarded by Charon and the three headed dog Cerberus. Orpheus used his playing of the lyre to charm them, and it was so irresistible that Cerberus felt asleep and Charon transported Orpheus into the underworld to meet Hades, the king of the realm of the dead. When Orpheus saw Hades, he started singing accompanied by his lyre, and the music was so divine that all hell stood still; then Hades allowed Orpheus to take Eurydice back to the world of the living.

Death is a universal feature of human life, and life is shaped by impermanence and finiteness. When confronted with mortality because of a terminal illness, the individual goes through a process that resembles the tasks undergone by those who are grieving the death of a loved one[1] . This experience is called anticipatory grief, and it stands for the physical, psychological and cognitive changes that happen as a consequence of the threat of multiple losses that a person faces when being terminally ill[2] . The experience of anticipatory grief involves the need to acknowledge the reality of one's mortality; going through the emotional pain associated with the prospect of having to die; the adjustment to the loss of one's identity, status, friendships, independence and ultimately life; and the need to find a way to "relearn" how to live, including death within his own life and finding existential meaning in the challenges and obstacles that come with the illness[3].

Spirituality and/or religion and music are essential and universal features of human life. They have an important role in facilitating the journey of accepting one's death, easing the anticipatory grief and finding peace in it. As it will be argued, this is the case because they share certain characteristics that enable the person not only to perceive death as a *doorway* rather than as an end-wall, but also bring the opportunity to transform life while dying.

Spirituality and Religion

The scholarly world in the field of healthcare research seems to lack a standard definition of what spirituality is, although certain aspects appear repeatedly in the literature[4] . These aspects have been well summarized in the Consensus Conference's definition of "spirituality", which accounts for "the aspect of humanity that refers to the way individuals seek and express meaning and purpose and the way they experience their connectedness to the moment, to self, to others, to nature, and to the significant or sacred"[5] . Spirituality is a universal human dimension, and is independent of institutions, models and traditions. It is both relational and associated with inner strength and peace, and it provides values that function as a standard that guide one's

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life. Spirituality can be expressed through various means that include communal practices, individual meditation, enjoyment, or strong adherence to the environment, and it may or may not appear within the religious context[6] .

Central elements of the spiritual questions are those related with meaning of life, human existence, and meaning of being. Because spirituality involves questions about meaning, and meaning is closely connected with existence, death is therefore related to spirituality as an event that threatens our current life[7] . Death makes future projects unavailable and questions the validity of our past, as there is a possibility that our achievements, which constitute our legacy, will be forgotten and ignored. However, our awareness of death can shed light into our present and give meaning to our actions, forcing us to stop projecting things into the future and to re-focus our attention to search for what is meaningful here and now.

Religion, on the other hand, refers to an institutional system of faith, worship, values, doctrines, rituals, customs and practices that aim to give meaning, provide a sense of connection with others through the community and with God, engage with the mystery of life, and provide a framework within which the believer can understand existence. Religion is also connected with the spiritual dimension of the individual, although a person can be deeply spiritual yet not religious.

Kenneth I. Pargament understands religion as the "search for significance in ways related to the sacred"[8]. In his definition, "search" refers to the action that individuals take in order to find meaning, which involves discovery of something significant, conservation of what has already been found, and transformation of the search for the content of life. "Significance" implies the notion that people strive to attain existential meaning, which can be objective and subjective. Finally, "sacred" refers to concepts of God and higher powers that function as the source of meaning in the individual's search for significance.

Spilka et al[9] notice some differences between the nature of spirituality and the nature of religion: firstly, spirituality does not require an institutional framework although it can have it, whereas religion cannot exist without such an institutional reality; secondly, religion (unlike spirituality) always has a public dimension such as signs and symbols that identify it, visible places to worship, and a community; thirdly, a spiritual person does not need to believe in a deity or transcendental reality, whereas religious people in general refer to some form of it; and finally, religiousness invariably involves spirituality, but spirituality does not necessarily involve religion.

Yet spirituality and religion also have common elements: both are multidimensional –including the quest for an ultimate concern, the aim of unifying one's personhood, the need to have a meaningful identity and purpose, and the search for authenticity—[6] ; they are highly changeable with time and circumstances; they are essential dimensions of the person's life, especially when facing illness[10] ; they allude to a transcendental (or existential) search that enables the individual to find meaning in life and understanding one's place in the world; and they affect the patients' quality of life, quality of care and overall wellbeing[11]. Therefore, it can be argued that spirituality and religion refer to the dimension of the individual throughout which the person searches for meaning, regardless whether the meaning is religious or not[12] .

The nature of music

Music has a mysterious and abstract nature, which make defining its nature a difficult task. It is the only art that is intangible, yet its power is transcendent and universal: a musical piece is written in a symbolic manner as a score, but its meaning can only be expressed through play. Moreover, its existence in time and space unfolds as it is created, unlike the visual arts, which can be perceived all at once. The musical performance is a subjective interpretation of a score, and the effect of the interpretation is the result of a number of elements, including the listener's own emotional state, the setting, and the performer's ability to convey meaning through sound. People's experiences of the same musical work widely differ, and the meaning that the composer wanted to convey is not embedded in the musical notation in any explicit way. As Gadamer[13] notices, music's meaning can only be received through a direct interaction with sound – in a similar way as a text, which solely becomes intelligible by reading it.

The experiential impact that music can have on the individual is also mysterious: the performance itself vanishes instantly and forever (unlike for example a work of painting, which can be physically revisited), but it can have a lasting effect on the person despite its immaterial and impermanent nature.

Music as an art can communicate things that are otherwise inexpressible, and it can trigger deep and powerful emotions in a puzzling way, as it lacks explicit semantic content or identifiable elements that resemble the physical world. Music also has the capacity to convey the essence of existence[14] in the sense of connecting with the deepest part of the human being in a very direct, unique, and personal way, while shedding light into the content of one's life. The experience of music can occasionally be transcendental: when that occurs, the individual is directly faced with life's most pure beauty and truth, and with the overwhelming feeling of just "being" in the here and now fully – something that could be described as a "holy" moment. It is likely due to these attributes that despite music's detachment from the physical world in a formal sense (i.e. as it is not an art that can be touched, and it does not exist materially in the world), humans find in music a relatable reality.

Capturing the meaning of music does not necessarily require intellectual engagement as reading a written text would. However, a musician or an individual with musical knowledge is likely to perceive music differently to a neophyte, because elements such as musical form or style can be learnt and recognized, which will subsequently influence the way music is deciphered.

The perception of time is also altered by music: as Savage points out, "music exercises its power to re-describe affective dimensions of experience through creating different worlds in which the ordinary sense of time is surpassed by a 'time beyond time' or a feeling of 'being out of time' - in short, by 'eternity'"[15] . In this respect, research[16] has shown that waiting time is perceived to be shorter when there is accompanying music than where there is none, and this is especially marked when the individual enjoys the accompanying piece. The emotional response that music triggers also influences time perception: pieces in a major key are interpreted as "happy" and are often associated with a fast tempo; conversely, pieces in a minor key are generally perceived as "sad" and tend to be played in a slow tempo[17] . Interestingly, both happy and sad music can be experienced as very pleasant. It is this positive valence which has the power to shorten the passage of time[16] , making it more enjoyable and bearable and potentially having a positive impact on symptomatic patients that are terminally ill.

Finally, the quality of music to transcend space and time can be powerful and transforming. As Gadamer[18] suggests, music can project variations of possible inhabitable worlds, thus freeing the space in which we physically exist. This is the case because music has the potential to "renew" the space in which it is experienced depending on the mood or feeling that it expresses, and how those messages are received by the listener[15] . For example, Mozart's Requiem was composed as an expression of mourning and musical exploration of death and dying. Even though this piece was composed in the 1700s in a specific cultural setting, it has long been recognized as a transcendent expression of loss. It crosses boundaries of time and space by evoking the universal human emotion of grief in settings and time periods long removed from the original context in which the piece was composed. Yet at the same time, these universal feelings of grief evoked by the piece are patterned by the individual's unique cultural milieu, and thus the music will resonate differently with each listener.

Religion, spirituality and music at the end of life

Spirituality and religious beliefs influence the way individuals embrace death because they provide meaning. "Meaning" here refers to what matters most and gives value to an individual's life, forms its existential structure, and makes life desirable on its own. Meaning also has a relational component which is particularly relevant at the end of life: it can help in restoring one's relationships with others, and/or one's sense of self. And while this may not bring a "cure", "healing" in the sense of recovery of wholeness can be possible to the very end of life[19]. Moreover, finding meaning in difficult circumstances often reduces or even solves[20] the suffering, because the element that causes suffering is no longer regarded as a threat to the integrity of the person.

The hazard that a terminal illness poses to one's existence and life meaning forces the individual to rely on a system of tools. That system includes beliefs and practices that can help to make sense of and deal with the existential threat to the person. In this sense, spirituality and religious beliefs provide content to the loss (or losses), and to those who believe in an afterlife they give content to whatever comes after death. Religion in particular removes the uncertainty of death by offering an explanation and an appropriate framework to understand one's end and its implications, thus granting a sense of reassurance and a narrative that helps with what is otherwise utterly daunting. Depending on the religious denomination the beliefs regarding the afterlife vary, although in general the idea that death is not the "absolute end" is commonly accepted.

One approach[9,19,21] to understanding how religion and spiritualty function as tools to provide meaning at the end of life is the idea that the existential threat can be reshaped by using secondary forms of control. This refers to the ability of the individual to change oneself so that the situation is perceived differently altogether. Three forms of control are particularly relevant:

1. **Interpretive control**, which refers to the process of re-interpretation that individuals undergo when facing a major difficulty that feels overwhelming. By giving a new interpretation the problem becomes to some extent under control, and the stressful situation appears to be less threatening.
2. **Predictive control**, which refers to the positive attitude towards future regardless the difficulties in the present. This enables the person to feel that "things will be all right", switching the focus of concern from the present threatening reality to a better future that is about to come. An example of this is the story of a devout Jew who as a Nazi prisoner in Auschwitz was given the number 145053. When he looked at it, he suddenly realized that he was going to live because the numbers added together totaled 18, and 18 is a number that in Judaism means life. Subsequently he felt that God was speaking to him through the number, and that despite the present difficulties, "everything was going to be okay in the end"[9] .
3. **Vicarious control**, which refers to the moment in which due to the inability to cope, the religious individual turns fully to God. By doing so, the deity becomes the support for one's troubles, and the source of strength that the individual lacks. It is

often the case that identification with the deity gives enough tools to regain the sense of control over an overwhelming situation. For people who are not religious, vicarious control can be exercised by turning to members of the community, friends and/or family, who can be a positive source of support and strength while facing unmitigable suffering.

Music is a vehicle of expression, and as such it conveys meaning[22,23] . This is important for patients at the end of life, as musical meaning has the power to modulate emotions[24] , which can be used to shift one's mood or perception of reality – especially when it is unpleasant or difficult. Listening to a particular piece when feeling overwhelmed or sad can help overcome those negative emotions by shifting the focus to a different perception of reality. In addition, the meaning that a musical piece conveys is not exhausted by its experience: on the contrary, as Gadamer suggests[24] , repeated exposure to a play of art enables the individual to gain a richer understanding of meaning. That implies that a patient can benefit from the substance of music and even grow spiritually with it by listening to it time and again.

Music can also evoke memories, transporting the listener back to moments associated with a particular piece. This is known in the field of psychology as "reminiscence bump"[25]. Janata et al[26] found that popular songs could elicit autobiographical memories, which were associated with strong emotions. This seems to occur in the medial prefrontal cortex, which functions as a nerve center that enables association between certain musical features with autobiographical memories and emotions[27] . Music's evocative power has been used to help patients with dementia in particular: while they often cannot communicate with words, they may be able to sign a song. This is possible due to the association between music and deep memories, which are not affected by the disease.

Rituals

Religious and spiritual rituals may help to commemorate events, to facilitate the process of reminiscing, or to help communication amid the family members by strengthening the bonds between the terminally ill and his social circle, all of which may be positive in the process of accepting death.

Among all rituals, prayer occupies a central position. Prayer is widely practiced and is regarded as the core of faith[9], and although some psychologists see religious prayer as a form of control[9] in general it is considered a positive tool to cope with difficult circumstances, including a terminal condition. There are many forms of prayer, although the most stable types identified in research are: petitionary, ritualistic, meditational, confessional, thanksgiving, intercessory, self-improvement, and habitual prayer[9].

For those who follow no religious faith, rituals may involve meditation or attendance to particular gatherings or events in which the individual can convey and share his values, beliefs and ethical system. The observance of ritual practices enables the person to keep a sense of identity, connectedness and meaning through actions, which can be helpful in the face of a terminal illness by providing an explanation or a channel to canalize the impeding loss. The importance of rituals can be appreciated in that while people who follow a particular faith tradition often draw upon particular liturgies, "those who have no connection with a faith community may still seek ritual expression for their grief patterned upon faith practices"[28].

Different religions have different rituals specifically directed to the dying. For example, the Catholic faith offers prayers and anointment with blessed oil through the sacrament of the sick, and in the Buddhist tradition the body is accompanied all the time until there is a sense that the person's spirit has finally exited the corpse. In many religious traditions it is common to touch or lay hands on the dying person to provide a physical and spiritual connection as death occurs, and the ritual of sitting with the dying in a "meaningful" or "ritualistic" way has an important value across different cultures. Other rituals like the Catholic confession or the Christian reflection on the virtues of faith, love and hope may also bring the individual closer to understanding the nature of the wrongdoing and find ways to change, which may function as means of forgiveness. In Buddhism, the spiritual teacher plays a dual role: he makes sure that the transition is peaceful and calm for the dying, and also teaches family members about the importance of accepting death and resolving conflicts in order to find closure[29]. These tools help those dying and their families to cope with distress, restoring the sense of wholeness and integrity and helping to improve the relationship with oneself and others.

With regards to death itself, rituals vary from tradition to tradition but all share in common the goal of facilitating the transition between life and death. In Judaism, when the person passes away the body is removed to a mortuary and a funeral is celebrated within 24 hours of death. However, if the death occurs on the Sabbath (Friday sundown to Saturday sundown) or on festivals, it is common to request for the body to remain where it is until the end of the sacred period so that its holiness is not compromised[30]. After the funeral, Jews sit "shiva", which is a period of 7 days from the day of the funeral that enables family members and friends of the deceased to grieve while being supported by the community. In Islam, when the patient is near death a family member or the imam can recite a chapter of the Holy Qur'an, and then the body should be washed and enshrouded in three white sheets. Then the body is interred in a plain pine box[31].

Like prayer and rituals, music enables a spiritual connection between individuals and groups to each other and to their spiritual dimension[32]. This potential to facilitate communal activity and communication explains why music has a central place in the life of many religious communities[33]. Moreover, music can be a source of ease and calmness: hearing familiar hymns can give spiritual comfort to the dying, and music is often part of ceremonies and rituals around death, thus helping those who are grieving the loss of a loved one.

Music also has the power to create a space where the symbolic meaning of religious rituals is highlighted, and it facilitates sharing and understanding of those rituals among different cultures and locations[33]. Finally, music has a role in the experience of worship itself, as well as in helping the worshiper understand what it means to engage in that communal, experiential ritual and be part of a community.

Hope

Both spirituality and religion offer people hope –i.e. the desire for a future and the belief that that future is possible despite uncertainty[34]– in the midst of crises, in the course of a serious condition and when facing the end of one's life. At the beginning of the illness spirituality and/or religious beliefs may offer hope for a cure, and when a cure becomes unlikely, they may offer a hope to have comfort, to be surrounded by those who are loved, or to have a peaceful death.

Specific religious beliefs[19] can give people concrete hopes while facing death: Protestants have hope in the concept of salvation in death, and see in Jesus' dying and raising from the dead a model to understand that participation in His death gives eternal life. Catholics may have hope in a life beyond death, in accordance with the promise that Jesus made regarding the victory over death through resurrection. Jews believe in the resurrection of the body that merges with the soul and hope to continue living through their offspring, and Buddhists' and Hindus' belief in rebirth and in the law of karma offers the hope of a possible attainment of *nirvana*.

Finally, the positive influence of religion in accepting one's death may not only be connected with its assurance of an afterlife, but also with the hope to affirm one's worth and dignity while still alive.

Music can also convey hope by transporting the listener to a different realm through memory, as explored above, and by changing the relationship with time and space. In particular, music that is religious and spiritual in nature (for example Psalm 23, "The Lord is my Shepherd") can convey comfort and guidance to the listener, and for those who believe in it, the reassurance of the afterlife.

Framework

Religion also provides an appropriate framework of existential exploration to evaluate and better understand the nature of an undesirable situation, as well as to explain from a broader perspective one's physical reality as creatures of God or the divine. Doctrines provide clear descriptions of the ultimate reality, which function as structures to shape and direct people's lives.

For those who do not follow any particular faith, spirituality underlines one's sense of "worth" when reviewing one's past life, family, and friends, as well as the bonds the patient may have with them. As Argyle notices[28], "spirituality is … not simply an intellectual proposition but consists of cognitive, emotional, and behavioral components that contribute to defining the person and to the way life is experienced". That is why religion and spirituality can provide a useful framework to consolidate one's sense of identity in relation to what is perceived as most important in life, and that transcends one's existence.

Music enables the creation of a safe ontological space. This space enables the person to explore the nature of being, providing a framework where the individual can more deeply understand their feelings and emotions without having the boundaries of words[35]. It enables the analysis of complex thoughts that would otherwise be perhaps difficult to articulate, and it provides a structure to reflect and gain insight into the inner self. This quality, in a similar way as religion and spirituality does, can facilitate the evaluation of a negative situation, and it can help the patient with reframing the meaning of dying and turning it into a more positive experience.

Community

An institutionalized religion involves a community. That may enable devout individuals to lessen their fears through sharing and through the neutralization role of the rituals, traditions and doctrines that can be experienced within a group. Moreover, belonging to a non-religious community may provide a supportive space, and may be a source of strength by empowering association with other members of the group, which can be beneficial at the end of life[36].

Music has had a central role in our evolutionary history, particularly because it encourages social bonding and group cohesion[37]. Music is inherently relational, and at a minimum its experience enables a connection between the composer, the artist and the listener that transcends any physical boundaries. Music can also be enjoyed within a group, can bring people together through dance, and it can create a space where communication is possible without physical interaction. As Cross notices, "music allows each participant to interpret its significances individually and independently without the integrity of the collective musical behavior being undermined"[38].

Guidance

Another function that is specific of religious beliefs and doctrine is to provide guidance regarding ethical decisions. For example, the Catholic Church in the United States publishes the *Ethical and Religious Directives for Catholic Healthcare Service*[39], where the moral doctrine of the

Church is outlined in order to help Catholic healthcare professionals make decisions. In Islam[31], the patient is encouraged to have faith in God rather than in the modern medical treatment, and therefore Islam regards the recitation of the Qur'an during illness to be a health-giving method as important as medicine itself.

In the setting of end-of-life care, ethical issues may include making clinical decisions like withdrawing advance life support, "Do Not Resuscitate" order, making plans for advance care, or ordering an autopsy. While in some cases[40] institutionalized religions can be a source of distress if the patient is confronted between his own desires and the obligations of his religious faith, in other cases the ethical and doctrinal guidance can remove the responsibility of making a decision away from the patient and families. For example, Judaism does not allow autopsies as it is seen as a mutilation of the deceased body. Therefore, while the question of whether or not an autopsy should be requested may be a source of anxiety and conflict for a non-religious family, a Jewish family will be at peace with not requesting one, in accordance with their religious beliefs.

Transcendence

An essential characteristic of spirituality and religion is transcendence. In the context of end of life, transcendence can have the power to restore the wholeness of the person by placing the individual into a broader context that goes beyond the particular problem that is causing suffering.

Transcendence can be experienced through a particular religious denomination, though in itself as a transpersonal dimension it does not require a religion to emerge. Having said that, some religions like Christianity offer a concrete explanation of suffering by linking pain or loss with the suffering of Christ: through this connection, the religious individual transcends his own pain and suffering is endured. But for patients that are not adhered to specific religious beliefs (or even for atheists), the need to transcend death may be achieved through strengthening particular relationships, leaving certain legacies in the form of narratives or other means, or by accomplishing one's wishes.

Transcendence is also a key element of music, and therefore it can play a relevant role at the end of life[41]. The power to transform the space in which a musical piece is experienced can facilitate coping with an otherwise finite physical existence, and it can help the individual to regain a sense of serenity and peace by evoking past places, times and memories. Moreover, music enables a deep connection with the meaning of life[42], and it helps enhancing one's relationship to spirituality. This can help easing critical transitions, like the one from life to death. It does so by transporting us to a dimension where the unspeakable can be explored.

The promotion of spiritual care at the end of life

While faced with a terminal condition, profound questions about the meaning of life, identity or purpose may emerge and answering these questions is as important as answering those about treatment. As Viktor Frankl points out, suffering destroys when it has no meaning[43].

Spiritual care at the end of life involves most importantly listening to those who are facing a life-threatening situation, while providing a space where the spiritual dimensions of the individual can be expressed, explored and nurtured[28]. This implies acknowledging the patient's beliefs, values, and connections, and helping the individual finding meaning in his life. The provision of spiritual care can be challenging due to its complexity, and while its importance is acknowledged, it often remains unclear how, when and by whom the work should be done[44].

There are a variety of models that assess spirituality in the health care setting. Cobb[28] suggests that spiritual care should include an initial assessment, the identification of needs through the exploration of the patient's faith and/or spirituality, and the supply of resources based on the information gathered previously. Maugens[45] proposes the mnemonic SPIRT as a structured way to explore the spirituality of the patients ("S" for ***S**piritual belief system*; "P" for ***P**ersonal spirituality*; "I" for ***I**ntegration* with a spiritual community; "R" for ***R**itualized practices and **R**estrictions*; "I" for the ***I**mplications for medical care*; and "T" for ***T**erminal events planning*). In a similar line, Puchalski[46] suggests the mnemonic "FICA" to remember the four core elements of the spiritual history: **F**aith and belief (e.g. What gives your life meaning?), **I**mportance (e.g. Have your beliefs influenced how you take care of yourself in this illness?), **C**ommunity (e.g. Are you part of a spiritual or religious community?), and **A**ddress in care (e.g. How should this issues be addressed by health care providers?). Finally Ferszt et al[47] developed a tool to evaluate spirituality focusing on four areas of assessment: connection (e.g. Who are the persons or communities you look to for support?); meaning and joy (e.g. What has been most important in your life?); strength and comfort (e.g. Is there anything that is comforting to you now?); and hope and concerns (e.g. Is there anything that you hope for?). All these tools can help the healthcare professional to gain a better understanding of their patient's spiritual and/or religious dimensions.

Some patients will express their spiritual needs through a structured religious faith and in those cases the community or some members of it may provide support. For patients who are not members of a religious denomination or who lack a supportive community it is important to facilitate spiritual care within the healthcare setting. Regardless the religious denomination or lack of it, the providers of pastoral care should offer an auxiliary listening environment, enabling the individual to share the life stories and to reflect upon the spiritual and/or religious issues that are felt as important at that time.

Spiritual care is not about imposing new tools or offering "better" spiritual frameworks, but rather about embracing and valuing the individual's life, beliefs and experiences[28] in order to enable growth and development from it. This process may require "assistance", and thus the spiritual care practitioner can provide support and a structure to help the individual make good use of his own resources. Ideally the team should be readily available to give adequate aid, if not by offering it directly, by referring the patient to the appropriate person.

The provision of spiritual care requires certain facilities such as a chapel or a prayer room, sacred texts, prayer mats, and rosaries, among other items, and these should ideally be readily available for the patient. The religious needs may also include the wish to resolve unfinished or unanswered religious questions, and/or to gain a sense of hope about the afterlife. Some patients may express the need to seek for reconciliation, redemption, divine forgiveness, mercy, grace, healing and strength for God, and in order to achieve this the use of a religious support system, religious literature, having visits by the clergy, or performing certain rites may be helpful[48].

Finally, due to the complexity of spirituality and the implications of religious beliefs, those working with patients at the end of life should ideally receive ongoing training in order to acquire the adequate knowledge and skills to help the patient in that dimension.

Therapy with music at the end of life

Music has traditionally played an important role in helping with the dying process[49], especially as part of religious practices at the end-of-life[50]. It is only recently that research is supporting this practice within the healthcare setting[51].The introduction of complementary models such as therapy with music has been shown[52] to provide spiritual comfort and alleviation of suffering in particular at the end of life, as it helps the individual reconnect with important aspects of existence such as the nature of relationships or the purpose of life. And as explored above, the power of music to convey meaning, evoke memories, facilitate rituals, enable and strengthen interpersonal relationship, convey hope and facilitate a framework to explore human impermanence makes it an ideal vehicle to facilitate the end of one's life.

Music therapy

Music therapy is a complementary service that is offered in a variety of medical settings, including hospices and palliative care settings. The American Music Therapy Association defines music therapy as the "clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship by a credentialed professional who has completed an approved music therapy program"[53].

Music therapists are Board Certified (MT-BC) by the Certification Board for Music Therapists (CBMT)[54], and offer tailored interventions using music to facilitate communication, and to provide physical, spiritual and emotional well-being to patients(55, 56). They employ a wide variety of methods, including improvisation, evoking memory, enhancement of life review, creation of audio recordings, relaxation techniques, guided imagery or instrument playing(41, 54).

The therapist involves the participants actively or passively depending on the therapist's assessment, and on what the patient and their family define as their most immediate need. Goals are made in conjunction with the medical team. Sometimes a patient may request a specific piece that has a unique meaning, while at other times the aim may be to access a memory or emotion associated with a particular song, as a resource or tool for healing. This can then be facilitated by the music therapist, whose aim is to create a safe space where reflection and communication is supported in a non-judgmental way, and where feelings can be validated[55,57] . The abstract nature of music enables conveying complex emotions that can be difficult for the patient to verbalize or express otherwise, and the choice of a particular piece can help with the expression of a deep feeling that may be too daunting or complex to convey in any other way[58].

Music has many therapeutic benefits: it has been shown to reduce anxiety and pain, help with depressive symptoms and improve quality of life[59]. There was also a small reduction in heart rate, respiratory rate and blood pressure, as well as fatigue. In addition, music can be used as a tool to help with the expression of difficult emotions[60], which in turn can improve the patient's encounter with mortality.

In the palliative care setting, where pain management is often challenging, one study[61] showed that music therapy can significantly decrease the pain scores for the patients in the intervention group. In patients mechanically ventilated, listening to music had beneficial effects on anxiety, and it consistently helped reducing respiratory rate and systolic blood pressure[62]. Finally, music has been shown to promote complex positive emotions such as forgiveness, peace and resolution, which can be especially helpful for patients facing death[63].

Other musical interventions

The term "music thanatology" was coined by Therese Shroeder-Sheker. It refers to a contemplative practice that aims to help patients who are at the end of life achieve a sense of serenity and calmness through music, as if music would pour "over the body like a balm"[64]. The practice has been expanded all over the world through the *Chalice of Repose* Project[65], and trained musical thanatologists use a harp or their voice to offer dying patients and their families the service of the "music vigil" at the bedside. The aim is to relieve physical symptoms such as pain, and to function as a calming tool so that the transition from living to dying becomes easier, more serene and peaceful, blessed. The vigil also helps process difficult emotions for those who are with the deceased, as listeners can find comfort in the presence of the artistic beauty conveyed by the musician.

The session usually last up to an hour, although it varies depending on the needs of the patient and their relatives. The key is for the musical thanatologist to be aware of the needs of the people present in the "music vigil", and to create the appropriate musical "prescription" in order to bring physical, emotional and spiritual comfort to the suffering soul. This requires a constant awareness of the individual's needs, an active engagement between the musician and the patient, and the ability to create a suitable environment in which the therapy can be conducted.

Patients that are critically ill in an intensive care unit (ICU) and are often unable to communicate may also benefit from hearing live music played by professional musicians. One such musician, professional guitarist Andrew Schulman worked alongside music therapist Joanne Loewy, director of The Louis Armstrong Center for Music and Medicine (LACMM) in the surgical SICU (Surgical Intensive Care Unit) at Beth Israel Medical Center. Volunteering in the LACMM, as a 'resident visiting artist' for several years, he and the former SICU director of the unit Dr. Marvin McMillen observed how live music helped to brighten the spirits of patients who were critically ill. Andrew Schulman, having directly experienced the positive impact that music could have on critically ill patients, was formerly himself a patient of Dr. McMillen's and described himself as "clinical dead" in Beth Israel's SICU. He was resuscitated and put in a medically induced coma and while unconscious, Mr. Schulman's wife suggested to Dr. McMillen (his attending physician) and the medical team to bring to the SICU Andrew's iPod with his favorite piece of music, so that Mr. Schulman could listen to it while he was in a coma. That intervention led to an improvement of Mr. Schulman's health condition. 6 months later and fully recovered, Mr. Schulman returned to the same SICU, where he played for other critically ill patients and witnessed first-hand the effect that music had on them (just like it had had on him). After participating in the LACMM's Environmental Music Therapy study, Schulman began to witness the changes that developed in fragile patients through live music performance. The concept of a medical musician initiative, which he started with Dr. McMillen is seeking its way years later toward gaining a growing status as a discipline within critical care[66].

A medical musician, according to Schulman, is a "professional concert level musician with pertinent training in critical care medicine, who is a member of the medical team in a critical care unit"[66]. Unlike music therapists, who use music as a form of psychotherapy and can employ their techniques in a variety of settings, including ICUs, the medical musician focuses on critically ill patients only, and seeks to understand what the patient needs through "observation and intuition" alone [67]. The aim of the musician is to choose the most appropriate piece depending on the patient's needs in order to help them through their recovery process, based on a wide repertoire inclusive of a number of styles such as classical, folk and traditional music.

Conclusion

Like in the Greek myth of Orpheus, who used his divine musical skills to cross the River Styx and get to Hades in the realm of the dead, music can ease the transition from living to dying. Spiritualty and/or religion are also fundamental features of human life, and as such have a central role in the process of anticipatory grief and in finding existential meaning at the end of life.

As argued throughout the essay, religion, spirituality and music are a source of meaning, provide or facilitate rituals, offer a framework to revisit one's life, convey hope, reinforce the feeling of community and relatedness, can be a source of guidance, and highlight the sense of transcendence that may help the patient to alleviate the suffering and fear of death, and to eventually "die well".

The centrality of spirituality, religion and music at the end of life reflects the crucial role that values and existential search for meaning play in the healthcare setting, especially in the way people face illness and death. This highlights the importance of shifting the paradigm of the provision of care at the end of life, moving from the common interventionist and technical approach where mainly length of life is praised and death is medicalized[68], to a humanist model in which quality of life, alleviation of suffering and consideration of the specific needs of the patient come to the front line. Spiritual care and therapy with music can help achieve this goal, thus enabling patients to find peace, closure and meaning during their symbolic journey crossing the River Styx.

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Full-Length Article

Medicine's Melodies: *Music, Health and Well-Being*

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Abstract

Most of what we hear about the connection between music and health is largely anecdotal. The past decade has seen a renewed interest in the connections from researchers conducting rigorous experimental studies. In this broad overview, I will review the current state of knowledge, touching on music therapy for both physical and psychological health, music for the management of pain, and musical interventions for dementia patients.

Keywords*: music, medicine, health, well-being, therapy* multilingual abstract | **mmd.iammonline.com**

Prelude

Beliefs about music's power to heal the mind, body and spirit date back to the Upper Paleolithic era, around 20,000 years ago, when ancient shamans used drumming in the hopes of curing a wide range of maladies, from mental disorders to wounds and illnesses [1]. Music was also used as therapy in Old Testament times [2] and Classical Greece [3]. During the 11th Century B.C.E., near the end of his life, King Saul suffered from periodic depressions and agitation. On such occasions he would summon David, reputed to be among the greatest musicians in the kingdom:

> "David would take the lyre and play it; Saul would find relief and feel better, and the evil spirit would leave him." [4]

In modern times, music therapy was reintroduced during World War II to treat wounded veterans [3]. Some of the beneficial effects across all these periods may have accrued by putting patients into a trance state [5], or by accessing the subconscious, thereby "opening the healing mechanism for the patient"[6]. Science has only recently confirmed what shamans and other faith healers knew: that listening to music facilitates entry into the brain's default mode network (DMN) [7], a path to the subconscious [8].

From Saul to Science

Across much of the last 40 years, most of what we knew about the use of music for medical interventions, both psychological and physical, came from anecdotes, speculation, and case studies rather than controlled experiments. Many practitioners lacked formal certifications in music therapy, and many had no training in medicine, scientific experimentation, psychotherapy or nursing. This is not to say that music interventions were not therapeutic, but there was little consistency or standardization as to how such therapies were delivered. Many approaches and doctrine lacked scientific evidence. Three important developments changed this in recent years.

First, the American Music Therapy Association became more well-known, and in 2008, they formally adopted the phrase "evidence-based" in their defining statement:

> "Music Therapy is the clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship by a credentialed professional who has completed an approved music therapy program" [9].

In the news media, there were approximately 4 articles mentioning evidence-based uses of music from 1998-2008, but between 2009 – 2019 there were 185, with nearly all mentioning the AMTA.

PRODUCTION NOTES: Address correspondence to:

Daniel J. Levitin, E-mail: dlevitin@minerva.kgi.edu| COI statement: The author received support for the research and writing of this article from the Kim & Glen Campbell Foundation. The author reports that he has previously received financial support from Fender Musical Instruments Corporation, Apple Corporation, and Sonos.

Second, researchers began to apply more rigorous methods and controls. Of 4718 articles indexed by PubMed on music therapy in the decade 2008 – 2018, one-third (1509) used a control group [10], an increase from only one-tenth in the previous decade [11]. Two developments were key: the invention of neuroimaging technologies allowing us to see the brain in action in real time, and personal computers with digital editing and playback software. This allowed researchers to parametrically vary stimuli with great precision, and to play them back the same way every time, even after multiple duplications of a file — something that was never possible in the age when stimuli were prepared by editing tape, and magnetic recording tape and vinyl records were used for stimulus presentation.

Third, dedicated University courses of study for music therapy have been established, with some of the more prominent programs being at The Frost School of Music (University of Miami), Western Michigan State University, Berklee College of Music, Arizona State, University of Georgia, and Colorado State in the U.S., and in Europe/U.K, Nordoff-Robbins, University of Augsberg, the University of South Wales, Anglia Ruskin University, University of Vienna, and Bergen University. The expansion of board certifications and licensure — and awareness of them — helped to bring more rigor to training and treatment plans.

Together, these developments have created an exciting climate of innovation alongside renewed interest and rigor in the scientific basis for music therapies and interventions. A wide range of journals now publish empirical articles relevant to these topics bringing them to the attention of a widening circle of researchers. In addition to specialized journals such as *The Journal of Music Therapy, Music and Medicine,* and *Music Therapy Perspectives,* the work of our colleagues is found in *Brain, Human Brain Mapping, Music Perception, Trends in Cognitive Science,* as well as *Nature, PNAS,* and *Science* among others.

All of this was buoyed by increased public and news media interest in music and the brain, as evidenced by popular books dedicated to the topic, beginning with the 1997 publication of journalist Robert Jourdain's book *Music, The Brain, and Ecstasy* [12] up through this year's publication of *Why You Like It* by Nolan Gasser [13], musicologist and chief architect of Pandora. In addition, the well publicized use of music therapy to aid in the recovery of shooting victim Congresswoman Gabby Giffords may also have a played a role in the public's curiosity about, and acceptance of music therapy as a serious medical option.

The neuroanatomy of music (a brief overview)

Music activates nearly every region of the brain that has so far been mapped [14].

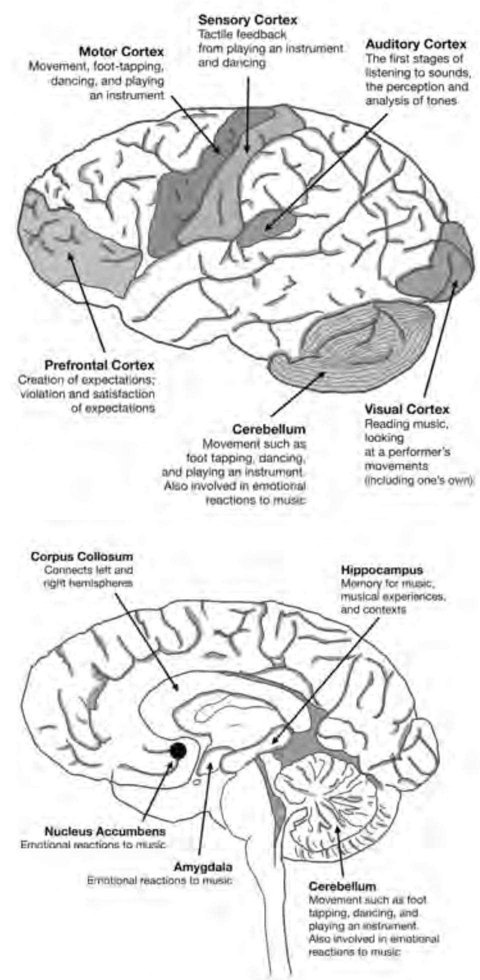

Figure 1. *Music activates a wide range of brain regions. Based on [15] and updated with new information.*

Sound waves in the air cause the tympanic membrane to vibrate, and as the resulting waves pass through the cochlea, frequency-selective neurons send signals upstream to the brain stem, inferior and superior colliculi, and primary auditory cortex (A1) [16–18]. From A1, the signal is sent to special-purpose processing circuits operating quasi-independently, and in parallel, to extract pitch, duration, loudness, timbre, and spatial location. The individual extracted pitches are strung together as sequences that yield perceptions of contour, melody, tonality (e.g. major/minor)[19] and harmony; the durational information is sequenced to yield tempo, rhythm, accelerando and ritardando [20]. The loudness information yields the dynamics that are so important in musical expressivity, including crescendo and decrescendo [21]. Although these different parameters are processed independently, it all comes together so quickly (on the order of tens of milliseconds) that we end up with the phenomenological impression of a holistic musical piece. The nature of these binding processes is an area of active investigation [22]. Evidence for the separability of musical parameter processing comes from case studies of people with congenital or acquired amusias [23, 24] as well as neuroimaging experiments [25].

Listening to music activates:

- motor cortex when we tap our feet, snap our fingers, and dance [26];
- pre-motor cortex and motor cortex even when listeners remain perfectly still, indicating that the cortical motor response is automatic and involuntary [26–28];
- sensory cortex as we obtain sensory feedback from our motor movements, plus vibratory stimulation of skin and through bone conduction [29–30], and, as above, even while remaining perfectly still [31];
- visual cortex as we watch musicians perform [32];
- pre-frontal cortical regions track music as it unfolds over time, generating expectations, and comparing those predictions with what actually occurs [33-37];
- emotional reactions to music tie together circuits in the cerebellum, frontal cortices, and the well-known "pleasure network" of the brain incorporating the nucleus accumbens, ventral tegmental area and amygdala [38];
- memory circuits in the hippocampus [39] as we try to index stored musical memories — patterns — that are similar to what we are hearing;
- autobiographical associations in memory [40-42]. For familiar music, this might be the last time we heard the song, who we were with, particular emotions it has evoked in us in the past, and other songs we know by the same artist. For unfamiliar music it will invoke sonic patters that the current piece may have in common with pieces we've heard before.

Why might music have therapeutic properties?

The ability of music to activate such a wide network of brain regions places it in a privileged position to effect physiological changes in the brain. When used as part of an evidence-based therapeutic program, it has been found to be effective in a wide range of health applications, from pain management, stress relief [43,44], mood induction, relief from anxiety, and cognitive difficulties often associated with Alzheimer's Disease, dementia, and cognitive impairment.

According to the model of Hillecke and colleagues [45], music therapy works through modulation of five factors: attention, emotion, cognition, behavior, and communication. To Hillecke's list, one might add social engagement, memory, and motor systems.

Stefan Koelsch has articulated 7 ways in which music may modulate emotional states, and thus lead to therapeutic outcomes, what he calls "the 7 Cs":

> “Humans have a need to engage in social activities; emotional effects of such engagement include fun, joy and happiness, whereas exclusion from this engagement represents an emotional stressor and has deleterious effects on health. Making music is an activity that involves several social functions:
>
> (1) when we make music, we make *contact* with other individuals (preventing social isolation);
> (2) music automatically engages *social cognition;*
> (3) it engages *co-pathy* … interindividual emotional states become more homogeneous (e.g. reducing anger… depression or anxiety… thus promoting interindividual understanding and decreasing conflicts);
> (4) *communication*…
> (5) *coordination* of movements (requiring the capability to synchronize movements to an external beat);
> (6) performing music also requires *cooperation* (involving a shared goal and increasing interindividual trust); and
> (7) as an effect, music leads to increased *social cohesion* of a group.
>
> Music seems to be capable of engaging all of the “Seven Cs” at the same time, which is presumably part of the emotional power of music” [46].

From a cognitive perspective, music's ability to trigger so many beneficial effects may derive from the same reason it is one of the last things to go in cases of severe memory impairment: its multidimensionality. Music is made up of both simultaneous pitches (chords) and sequential pitches (melody); durations which translate into tempo, rhythm, syncopation, "swing" and "groove"; tonal complexes (timbre); loudness (dynamics); and if the music has lyrics, semantics. It is a highly structured medium. There is a grammar for pitch, rhythmic and loudness sequences, and they cannot be combined in just any random order [47,48], leading to a complex interdependency in the way they become encoded in memory. And with lyrics, the mutually reinforcing cues of rhythm, accent structure and rhyme scheme provide additional structure and constraints. The components of music are so highly structured and intertwined that much of a musical representation could become damaged, and the music would still be recognized, and in many cases, perceptual completion processes would restore the missing components based in Helmholtz's principle of unconscious inference [49].

Embodied Cognition

Many musicians continue to thrive well into their late 80's and 90's — Pablo Casals, Artur Rubinstein, Arturo Toscanini, for example — and an emerging theory about why this is so is known as "embodied cognition." Our brains were built for exploring the environment. The enormous complexity of the human brain is primarily there to organize and support movement and action. When we cease to move, to explore our environment, when we no longer use our brains to organize physical action, they slow down, atrophy, and become disorganized [50]. Is an act of literal movement, and metaphorical navigation, as we explore and find our way around tonal and rhythmic space. A key to this is the recognition that playing a musical instrument always requires movement of some kind — there can be no sound without physical movement: plucking, bowing, breathing, fingering, pressing or banging. (And singing requires the movement of the vocal folds, jaw, tongue and lips). All of these activities require precise, fine muscle movements, coordinated with millisecond accuracy. Exploring our musical environment exercises those same areas of the brain that are activated when we explore our physical environment. Playing a musical instrument requires more training than becoming a neurosurgeon.

A systematic meta-analysis showed that for adults with mild cognitive impairment (MCI), exercise had a significant beneficial effect on memory [108]. Adults with MCI have a considerably increased risk of progressing to dementia, and the risk is increased by atrophy of the hippocampus [108]. Physical activity may be just as effective as pharmaceutical agents in improving and maintaining memory, as well as global cognition, and delaying the onset of dementia as well as other neurological diseases such as Alzheimer's and Parkinson's. And playing a musical instrument and singing may be just as effective, if not more, than the types of coarse movements required for exercise. Perhaps, as Cicero suggested, it is this kind of interaction that "supports the spirits, and keeps the mind in vigor".

The embodied cognition view further states that our cognitive and perceptual abilities are not a static endowment but rather emerge from fruitful and active exchanges with the environment. As children, we gain a sense of agency and control over the environment through our interactions with it. We can lose that sense of agency and control if we reduce our interactions with the environment, which can lead to a loss of motivation and confidence in our ability to interact, setting off a downward spiral. This is particularly a problem for older adults who are already experiencing three kinds of bodily changes that may spur them to interact with the environment less. First is loss of dexterity, which comes from a general slowing down of nerve transmission speed, loss of nerve conductance, and eye-hand coordination. Second is a loss of motivation, which may be born of isolation and feelings of loneliness. Third is a loss of joy and pleasure at doing things for oneself, partly owing to reductions in the production and uptake of dopamine, the brain's reward chemical signaling channels.

Taken together, these can lead people to curtail activities unnecessarily, that is, not for health or safety reasons. Abandoning a particular activity, such as playing a musical instrument or slicing vegetables, leads us to perceive ourselves as "someone who doesn't perform these kinds of actions anymore," and a self-image as a partial non-agent in the world. This can be one of the worst things about aging. There is currently no work (that I'm aware of) studying the intersection between embodied cognition and music making, but it may prove highly beneficial to do so.

Emotional Modulation

Many people intuitively use music to modulate their moods throughout the day, selecting certain kinds of music to help them wake up in the morning or calm them before sleep, to help with an exercise workout, comfort them after an unpleasant interpersonal encounter, or set a mood for a party [51].

Music elicits a wide range of emotions, including joy, exhilaration, calm, fright, sadness, and awe [52-54]. The most robust and well-established finding is that music can induce feelings of intense pleasure [14], euphoria [55], and trance states [56]. The neurochemistry of these feelings has been attributed to music's ability to modulate levels of dopamine, endorphins, and opioids in the limbic system [38, 57-61]. Pleasurable music can moderate dopamine, serotonin, and opioid levels; soothing music can moderate prolactin [62-64]. Techno music (which is known to induce trance states) was found to increase plasma cortisol, ACTH, prolactin, growth hormone and norepinephrine levels [65, 66]. A meditative piece of music (by Ravi Shankar) significantly reduced plasma levels of cortisol and norepinephrine [67].

An interesting, and perhaps counterintuitive finding is that people vary greatly in their judgments of what particular musical selections and musical features induce specific emotions. In one study, 200,000 people rated 20,000 different songs along 200 dimensions [68, 69]. The same songs often appeared in different categories. For example, *Back in Black* by the heavy metal band AC/DC was rated as "exhilarating" by some participants and "soothing" by others. On further investigation, the participants who found it soothing were habitual listeners of Swedish Speed Metal (a heavy metal subgenre) and so, by comparison, AC/DC was relatively calm.

Moreover, a given piece of music can evoke different emotional responses throughout one's life, even throughout the day; there are times when we don't even want to hear our favorite piece of music. This underscores the importance of musical interventions being performed in close consultation with the patient, rather than using "experimenter-selected" music as hundreds of studies and interventions continue to do.

Health, Immunity, and Pain

Several studies have investigated the effects of music on salivary immunoglobulin A (s-IgA), a principal immunoglobulin secreted externally in body fluids, including saliva and mucus of the bronchial, genitourinary and digestive tracts [70, 71]. Salivary IgA is a first line of defense against bacterial and viral infections and a reliable marker of the functional status of the entire mucosal immune system.

Following music therapy, immunoglobulin A (IgA) levels have been shown to rise [72], as well as melatonin [73]. Increased melatonin production in turn leads to increased cytokines and the production of t-cells. Epinephrine and norepinephrine increase following music therapy, increasing arousal and attention. Mood changes are also well established.

Patients who listened to joyful music showed significant increases in arterial dilation [74], to a level obtained with aerobic activity or statin therapy. Among Alzheimer's Disease (AD), Mild Cognitive Impairment (MCI) and dementia patients, music has been found to be effective at treating disruptive behavior, anxiety, and depression, and is linked to improvements in Quality of Life and cognitive function [75].

Listening to music prior to surgery was found to be as effective as diazepam in reducing pre-operative stress and anxiety [76, 77]. Music reduces pain [78, 79]. Participant-selected pleasurable music differentially activated a network of pain-related brain regions, including dorsolateral prefrontal cortex, periaqueductal gray matter, rostral ventromedial medulla, and dorsal gray matter of the spinal cord [80]. An emerging body of thought on the nature of pain proposes that rather than a "pain matrix" in the brain, there is a "saliency matrix [81]." This theory emerges from the common observation that similar sensory stimulation can evoke wildly different mental experiences. The identical pressure on the underside of your foot is interpreted differently depending on whether you just stepped on a rock, or you're in a spa receiving a foot massage, indicating that the experience of pain is a cognitive construction, owing to interpretation and context. Pleasant music accompanying pain may serve to re-contextualize the experience, just as music of differing emotional valences can profoundly affect our experience of a visually ambiguous movie scene [82-85].

Special Problems of Aging

Musical memory is relatively spared in patients with AD and dementia, sometimes extraordinarily so [86-88]. Memory is especially preserved for long-ago learned songs, as opposed to newly encountered ones, and this finding is consistent with the overall profile of AD and dementia-related memory impairment, that episodic and recent memory is affected more profoundly than semantic and long-held memory.

An emerging body of literature indicates that music can play a powerful role in treatment for patients with dementia, late stage Alzheimer's Disease (AD), and other brain disorders associated with aging. Even though memory deficits are a hallmark of dementia, and in particular AD, a number of studies have found that *musical* memory can be preserved, even in the face of profound amnesia for other aspects of a person's life [89]. Some, like musician Glen Campbell, can continue to perform music at a world class level [90]. And it's not just memories for old, well-known music that are intact — people with dementia can even learn new songs [91]. Music also reactivates autobiographical memories in patients, which can provide comfort, alleviate depression, anxiety and agitation [92].

The neurological basis for this is just being uncovered. When AD patients listen to music they chose, activation increases in motor areas of the cortex, along with widespread activation throughout the brain, linking together the cortex and the cerebellum. This may account for the sense of "being alive" again, and for improved mood, memory, sense of self, and reconnecting with personal emotions. Musical memory remains intact even in the face of massive lesions to canonical memory areas such as right medial temporal lobe, the left temporal lobe and parts of left frontal and insular cortex, with similar findings in patients with bilateral temporal lobe damage [93].

Methodological Issues in Music Research

For centuries music therapy remained undefined. The phrase was used loosely to describe pretty much anything people wanted it to be. In the past ten years, there has been a growing recognition that progress in the field of music as medicine depends on careful scientific observation and controlled experiments.

A century of experimentation on music and health, broadly defined, tended to use music selected by the experimenter as conveying, in the experimenter's own judgment, certain emotional qualities. The trade-off here is between controlling acoustic properties of the music versus the emotional or valence responses to that music. In conducting studies that inform music therapy do we want to ensure that every participant in the study receives the identical acoustic signal, regardless of whether or not they like the music or what emotion they associate with it (or even if it is familiar)? Or, if we're studying an actual live, thinking person's reactions to music, would we rather control for how much an individual likes the music, their emotional response, and whether or not they've heard it before? Much experimentation was conducted with music composed by the experimenter, not by trained composers, in what strikes me as a misguided effort to control the stimulus.

Andrea Halpern was perhaps the first cognitive psychologist in modern times to employ real-world, well-known songs in rigorous experiments [94], and the field has seen an increasing trend towards doing so since then [95].

Some guidelines for future research methodology in experiments of music therapy interventions include (but are not limited to):

(1) *Control for familiarity*. Ask listeners how familiar they are with a given piece of music, by using Likert scales. It's also possible to verify familiarity by playing short excerpts of the music, a la Krumhansl [96] and Schellenberg [97, 98].
(2) *Control for pleasantness.* Ask listeners how pleasant or enjoyable they find a piece of music.
(3) *Control for emotional quality*. Ask listeners, through free-response or forced-choice, to indicate what emotion they associate with the piece [99-101].

Comparing one musical stimulus to another, or to a non-musical stimulus, can help to elucidate a number of questions of utmost interest to music therapists. Is music special? Might I get the same effect from, say, an audiobook, guided meditation, or podcast? By equating familiarity, pleasantness, and emotional quality, we can home in on answers to these questions. When contrasting two or more pieces of music, or a piece of music with another stimulus (e.g. speech), we accomplish an ecologically valid, real-world control by equating the music and its control stimulus across all of these dimensions. It doesn't matter if the acoustical profile of the stimuli are the same — what matters is how the listener perceives them.

Future directions

One promising area that remains underexplored is the use of music in group settings. Although music therapy is primarily administered in a one-on-one basis between therapist and patient, an emerging body of evidence suggests that group music listening may confer additional benefits. Group music listening and group music making have been likened to physical grooming among primates, as it supports social bonding [109, 110]. For music listening in particular, the great advantage over speech is that large numbers of individuals can participate together, at the same time. In music, this creates a choir; in speech it creates cacophony.

When people listen to or sing music in groups increased levels of serum oxytocin are observed, a social saliency hormone associated with feelings of bonding and trust [102,103]. Music fosters a sense of community; a sense of connection to others; and provides a shared experience.

Several communities are experimenting with intergenerational choirs that bring together children, adolescents, and older adults with dementia. One studied changing attitudes of younger people toward older adults through the use of collaborative singing [104]. Students, starting with the first rehearsal, were "buddied up" with a person with dementia and that person's family members, and they sat next to each other during most rehearsals. At the beginning of each rehearsal, time was given (15 – 20 minutes) for socialization, a chance for the buddies to talk with each other. All choir members are treated as equals and called by their first names, regardless of the age difference. Songs were selected that had more repetition, fewer rhythmic or tempo changes, and included songs well-known by all including *Stand By Me* and *Over The Rainbow*.

Before the choir began, 65% of the words that young people used to spontaneously describe older adults were negative, such as *sadness, sick, helpless,* and *deterioration*. After three months in the choir, 75% of the words that young people used were positive, such as *unity, love* and *caring*. One student said, "Months ago I was afraid of not knowing what to say or what to do [around a person with dementia]. But the issue was with me, not with the folks with memory loss…Spending time with my new friends with Alzheimer's helped me to see that we are not hopeless when we start forgetting; we are hopeless when we give up and decide not to live." One individual with AD said "When I spend time with the students, I feel energized and accepted. It is fun being around young people."

Group singing constitutes a real-life activity in a setting that is organic and natural, rather than clinical. But it is not for everyone — older adults with mobility problems, or other issues that may make group singing stressful, may benefit from group music listening. This may be one of the most promising avenues for future research. Listening to music causes synchronization of brain activity, when people listen to the same piece of music [105]. No one has yet done the study, but based on the literature, a reasonable hypothesis is that such group listening to music may foster intra-group cohesion, increases in mood and feelings of well-being, and increases in oxytocin, serotonin, dopamine and endogenous opioids. As Pink Floyd sang in 1967, "Music seems to help the pain… to cultivate the brain,"[106] a sentiment echoed thirty-five years later by German artist Sarah Connor: "People have always been singing to wipe away tears, to ease all the pain. Music has always been healing."[107]

Finally, there are indications that one of the most promising areas for studying music, especially among older populations, is to adopt the embodied cognition approach to explore whether playing musical instruments and singing can delay the onset of cognition impairment, enhance quality of life, and possibly increase lifespan.

Conclusions

For decades, music therapists have combined art and science to develop therapeutic relationships and systematically deliver musical interventions that promote recovery, resilience, and enhanced quality of life. More recently, music therapy researchers have begun to generate evidence for the efficacy and effectiveness of these interventions, while cognitive psychologists and neuroscientists continue conducting rigorous scientific experiments to better understand the underlying mechanisms, and the effects of listening to and creating music on the brain. Future goals are to use what we are learning about the relationship between music and the brain to better understand how and why music therapy interventions work, to enhance their efficacy and generalizability, and to educate medical professionals about their benefits.

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Biographical Statements

Dr. Daniel J. Levitin is a cognitive neuroscientist specializing in studies of music, using a variety of converging approaches, such as neuroimaging, psychophysics, behavioral experiments, pharmacological interventions, genetics, and studies of patient populations. He is also a remusician who has performed with Rosanne Cash, David Byrne, Bobby McFerrin, and Victor Wooten among others. Levitin is Founding Dean of Arts & Humanities at the Minerva Schools at Keck Graduate Institute in San Francisco, and James McGill Professor Emeritus at McGill University in Montreal.

Full-Length Article

Uncommon music making: *The functional roles of music in design for healthcare*

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Abstract

In this paper, we discuss uncommon settings and roles for music in order to demonstrate how music can aid in the design and implementation of socially responsible healthcare products that are encouraging, inclusive, and sensitive to critical contexts. We review three music-inspired design cases (CareTunes: Musical Alarms for Critical Care, Music and Senior Exercise, and We Are All Musicians and the Adaptive Use Musical Instrument) in which the authors took part. The literature review and the analysis of the case studies provide the following insights: music enhances sensory experiences, facilitates physical engagement with the world, music can guide medical professionals in critical contexts, and music creates social cohesion. All of these projects demonstrate the importance of involving participants (users or performers) in the process to address their life experiences. The use of music in design applications is experienced as a positive influence that can facilitate wellbeing for community members, persons with disabilities, medical patients, and healthcare professionals in the workplace.

Keywords: : ***design interventions, music-inspired, community music, medical device, healthcare, wellbeing***

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Introduction

Music is embedded in many aspects of our daily lives. In this paper, we will discuss some uncommon settings and roles for music, demonstrating how music can aid in the design and implementation of socially responsible healthcare products that are encouraging, inclusive, and sensitive to critical contexts. After an introduction to the benefits of music and its functional role in societies, we present three design cases within the healthcare domain that incorporate music to empower clinicians, elderly patients, and people with physical disabilities. Finally, we reflect on music's potential as a tool for social intervention that can change and enhance familiar experiences.

Music and wellbeing

For most people, listening to music is a pleasurable activity. Likewise, singing or playing a musical instrument, whether on one's own or in a group context, can be highly gratifying, evoking a sense of achievement. However, the extent to which music influences our sense of wellbeing can go beyond pleasure and achievement due to its pervasiveness [1]. Being involved in musical activities shapes the way we perceive and process sensory information, influencing language acquisition, literacy and numeracy skills, and overall intellectual development [2, 3, 4, 5]. Active engagement in music boosts creativity and facilitates academic and general performance levels [1]. Playing music with others can reduce stress and increase proximal relationships among individuals, therefore helping with the personal and social development of young adults [6]. Moreover, playing instruments is a physical and rhythmic activity that not only improves spatial coordination and temporal reasoning, but also sharpens fine-motor skills. Overall, music has profound effects on sensory and intellectual development and therefore positively influence health and wellbeing.

Functional roles of music in society

In addition to promoting health and wellbeing, music performs a variety of functional roles in different contexts due

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to its positive effects on our physiological, psychological, and social health [7, 8]. For example, music is often used to induce and enhance emotions, playing as a backdrop to emotional scenes in films, in advertising, and in therapy contexts, among other fields [9]. In film soundtracks, music not only facilitates the narrative, but also conveys the emotions the characters are experiencing, shaping, in turn, the emotional response and mood of the audience [10, 11].

Music also can be used to alter our time perception. By providing listeners with a continuous perceptual experience that develops and changes over time, music allows listeners to discover new patterns and make new connections, reducing boredom. This is why music is used in elevators and by call centres while we are on hold—music changes our perception of the passage of time, making it less tedious [12]. Some scholars have speculated that music may have developed originally as a safe way for early humans to pass time in a manner that is analogous to the sleeping habits of other predators [4].

Clearly, music can be used to enhance or otherwise affect a wide spectrum of the human experience. In recent years, a growing number of stakeholders within healthcare contexts have become interested in exploring the functional roles of music for patient treatment and clinical workflow.

Targeted musical interventions in healthcare

Previous research has shown that music can be a highly effective tool in healthcare settings. For example, a recent study showed that music created specifically for preterm babies helped their brain development in their last three months spent in neonatal intensive care units [13]. In addition, music has been shown to aid in the (self)-regulation of emotions in (critical) healthcare settings [14, 15]. Music has been used in tranquillity rooms in which people (including those who are under stress due to perceptually and cognitively demanding routines) restore their senses and regain control of their mental processes and positive emotions [16]. Tranquillity rooms help people cope by giving them a respite from noisy and hectic environments, eliminating potential stressors such as loud noises and beeping alarms as described by the appraisal theory of Lazarus and Folkman [17].

In addition, music has been applied in various clinical settings as a stress reliever during pre-operative and/or post-operative stages. There is consensus amongst the studies that conducted systematic reviews and meta-analysis that music can act as medical treatment pre- and post-operatively in such a way that it significantly reduces pain amongst adults and children [18 – 20]. This pain-reduction effect is stronger for conscious patients and self-selected music in comparison to sedated patients and no music. The reviewed studies show similar effects for the indicators of anxiety and stress (e.g., systolic blood pressure, heart rate and neuroendocrine stress response). The effects can be explained as the following: Music modulates attention in a way that distracts the patient from anxiety and pain-inducing stimuli during medical procedures [21, 22]. Peaceful sounding music, characterized by low arousal and positive valence, was found to be more effective at improving patient recovery than music with high arousal or white noise [23]. Furthermore, patient exposure to relaxing music (such as Pachelbel's Canon in D major) prevented increases in anxiety, heart rate, and blood pressure when patients were triggered by an oral presentation task [24].

In addition to reducing stress, music has been shown to have positive therapeutic effects on some psychological disorders [21, 25, 26]. In music therapy, music modulates attention and is used in various attentive disorders. It further regulates emotions as it modulates all major limbic and paralimbic structures involved in the maintenance, initiation, and modulation of emotions. Therefore music can be an effective treatment for affective disorders such as post-traumatic stress disorder (PTSD), which involves a dysfunction of the limbic system. It also modulates cognitive functions, such as memory processes (encoding, storage, decoding of musical information) and, as such, aids memory function among Alzheimer's patients. Music can also enable communication, serving as an effective treatment for selective mutism and other communication disorders [21].

We are inspired by the positive effects that music has had in various healthcare settings, and by the possibilities that such settings open for designers and musicians alike. The three design cases below present uncommon approaches to music-inspired products, services, and systems.

Music-inspired design cases

1. **CareTunes - Musical alarms for critical care**

Audible alarms are fundamentally designed to be a crucial work tool for clinicians, but clearly have negative consequences for patients' mental and physical health as well as clinicians' well-being and work efficiency [27 – 31]. The raison d'etre of designing audible alarms is to inform clinicians about critical changes in a patient's physiological data, including the incoming vital signs as well as the status of patient's overall recovery. Currently, there is an excessive amount of non-actionable audible alarms in intensive care units [32 – 34]. Clinicians, especially nurses, often ignore the sound of alarms and do not (immediately) attend to the functions the alarms individually represent [35, 36]. This situation, as indication for alarm fatigue, limits the efficacy of audible alarms, which often communicate critical information.

The multiplicity of alarms in most hospital settings also causes anxiety among patients and visitors. Because alarms are often associated with a patient's vital signs and are used to indicate the necessity of medical action, patients and visitors often find these sounds distressing. In addition, medical alarms may have profound psychological effects such as contributing to patient delirium and Post Intensive Care Syndrome (PICS, which is similar to PTSD) in the long term after hospitalization. Music can be an effective intervention in the cacophony observed in many hospital settings, contributing to healing and a work environment that reflects the purpose of critical care, which is patient recovery through rest and, if possible, deep sleep. Eliminating redundant alarms and the cacophony of sounds would adhere to the original purpose of critical care.

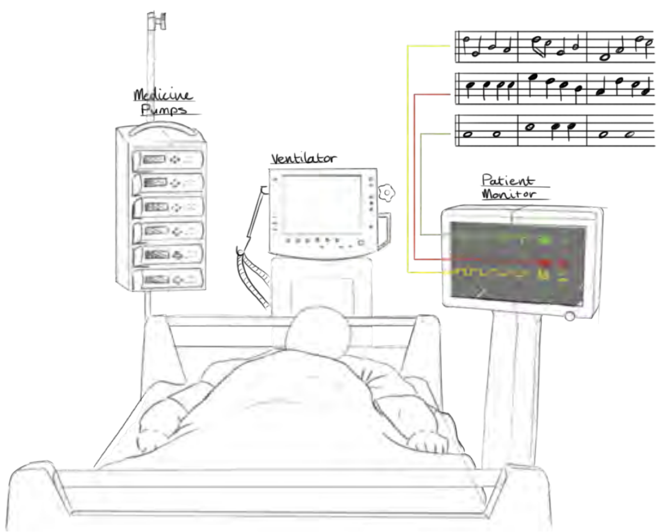

Figure 1. *The concept of CareTunes [37] is shown.*

Figure 1b. *The image depicts the interactions with nurses.*

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CareTunes (see Figure 1) is a concept that challenges the clinical utilization of audible alarms or the beeps of patient monitoring devices found in Intensive Care Units [37]. CareTunes is a continuous musical stream that summarizes patient vital signs and presents them in a coherent, logical, and pleasant way to clinicians, the ICU nurse in particular. With CareTunes nurses can have a clear understanding of the overall criticality of the patient status, their trend toward recovery or deterioration, impulsive changes in the vital signs of the patient, and the history of the changes of vital signs. The nurses' task at the nurse stations is to listen to the musical piece that represents a particular patient, recognize the onset of a critical event, and diagnose the source of the problem (e.g., heart, respiration)—all by listening to the music associated with a particular patient. The musical piece created by patient vitals will sound more pleasing than erratic audible alarms due to the harmonic and structured musical features of the data-driven composition. In addition, CareTunes music could be used in patient rooms as a positive indicator of patient status as well as a relaxing ambient sound similar to the music used in sensory rooms.

The main functionality of CareTunes [37] is collecting data from monitoring devices and transforming it into musical motives, i.e. continuously sonifying incoming data. That is, a range of data is selected and increase and decrease in the data is indexed to sonic notation such as increase or descrease in pitch, tempo and meaningful use of silence and intervals (see [38] for more info on data sonification). The following questions are essential when considering CareTunes as a musical monitoring system for medical patients: Which vital signs can we use for data sonification? How can we create harmonicity when sonifying data? What timbres (e.g., instruments or other harmonic devices) can be used together? How can we communicate the trend in patient recovery / deterioration and the changing criticality of information? Should there be a difference between the musical composition for nurses' workflow and for patients' need for comfort? How about the effects on the user? How pleasant is the musical motive when perceived by nurses? Do nurses feel calmer? Are they better informed about the onset of the critical events? Can untrained people (e.g., visitors) relate to the musical stream and ascribe meaning to the heard sound? Will the musical monitoring of patients fit within nurses' busy schedules?

For prototyping, 48 hours of patient data that are critical to patient monitoring was used (including heart rate, oxygen saturation, and blood pressure). Distinct musical roles (similar to the roles of the instruments) were assigned to patient vitals (see Figure 2): heart rate was represented by a percussive sound (e.g. beat on a drum), oxygen saturation by chords (e.g. guitar), and blood pressure by melody (e.g. piano-like sound). For status changes, a low-pass or high-pass filter was used for decreasing or increasing values respectively.

Following interviews and discussions with clinical care nurses, we revisited CareTunes adding a "musical updates" feature in which a continuous stream of musically-expressed data is reduced to particular musical motifs to inform the nurses about trends in patient monitoring. Critical care nurses at Erasmus Medical Centre Rotterdam found this version more fitting for their workflow than the previous version in which they had to search for trends in continuous patient-made music. A special screen is also designed to depict the changes in the musical updates for critical care nurses to refer to at their station (see Figure 2).

Figure 2. *CareTunes as musical updates with the function of each musical motif is shown on the left. The right image depicts the visual display of CareTunes to be used by critical care nurses [37]. An interactive demos can be found on <http://koenbogers.nl/>.*

CareTunes brings together the knowledge and skills of designers, researchers, artists, engineers, and clinicians in a unique and creative way. This project allowed us to demonstrate our vision and poses critical questions regarding sound design in health care. We developed an effective alternative to the alarm-dominated cacophony of intensive care units, one that consisted of pleasant-sounding music that communicated vital information in a way that nurses could understand. CareTunes makes it clear that pleasant sounds can be informative and represent criticality in intensive care units.

The design of CareTunes is meant to trigger public discussions on the auditory quality of critical care environments, including the effects of noise on clinicians and patients, as well as the limited design space imposed by healthcare policies and international standards. Since its materialization by Koen Bogers (2018) [37] and especially its debut at the Dutch Design Week 2018 (The Silent ICU display by Critical Alarms Lab [39] at the Embassy of Health Exhibition), CareTunes served its purpose to debate the validity of auditory warning systems and how we can shape the future of information system design and auditory design for critical care environments.

Four different stakeholders worked together in the conceptualization and creation phase of CareTunes [40]. An electronic music artist ensured the musical quality of the project; a clinician with a musical background reflected on the clinical utilization; a data-driven medical device company contributed to the viability of the product; and designers and design researchers worked with critical care nurses to determine the intervention point and type. These stakeholders (see the Acknowledgments) were instrumental in conceptualizing and developing CareTunes, and each one gained new integrated knowledge and skills about designing with music.

2. Music and Senior Exercise

There is extensive research demonstrating the positive relationship between music and motivation during exercise [41 – 44]. According to Wongkee (ibid) [44], "musical melodies and rhythms make exercise more enjoyable and divert exercisers' attention from their physical discomforts". Indeed, a recent pilot study investigating ways to generate music while exercising, using a variety of user-friendly, adaptive music technologies, suggested that seniors are motivated to exercise and engage more with one another while making music [44].

We conducted two ethnographic studies with participants at Seniors' Recreation Centres in Ottawa, Canada. During the first study, we focused on the sensory experiences of seniors in post-rehabilitation exercise classes in order to design wearable devices to support their exercise. Their classes were different than music-driven fitness classes in which the instructor leads a group of participants through a range of quick-paced exercises with a rhythmic musical soundtrack [45]. In these classes, due to the extent of rehabilitation the participants need simply to be able to walk down the street, many of the exercises were slow and targeted to specific users' needs, with no musical soundtrack. One of the important findings of the first ethnographic study was that "one-kind-fits-all" wearable exercise monitoring support devices were unacceptable to the seniors. Moreover, we recognized that the participants were not only at the centre to exercise; they were also keenly interested in social interaction. We wondered if their social interaction could be enhanced by a shared music-making experience during exercise, making it more fun and socially cohesive.

This led to our second ethnographic study, in which we focused on the link between music and exercise, especially the motivational qualities of music. Building on the work of other researchers, we theorized that incorporating music into seniors' exercise classes would reduce perceived effort and increase the positive effects of exercise [43, 46]. Since this was a design-driven inquiry, the main question we asked was "How can design contribute to developing responsive music making objects that create positive exercise experiences for seniors [36]? We engaged the seniors in making music with adaptive musical instruments such as the Adaptive Use Musical Instrument (AUMI) software (see Table 1: Figures 3a and 3b) on iPads and the SensAble Adaptive Music Interface (SAMI) developed by Dr. Adrian Chan and his research team at Carleton University in dialogue with composer and percussionist Dr. Jesse Stewart. (see Table 1: Figures 4a and 4b).

Table 1. *Adaptive Musical Instruments*

<table>
<tr><th>Adaptive Use Musical Instrument (AUMI) [44]</th><th>SensAble Adaptive Music Interface (SAMI) [44]</th></tr>
<tr><td>The AUMI software is accessed on an iPad mounted in a position that enables the iPad camera to track users' movements. The screen is divided into a customizable number of zones that can be resized and arranged horizontally, vertically, radially, or in a grid. Each zone is assigned a different pitch or sound (see Figure 3a). A circular cursor on the screen follows the movements of the user. As the cursor moves into different zones, the corresponding sounds are triggered (see Figure 3b), creating music. The tuning, instrumentation, and scale are all customizable so that musical output can be set to group preferences.

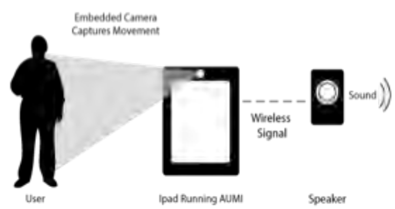

Figure 3a: *Diagram of AUMI*

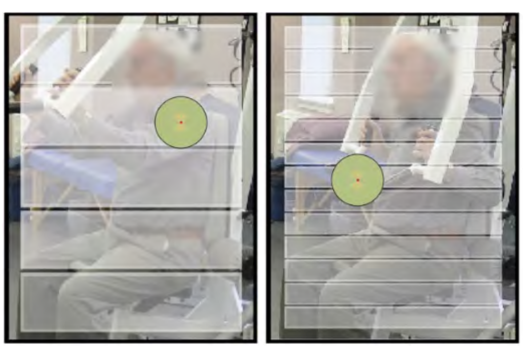

Figure 3b: Screenshots of AUMI interface using 5 and 13 notes</td>
<td>The SAMI system includes a foam ball with an embedded gyroscope and an accelerometer that trigger audio responses from a computer running a synthesizer program known as DIN (see Figures 4a and 4b). Depending on the speed and direction of the ball, the sensors will trigger different keystrokes, and in turn, output different musical pitches, the tuning and timbre of which are customizable within the DIN software. SAMI was chosen as a technology probe because, unlike the AUMI, it requires the user to interact with a physical object to create music.

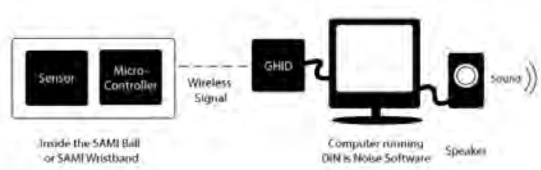

Figure 4a: SAMI system overview

Figure 4b: SAMI system with foam ball</td></tr>
</table>

Through both ethnographic inquiries and design studies, we observed that participants could exercise on their own, moving the ball around in space or together by tossing it to one another. This led to insights about using responsive music making devices for exercise:

- Music making during a seniors' exercise class may provide **engagement** and **motivation** for those exercises and having **sensory feedback** (audio and visual) about the exercise contributes to participants' **positive motivation,**

- The **music should be pleasant** for the user and **not distract them** from completing their exercises properly,
- It should allow the **users to feel in control of the music making**, and
- Give the instructors and users a **tool to monitor** their exercises and **fitness progress** [44].

Based on these recommendations we then wondered, "What could responsive musical instruments for exercise be like? Sound like? Work like"? In our next project, four industrial design students tackled this new question. They were participant observers in Seniors' Gold Club Fitness Classes at a different local community centre. There, they participated in classes, talked to instructors and the senior exercisers and held co-design sessions with them to enlist their help in designing exercise equipment that they would want to use [47].

This study supported the cultural value of the music in the classes – mostly related to the exercisers' teen years. It found that social interaction was minimized due to the volume of the music during the class and listening to the instructor over the music increased the challenge for some. In fact, some exercisers were challenged to keep up with the music; some people had difficulty adjusting to rhythm and others had difficulty isolating ambient noise from immediate noise (person talking in front of them). As noted, people tended to prefer music with which they are familiar since it is easier to find and follow the beat. The type of music, or specifically its tempo, melody, lyrics and rhythm can have an effect on its motivational qualities [48]. The student designers realised that there could be potential for a stronger connection between the music and the exercise class participants. According to the literature, "performing and creating music in groups can provide additional benefits for individuals, giving participants an increased sense of pride and accomplishment, increased social satisfaction and affirmation, which includes positive social relationships" [49].

After conducting a co-design session in which exercisers and designers developed ideas for exercise equipment together, the students became aware of specific issues of importance to those individuals. The student designers then spent months refining the design concepts by making working models and prototypes and conducting usability tests to ensure users would find them comfortable and functional. Each of the students focused on a set of exercises for different areas of the body which led to different outcomes for responsive music making. 3 of these are shown in Table 2 and Figures 5, 6, and 7.

Table 2. *Concepts for Responsive Musical Instruments for Exercising*

Pulse: Musical Dexterity Exercise Instrument [50]

This student focused on an instrument that strengthens dexterity. The concept emerged from a co-design session with older exercisers who wished they could have more exercises for their hands. After iterative concept development and usability testing a hand held instrument for grip strength, finger flex and wrist flexion was designed. Each exerciser would work with 2 instruments, 1 in each hand, by flexing, twisting, or squeezing to produce different musical responses (see Figure 5). These movements control the musical reverb, echo, filter as well as other effects selected on a mobile application.

Figure 5: *Musical Dexterity Exercise Instrument.*

Harmony: Balancing Exercise Instrument [51]

This student developed a Balancing Exercise Instrument that places emphasis on music, synchronicity, creativity and social interaction for older adults (see Figure 6). While a person is balancing on the device it responds to how balanced the exerciser is. If the exerciser is not balanced the music emitted by the device becomes muffled and the board vibrates. A team of balancing exercisers can gently compete with another team by modulating the musical output on their boards in response to active balancing movements.

Figure 6: *Balancing Exercise Instrument.*

Maestro: Collaborative Music for Older Adults' Exercise [52]
This student generated a system of hand-held devices that enables a group of participants to collaboratively adjust the music they emit and hear in real time, while working on their upper body range of motion (see Figure 7). It not only connects with a hub to display exercisers' individual results, it also provides new opportunities for novel exercise activities in which the music-making exercisers vary their range of motion movements so that they can collaborate in altering the volume and/or tempo of the music.

Figure 7: *Maestro devices are organized on a hub, and used individually.*

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These studies provided insights into the motivational contribution that music already makes to exercise for the senior population, and suggested additional possibilities for the incorporation of musical features into the design of exercise devices. They confirmed the need for flexibility in incorporating music into design interventions since exercising seniors have different musical preferences, most of which are familiar pieces from their younger years. Musical exercise devices could allow individual exercisers to have more agency in selecting the musical output and in using musical feedback for measuring their progress. In addition to motivating individual exercise, musical interventions were also shown to enhance social interaction. Indeed, responsive musical instruments can do so through different formats, either for individual exercise challenges or for group exercise activities. For example, teams of exercisers could modify the qualities of the music through their exercise movements in friendly competition. The projects provide initial examples of ways that small teams of exercisers can manipulate musical structure in response to their behaviours and influence their social interaction during exercise. These exploratory prototypes illustrate how musical feedback could enhance exercise, engagement, social interaction, and fun in a variety of uncommon ways that bring music and exercise together. We look forward to bringing these devices to market after further development; indeed, several of our participants were disappointed that they are not yet available to purchase!

1. **We Are All Musicians (WAAM) and the Adaptive Use Musical Instrument (AUMI)**

We Are All Musicians (WAAM) is an interdisciplinary research-creation project aimed at fostering accessible and inclusive group music making. In order to realize this vision, the WAAM project uses of a variety of adaptive use technologies in conjunction with more traditional musical instruments in order to facilitate inclusive group music sessions.

The Adaptive Use Musical Instrument (AUMI), as illustrated in Figures 3a and 3b above, has become an important tool within WAAM activities, particularly those involving persons with disabilities. The software's zoom function allows a user to focus on a person's entire body or on a specific body part. If, for example, an AUMI user with a spinal cord injury can only move a few fingers, the instrument can be configured to track the movement of those fingers and turn that motion into music.

The development of the Adaptive Use Musical Instrument has been an interesting example of co-design that involves composers, musicians, scholars, software developers, occupational therapists, and community members around the world [53]. The idea for an instrument that could adapt to anyone's range of motion came from American composer, improviser, and humanitarian, Pauline Oliveros (1932-2016). She enlisted the help of researchers in the United States and Canada, a loose collective that came to be known as the AUMI-Consortium. The Consortium has met regularly via video conference calls for more than ten years. There are now three versions of the AUMI—one for Mac, one for PC, and one for iOS devices—all of which are available as free downloads through www.aumiapp.com.

The We Are All Musicians project has used the AUMI in a variety of settings, including several hospitals. For example, in 2016 WAAM partnered with Artswell (a non-profit organization dedicated to using the arts to improve the quality of life and well-being of individuals living with the effects of age, illness or injury), the Alzheimer's Society of Ottawa and Renfrew County, the Bruyere Continuing Care Centre in Ottawa, and the National Arts Centre to co-facilitate a program called "Music Matters."

Through the Music Matters program, we made music twice a week for eight weeks with a group of eight seniors living with Alzheimer's and other forms of dementia, as well as their caregivers who, in most cases, were their spouses. One thing that many members of the group had in common was a deep love for music. Several participants had extensive experience singing in choirs. Other participants had little or no prior experience performing music, but nonetheless shared a passion for music.

Part of the intention behind this project was to provide an opportunity for all of the participants to have a new musical experience that would be shared by both caregivers and those receiving care. Through an eight-week long process of musical exploration and dialogue, we co-created an original piece that combined music, poetry, and dance, performing the results of our collaboration at Canada's National Arts Centre on May 1st, 2016.

At first, most of the participants showed little interest in the Adaptive Use Musical Instrument, preferring to sing songs from their youth. However, the AUMI played an important role in enabling one member of the group to participate. After one of our singing sessions, a participant named Felix said "I like to sing with my feet." He went on to explain that he much preferred dancing to singing. So we included a dance number in which the Adaptive Use Musical Instrument translated Felix's dance movements into sound. Using the AUMI in this way inverted the traditional relationship between music and dance: instead of the dancer responding to the music, the music was generated by the movements of the dancer. For Felix, the AUMI provided a gateway into the music, enabling him to participate in a manner that was fun and enjoyable for him.

When interviewed about their experience in the Music Matters program, other participants indicated that it was a positive experience for them too: "It makes me happy. It makes me very happy" said one participant. Another said "It means a fair bit, because we enjoy music and we enjoy the people here. We're all probably more or less in the same boat." Several participants even indicated that the experience had a positive impact on their cognitive health. One participant said "It keeps my brain moving. It makes me think." Another stated "Singing is a very healing thing at any time. And it's also fun."

The Music Matters project as a whole highlighted the power of music to bring people together, to promote health and wellbeing, and to foster a sense of community across differences in age and cognitive health. Angela Parić, a graduate student in the Health Sciences Department at Carleton University, studied the health impacts of the Music Matters program, finding that care recipients' levels of enjoyment and willingness to initiate music making both significantly increased throughout the program. In general, care recipients were "more relaxed, content, and cognitively engaged" during and after Music Matters sessions than they were at the outset. Likewise, caregivers reported fewer negative emotions following the Music Matters program. However, caregivers also reported a decrease in their own sense of well-being. This unexpected result may be due to "caregiver burnout" and increased levels of awareness of the challenges of being full-time caregivers [54].

Since 2018, the WAAM project has been using the Adaptive Use Musical Instrument in another hospital setting—at Saint Vincent Hospital, a complex care facility in Ottawa, Canada. Each visit includes a group music making session and also one-on-one sessions with patients who are unable to leave their rooms. In the group sessions, the AUMI provides a way into the music for patients who are unable to hold or play other musical instruments. Likewise, in the one-on-one sessions with patients with limited mobility, the AUMI enables us to enter into musical dialogue with one another.

We have started to use the AUMI interface in a new way at Saint Vincent as well. In addition to translating movements into digital sound, we are using the AUMI to send MIDI (Musical Instrument Digital Interface) signals to solenoid strikers attached to an assortment of acoustic percussion instruments (bells, bowls, cymbals, tambourines, woodblocks, etc.). These items are propped up by mounts made of Lego building blocks (see Figure 9). The building blocks allow for rapid prototyping as we explore--with input from the participants--a wide variety of objects for their sonic potential. In a way, each session is an exercise in co-design as we work together to reconfigure the instrument (which we have been calling "moto-mechano-music") to meet the needs of those who attend these sessions.

The initial responses to the moto-mechano-music experiments have been very favourable. One participant, Scott Mayhew, who has been to every group session at Saint Vincent Hospital stated "I love this. It gives me joy and I am doing something. There is a community. We are doing something together" [55].

Figure 9. *Jesse Stewart of the We Are All Musicians project sets up the Moto-Mechano-Music system at Saint Vincent Hospital (Photo credit: Artsfile).*

Discussion of the design cases

The three design cases discussed above highlight the transformative potential that music can play in a variety of healthcare settings. The **CareTunes project** has turned clinical alarms into musical streams that convey critical information about hospital patients while improving the overall sound design of hospitals. Having musical alarms may improve clinician workflow as well as patient comfort during their stay. Consequently, patient outcomes are expected to improve contributing to more pleasant and shorter hospital stays and better recovery after hospitalization (e.g., less patients returning due to PICS). Clinicians may benefit from music that alleviates alarm fatigue and may even improve morale amongst them due to more efficient alarm responses.

The Senior Exercise concepts integrated music into new tools/instruments for exercise that could not only motivate elderly exercisers, but also give them feedback about their performance, while having fun. These uncommon music-making devices could provide senior exercisers with more agency in selecting and modifying their exercise music, individually and in groups. That could also contribute to a different kind of social engagement with fellow exercisers.

In the **We Are All Musicians project**, the Adaptive Use Musical Instrument has enabled people who might not otherwise have opportunities to make music to participate fully in group music making activities. AUMI and other adaptive and assistive music technologies are playing an important role in fostering inclusive music-making environments that allow people with diverse minds and bodies to collaborate with one another across differences of various kinds. In all the three cases, music-inspired design decisions have made a positive difference to a variety of users. However, we also demonstrated that for music to be an effective feature of a product, its relevance for user context and their concerns need to be first established. Thus, ethnographic studies are required to position music as positive intervention for the targeted audience.

Conclusion

In this paper, we examined the profound effects that music can have on health and wellbeing, and presented uncommon approaches to music and design in several healthcare settings. In our view, healthcare has much to gain from design with music in mind for the following reasons:

Music enhances sensory experiences. People with cognitive impairments (e.g. dementia), patients in hospital care, and children who are developing sensory skills (e.g. babies and toddlers) will benefit from interacting with music, which is a structured sensory input that acts as an auditory puzzle for the person to solve.

Music facilitates physical engagement with the world. The rhythmic and continuous nature of music engages our motor skills and encourages physical interactions with other people and the environment. Some people with physical disabilities (e.g., patients recovering from a stroke, seniors recovering their mobility after an injury, etc.) will benefit from products that use music as feedback system.

Music can be a functional tool for medical professionals. Many healthcare workers are wary of redundant medical alarms. In contrast, music can be used to convey medical information in a less stressful but effective manner, facilitating the workflow of medical professionals.

Music creates social cohesion. Music is a fundamental human right. As such, everyone should have opportunities to make music including persons with disabilities. Inclusive music making fosters social cohesion by creating bonds between individuals and facilitating a sense of belonging to a community.

Clearly, music has much to offer when it comes to design for healthcare. We have focused on the potential of music-centred design and related activities in healthcare settings; however, we want to emphasize the importance of longitudinal studies and clinical trials that aim to demonstrate the potential of music-inspired interventions to foster physical, cognitive, and emotional health. These studies are relatively rare [13], but necessary [56] to position music as an integral part of design for healthcare.

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Biographical Statements

Elif Özcan (PhD) is the director of Critical Alarms Lab at Delft University of Technology and Erasmus Medical Center (NL) and aims to highlight the value of human-centered research and sound-driven innovations for critical care.

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Jesse Stewart (PhD) is an award-winning composer, percussionist, and researcher dedicated to reimagining the spaces between artistic and academic disciplines, and to promoting inclusive music making through research, performance, and scholarship.

Full-Length Article

Medicine and Music Therapy and an Anesthesiologist's Journey Along the Way

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Abstract

A new and young anesthesiologist thrown into a large surgical arena once observed that many of the talented experienced successful surgeons, were older doctors who were set in their ways. As such, this often impeded effective communication between the anesthesiologists and surgeons.

The author, among the first to play music in the operating room, reviews his many years of experience as an anesthesiologist using music in his practice. This is followed by a review of his many diverse affiliations and associations with various professionals in music medicine and music therapy.

Keywords: ***anesthesiologist, music therapy, music medicine*** multilingual abstract | **mmd.iammonline.com**

Music in the Operating Room

I began playing music in the operating room in 1979 at Piedmont Hospital in Atlanta, Georgia. I was a new and young anesthesiologist thrown into a large surgical arena. Many of the talented surgeons were very experienced, successful, older doctors who were set in their ways, which often impeded effective communication between the anesthesiologists and surgeons. A few vascular surgeons, for example, would not communicate when they released the aortic clamp during abdominal aortic aneurysm surgery. This can be disastrous, necessitating a rapid response to profound hypotension and rapid blood loss by the anesthesiologist. Obviously, I needed to get some of these surgeons to both communicate and listen. I asked each surgeon to share with me, what kind of music they liked, and found that if I could get them to respond to music they liked, they would be more communicative and respectful. I played Mozart, Sinatra, George Shearing, Vivaldi, and Ella Fitzgerald, to name a few. I found that the music seemed to improve the surgeons' mood and performance. Sometimes playing new age music specifically helped them relax and become more centered [1].

Initially, I used a portable tape cassette player to play music in the OR. This developed into a CD/tape player car audio system built into a rolling anesthesia cart (see Figure 1).

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Dr. Schwartz offers patients "music to relax by" from his portable music cart.

Figure 1. *Dr. Schwartz with his rolling anesthesia CD/tape player music cart.*

In addition to the OR, I would roll this cart into the obstetric (OB) suite and play music to patients having C-Sections under spinal or epidural anesthesia. Giving the patient (and fetus) a choice of music for the C-Section provided a great distraction from worrying about potential pain and obstetrical complications. After delivery, it is common to give intravenous (IV) narcotics and sedatives to keep the patient comfortable. The patients with the music needed lower doses of sedation to reach a very relaxed level and reported lower pain levels overall [2].

I found that the music made the management easier both when the patient was somewhat sedated during surgery or fully asleep, as well as for sleep induction and emergence from general anesthesia. The music masked some of the normal background noise in the operating room, which can often be quite loud and already have a cacophony of noises overlapping with medical alarms [3]. It seemed as though the patients who were given general anesthetics had a smoother hemodynamic and psychological anesthetic induction and emergence. The most effective music choices had meaning for the patient and facilitated a connection with previous listening experience and associated emotions. This enabled the patients to benefit from previous positive emotions connected with past music listening so they would have a reduced stress reaction [4].

When choosing music for a patient, it helps if they can communicate their musical preferences. Patient–preferred music is overall more effective, as it can connect with past experiences to acoustically paint the patient's environment [5]. It also encourages the possibility of connecting with the patient on other levels. As an anesthesiologist, your first connection to the patient opens up avenues of healing. Intention, eye contact, and talking can all facilitate communication with the patient [6]. Part of this includes being sensitive to the overall "state" of the patient. One of the methods used in music therapy is called entrainment [7]. The music therapist plays music to match the patient's emotional and physical state, and changes the tempo and feeling of the music over time to slow down the patient's rhythms and affect emotional state changes. Similarly, a healer can interact with the patient by sensing the patient's emotional aura and physical state to bring about a shift. The desired changes are usually a reduction in heart rate, which usually signifies an emotional shift away from anxiety/depression and fear. As an anesthesiologist, I have used a number of ways to do this. One is to feel and inhabit the patient's state, using voice as a method to bring about a more meditative state. You can use "healing touch" to feel the patient's pulse or put your hand gently on the shoulder to express caring and empathy with the patient. Once in the surgical arena, whether the patient is nearly awake or deeply sedated, you can play the music chosen by the patient or a piece that relates to the patient's emotional state. One can then change the music material to bring the patient to a more restful/relaxed state. If the patient is about to undergo a general anesthetic, the music can be used during the anesthetic induction. Letting the patient visualize a relaxing place they would like to go is also useful. This can be done by talking to the patient and providing a brief guided visualization.

One of the most important things about playing music for patients is that it can be utilized to decrease the stress response. Patients frequently undergo negative psychological experiences including anxiety, depression, isolation, sleep deprivation, and periods of fluctuating consciousness with loss of orientation. The physiologic consequences include tachycardia, hypertension, decreased immune function, slower healing, increased oxygen consumption, and utilization of higher doses of anxiolytic and narcotic agents, along with potential side effects. In the mid-1980s, Dr. Ralph Spintge conducted the first studies showing that music can blunt the rise in stress hormones during surgical procedures under epidural anesthesia [8]. It is now much easier to measure heart rate variability (HRV) at any point in time by examining the patient's heart rhythm as a measure of stress reaction. HRV is derived by analyzing the heart's normal beat to beat variability. Having a decreased HRV is associated with surgical stress, aging, acute and chronic illness, and cardiac disease [9].

The stress reaction has evolved so we all have a balance between the two sides of the ANS (autonomic nervous system): the SNS (sympathetic nervous system) and the PNS (parasympathetic nervous system). The negative effects of a heightened SNS relative to PNS can be measured showing decreases in HRV (heart rate variability). This is analogous to the Chinese concept that an unbalanced and increased amount of Yin relative to Yang is detrimental to good health. Music has the potential to restore Yin and Yang and ANS balance, and increase HRV in medical patients.

Development of a Central Hospital-based Music System

Physicians and nurses in Piedmont Hospital strongly supported delivering music to more patients. In the 1990s, the hospital supported building a central music system with ten channels, broadcasted by dedicating a server to each music channel. The music was digitally compressed and sent over the hospital's local area network (LAN), and at each music location housed a small box with channel selection and conversion of the digital signal back to audio output from each unit (see Figure 2).

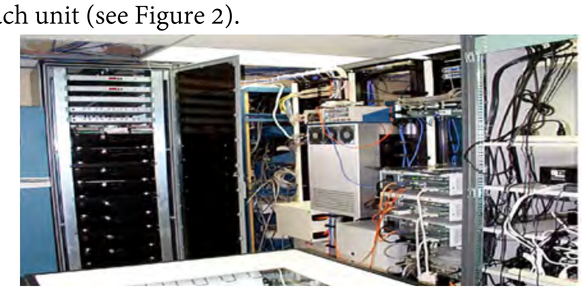

Figure 2. *Equipment used to broadcast music channels at Piedmont Hospital 1990*

Music could be played in all the operating rooms, pre and postoperative areas, labor/delivery and C-section rooms, GI lab, emergency rooms, intensive care locations for cardiac surgery, surgical and medical ICUs, and the coronary care unit. The music was also delivered to some patients with headphones in open areas such as preoperative and recovery areas. For operating rooms and individual patient rooms the analog output from the channel converter box was used to deliver the music to wall mounted speakers with subwoofers.

Presently, most OR music choices are made either through streaming or from portable storage devices. While music is often chosen for the benefit of the surgical patient, when the patient is totally asleep the music choice and volume are often selected for the benefit of the surgeon. I have worked with many surgeons who use the music to help themselves and the OR team find a flow and focus on their work. While this can positively affect the OR environment, some surgeons play stimulating music at high volumes to the extent that they mask the sounds of critical patient alarms. The Canary Box is one invention that attempts to mitigate this risk. An intelligent OR music system, the Canary Box helps to automatically control the volume of OR music during a potential emergency. Problematic changes in heart rate, blood pressure, and oxygen saturation trigger the music system to create an environment more conducive to focus in those high-stress situations [10].

Music and Cardiac Patients

The open heart surgery patients in the ICU appeared to benefit from the headphone music. I set up a small study on recovery of open heart surgery patients as they were waking up in the ICU. If the patient was not yet responsive, we would put the headphone unit on the patient and play the soothing piano channel. When the patients were more awake, the nurses would help them chose a music channel and listening times for the music. We did find that the patients with music had a smoother postoperative course. While the study size was small, it did show a trend for smaller doses of narcotics and sedatives and the patients were able to be discharged slightly earlier from the ICU to the cardiac stepdown unit [11].

It was through our mutual interests in music and the heart that I was invited to visit Dr. Thanassis Dritsas, a cardiologist and composer at the Onassis Cardiac Surgery hospital in Athens, Greece. Thanassis was doing work using music therapy with patients in the congestive heart failure clinic and in the EP (electrophysiology lab). It is not uncommon for there to be music performances in the hospital atrium for patients and staff.

Pregnancy, Childbirth and Music

When my wife was pregnant with our first child, I became interested in the fetal sensory environment. I read some of the work of Dr. Lee Salk, a prominent child psychologist at the time. Dr. Salk theorized that the fetus is attracted to the sound of the mother's heartbeat in the womb. In the early 1960s, Dr. Salk noticed that mothers usually hold their newborns on the left side of the chest over the heart. He conducted a study in the nursery of a New York City hospital that showed 80% of mothers do this, regardless of left or right sided hand dominance. He then went on to show that the mother's heartbeat rhythm soothed newborns and helped them gain weight faster. He theorized that the rhythms of the womb have a major effect on perception of music and music preferences. Salk analyzed 4 popular books at that time containing a large number of photographs and artistic representations of infants and adults. Almost 80% of these showed mothers holding their infants on the left side of their chests [12].

There were already some commercial tape recordings utilizing the sounds and rhythm of mother's placental blood flow, notably *Lullaby from the Womb* by Japanese obstetrician Dr. Hajime Murooka [13]. I became fascinated in the concept of creating a musical recording for newborn babies. If there was something significant in what the fetus perceives from these sounds, then it was probably based on the contour of the pulsating sound wave and the heart rate rhythm as well as the biologic rhythmic variability present in a healthy person. It was important to get a real-time recording that encompassed all of this. Together with my musician friends, brothers Burt and Joe Wolff, we used a doppler to record a representation of the rhythm and dynamics of maternal/fetal blood flow. We combined the recording with a musical rendition of what it might sound like to the unborn fetus to hear mother singing, as well as some soft, ethereal sounds [14].

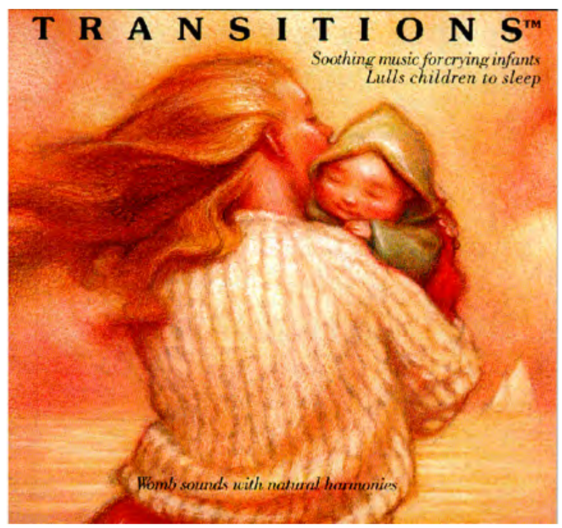

Figure 3. *Transitions CD* https://www.youtube.com/watch?v=ect7Ofza13I

The musical recording "Transitions" seemed to have a dramatic effect on some newborn babies. It seemed like this might be effective with premature babies, who lose the acoustical and other benefits of the womb early. I brought the "Transitions" recording to two neonatal nurses at NICU at Atlanta Medical Center. They conducted a study that showed the recording did have benefits for premature, agitated preterm infants with low oxygen levels who were being ventilated for premature lung disease. This was the first study to show a connection between playing music and raising blood oxygen levels [15].

I encouraged our hospital to deliver music in our neonatal ICU (NICU) at Piedmont Hospital. This involved installing CD players at 16 NICU locations rotating a sequence of 5 CDs. By this time, my interests had brought me to network with music therapists, physicians and healers. One of the first events for me was the 1998 meeting of the International Society for Music in medicine (ISMM) in Rancho Mirage, California. ISMM had been founded in 1982 by the anesthesiologists Roland Droh and Ralph Spintge. It was there that I met Ralph and we discovered our many shared interests. Following the ISMM meeting in San Antonio in 1996, Ralph and I were invited by Professor Roberta Kagin, the head of the music therapy program at Augsberg College in Minneapolis, to lead a Music Medicine Symposium. There, I met music therapist Ruthann Ritchie, who later collaborated on a study of possible benefits of music in the NICU at Piedmont Hospital in Atlanta [16].

With the help of Dr. Cheryl Dileo, a mentor and friend since the 1980s, our pilot study was published in her book *Music Listening in the Neonatal Intensive Care Unit* [17]. I also met Dr. Monika Nocker-Ribaupierre in Munich where I observed some of her with work using music therapy with mother's voice in the ICU [18] and contributed a chapter to her book *Music Therapy for Premature Infants* [19].

A number of esteemed music therapists worldwide were also conducting studies in the 1990s on premature babies in the NICU. Dr. Joanne Loewy, for example, established the Louis Armstrong Music Therapy program at Beth Israel Hospital in New York City in 1994. It was a full-scale music therapy department that, along with other hospital areas, offered services to the NICU, consisting of real-time music interaction with music therapists. It evolved into a fellowship training program whose graduates would go all over the world to start their own NICU music therapy programs [20]. Joanne and I shared a fascination with the elements involved in playing various incarnations of womb sounds to newborns. She incorporated some of these concepts in developing the Gato Box™. The Gato Box is a small 2-toned wooden box, that when tapped with a finger, creates a soft rhythm in a timbre meant to mimic the mother's heartbeat (see Figure 4). The breathing regulation technique utilizes a round instrument filled with tiny metal balls which when played skillfully rotate softly on a thick leather canvas. This instrument is known as the Ocean Disc®™, is meant to replicate the whoosh of the womb. (Figure 4). Rotating it simulates the variable rhythms present in the womb. This has become a popular tool used by music therapists to interact and entrain with NICU babies [21].

Figure 4. *Remo Gato Box and Lullaby Ocean Disc.*

Increasingly, NICU music therapy has been incorporated worldwide. This was accelerated by the development of music therapy NICU fellowship training centers, founded in the 1980s by music therapy pioneers Helen Shoemark from Melbourne, Australia, Rosalie Pratt from Provo, Utah, Jayne Standley from Tallahassee, Florida, Joanne Loewy from New York City, and Monika Nocker-Ribaupierre from Munich, Germany. All of them have been instrumental in encouraging a healthy international dialog between music therapists, physicians, and other music healers.

Beginnings of International Association for Music & Medicine (IAMM)

The second Mozart & Science meeting, held in Vienna, Austria in 2008 and hosted by Vera Brandes, Roland Haas, and Gerhard Tucek, brought together experts from around the world to share insights on music in therapy and medicine. There, David Aldridge and Joanne Loewy stirred up interest in bringing together founding members to start IAMM. It germinated into the Music and Medicine journal in 2009 where they were the original co-editors. Ralph Spintge replaced David Aldridge as co-editor the following year.

The first inaugural meeting of IAMM was at the University of Limerick, Ireland in 2009, hosted by Jane Edwards and the graduate music therapy department at the University of Limerick (figure 5). Jane served as the first president of IAMM for 5 years, followed by Patravoot Vatanasapt. IAMM began with Founding Members from around the globe (figure 5) ––doctors, nurses, music therapists and musicians, all of whom had experience and interest in building a world community of music and medicine.

Figure 5. *IAMM Founding Members at the Inaugural Ireland Conference in 2009***.**

The goals for IAMM were clearly provided by Joanne and David in the first volume of Music and Medicine:
"Our intention is to provide a venue for the development of theory based on practice, and we will draw on specific research in music and medicine. We invite participation through dialogue about the impact that music has on the brain, for human physiology, and in developing unique clinical areas, such as sleep investigations and pain management. Topics such as these are being addressed today but are published diversely in other journals. This means that we have a scattered body of knowledge, which we hope to unify within these pages. Although the fields of medicine, nursing, music, and music therapy have developed several venues for sharing clinical activity and research trials, there is currently no distinct journal devoted to the fields that integrate medical music therapy, and music and medicine. These individual disciplines are growing internationally but each separate from the other. Our intention is to bring that knowledge together" [22].

Looking back over the last 10 years, I believe that those goals have been culminated. As an anesthesiologist it has been remarkable seeing IAMM and the journal grow and become important vehicles for the sharing of research and ideas, and to be part of a healthy, cutting-edge dialog between divergent groups of professionals. It is by crossing borders that we can collectively increase the worldwide consciousness of the broad healing benefits of music.

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Full-Length Article

Music Playing a Role in Medical Interoperability

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Abstract

This article outlines interoperability, the exchange of information between distinct systems, specifically regarding how it applies to music in medicine. Interoperability is of growing importance in the increasingly high-tech medical world whose machines, monitors, and devices often utilize acoustic alarms. Additionally, this article expands on the definition of interoperability to include the integration of music such as music therapy with clinical medicine. Despite barriers pertaining to cost and infrastructure, the future of medicine is bright with the expanded, continued application of interoperability.

Keywords: ***Interoperability, Health Information Technology, medical alarms, music principles, patient safety***

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Introduction

This article discusses how interoperability, the exchange of information between distinct systems, can be utilized in various medical settings to enhance patient care. High-consequence industries such as medicine require coordination and clear communication to ensure success. In the constant buzz of medical settings, important patient information can easily get lost or may not be communicated quickly enough. Devices that utilize aspects of information exchange amongst distinct devices help to bridge these gaps and facilitate effective communication.

Interoperability

In this 21st century world, human life has become intertwined with technology. Technology is the purposeful application of knowledge that produces some form of superior operational capacity; yet it is pervasive and wildly diverse. Its electronic form maintains a large proportion of all technology, and for the most part, engages with one or more sensory system to create a human-centered interface for the presentation of information. In the realm of medicine, these electronic technologies define a new practice of medicine known as digital health, which can be taken one step further to interoperability.[1] By its formal definition, interoperability is the "ability of a system or a product to work with other systems or products without special effort on the part of the customer."[2] The information that can be accumulated and processed in an interoperable system yields data that better represent the patient as it takes more aspects of the patient's physiology into account. Following the logic that more input information yields better output data, an interoperable system can establish a far more comprehensive image of a patient's well-being. In other words, interoperability allows medical devices to communicate and analyze data such that outputs, or, for example, alarms, represent real-time changes in the patient's health.

The capacity of a system to integrate various digital health tools to effectively minimize outputs is one, nuanced description of interoperability. Broadly, interoperability requires a platform through which distinct medical devices can share information and benefits from the implementation of standards. However, medical devices may not all be using the same "language." To cross this barrier, an implementation of standardized input and output styles for distinct devices may boost interoperability and limit the variation between devices' data. Ideally, medical devices would be standardized for input and output in such a way that presents electronic information in the same form, allowing multiple platforms to be connected and deliver information in the same "language."

One application of interoperability in the medical setting is in regulating medical alarms. Currently, patient monitoring is a concerted effort of multiple devices, each with a unique threshold for alarm. However, in an interoperable system, the indication for an acoustic alarm would not be a single, numeric threshold but rather the result of the accumulation and processing of the information from each of the connected devices. An alarm system incorporating multiple parameters has the ability to make more robust conclusions leading to alarms that are stronger indicators of patient's physiology as well as the suppression of false alarms.[3] By making the indication for an alarm more complex and comprehensive, the

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overall hospital background noise made up partly of false alarms should logically be reduced. This noise reduction will allow for clinicians to better focus their attention on their patient while also trusting that the alarms they hear are significant. Medical devices' underlying purpose is to allow clinicians to study and modify patient care knowing that deviations form a set of 'normal' parameters will trigger an alarm. Interoperability holds the potential to progress medical device alarms towards this goal.

As knowledge of such benefits of interoperability has increased, so have the structures that define it and the companies that supply devices to support it. The Integrated Clinical Environment (ICE) is a universal term that defines the broad building blocks that are necessary in an interoperable system.[4] ICE, in effect, is a set of standards outlining how to integrate information from devices from different manufacturers in order to provide better, safer patient care.[5] With this outline to interoperability provided, it is only a matter of software engineers developing these 'middleware' programs and platforms before interoperability can become universal. For reference, middleware systems are the software programs with the ability to integrate data from multiple sources, such as distinct medical devices, and integrate them to provide a singular output stream according to a set definition of 'normal' parameters.

Motivated by the need for increased device synchronicity, the Office of the National Coordinator for Health Information Technology (ONC) prepared a guide to interoperability published in 2014 with the aim to provide a roadmap for continued advancements in interoperability.[6] As newer machines, treatments, and monitors are introduced to medicine, the need to integrate and organize their information and alert systems has increased. Habituation and desensitization are frequent obstacles faced by some hospital departments, especially those that are of higher intensity levels such as Intensive Care Units.[7] The body has a remarkable way of adjusting to continuous stimuli so that they become less noticeable over time. This is exactly what happens to those who spend a significant amount of time in hospitals with regards to the noise of its alarms. Clinicians are familiar with the high volume of false alarms in the medical setting, a factor linked directly to desensitization.[3] Furthermore, overlapping sounds can be indiscriminable; strict segregation and sequencing of alarm sounds via higher order information processing, such as interoperability, may relieve clinicians of this issue.[8] These aspects of current alarm failures indicate that device interoperability may see the largest positive impact in high-consequence medical environments, but may also be efficacious in a wide range of medical settings.

Hayhurst et al found that half of all nurses witnessed a medical error due to a lack of medical device coordination; a clear and fatal flaw of current US healthcare settings.[9] Medical device coordination refers to the shared information between these devices; a lack thereof may cause their alarms to risk being repetitive or false. With interoperable medical devices, medical alarms may be coordinated such that, based on multiple parameters, more extreme physiological changes induce stronger, more noticeable alarms and smaller physiological changes that do not represent detrimental changes to patient health may not trigger alarms at all. In this way, combining information from multiple different systems and processing it altogether may benefit clinicians' understanding and interpretation of alarms so as to improve patient care. With the potential to improve performance and increase accuracy, interoperability will revolutionize how patients receive medical care.[10] According to Dave Cassel, director of Carequality, an interoperability initiative with the goal of understanding the technology and the policies interoperability requires, "many physicians are connected to one data sharing network or another. If you connect just a few of these networks together, we are on the cusp of a quantum leap in interoperability."[6]

There are currently multiple programs to enhance or provide interoperability being developed around the world. Examples include the US-American "MDPnP" system, the Japanese "SCOT" and the German OR.NET programs.[11-13] Each of these interoperable platforms is simultaneously creating distinct pathways to provide interoperability.[14] In other words, these distinct programs are all attacking the issue of interoperability from different corners of the world, at the same time. Take, for example, the US-American MDPnP system that is associated with Massachusetts General Hospital and is exemplary of an effective interoperability program. MDPnP stands for 'medical device plug-and-play' and describes a platform that various devices from different manufacturers can simply connect to in order to establish interoperability. The MDPnP program convenes large-scale meetings with experts in disparate fields ranging from engineers to medical device vendors to the US Food and Drug Administration (FDA).[13] Interdisciplinary programs such the MDPnP program are key in the medical community's pursuit to obtain total interoperability as they are taking the lead in this aspect of medicine's future.

It is important to note that, despite the development of the aforementioned programs, there are currently no comprehensive, universal middleware systems in place to serve as the communication backbone of interoperability.[4] These ICE-defined middleware systems are necessary to integrate the various sources of data from the connected interoperable devices and process them into one, streamlined alarm indicator. While there is ongoing research into middleware, such as the development of interoperability platforms like iLandis, the journey to full interoperability has yet to be and will likely never prove to be easy. According to Hayhurst et al, the largest obstacles currently facing hospitals' transition to fully interoperable clinical spaces are poorly defined standards, incompatible systems, and unhelpful medical device vendors who are hesitant or unwilling to invest their resources in developing interoperability.[9] There are no medical or governmental incentives driving investments into interoperability nor are there incentives for medical device companies to develop systems with integrable data streams.

It is necessary that all healthcare professionals continue to be involved in the development and advancement of interoperability. Specifically, the end-user must be involved in the product development and usability testing to offer input on how to create the most acoustically ergonomic devices that are maximally user-friendly.[15] To continue, interoperability applies not only to medical devices, but also to electronic health records (EHR). Then, too, would general practitioners benefit from interoperability as it relates to accessing their patients' information collected at other medical facilities.[15] In other words, the continuing research and application of interoperability must incorporate all of the clinicians who will be using these platforms on any basis. Otherwise, the hospitals and systems applying interoperability will never reap the maximum benefits of their digital health tools.

The future of interoperability lies in the goal of continuing to integrate all technologies in hospital departments in addition to using advanced computer processing programs to understand the various informational inputs and in order to dictate which alarms should sound and when. While more machine-based, this type of advanced interoperability creates awareness of the patients' status and needs more holistically by combining and assessing a wide range of factors at any given moment. As Underwriters Laboratories principal engineer Anura Fernando concisely summarizes: "we will have achieved interoperability when we stop talking about it."[9]

Interoperability of Medicine and Music

There are several opportunities to increase interoperability in medicine, some of which include incorporating the basics of one everyday element – music. The combination of science and art has increased in parallel with support for various interdisciplinary programs. Music and medicine, both cardinal representations of art and science, respectively, can work together in several avenues to improve and advance the practice of medical care.

At present, music is already implemented into medical care for various avenues of treatment. It has been shown to help with pain management for people suffering from chronic pain, indicating a possible non-pharmacological pain management option.[16, 17] Amidst the national opioid crisis, the application of any non-pharmacologic treatment for pain should be welcomed and spread.[18] Additionally, collaborative songwriting has been used with Prisoners and ICU Patients to successfully relieve anxiety and depression, as well as Post-Traumatic Stress Disorder (PTSD) and Post-ICU Delirium Syndrome (PICS) symptoms.[19-21] The process of writing lyrics and music allows the release of emotion and memory in a cognitive stimulating fashion. In parallel, the therapeutic process and music activates an improvement in motor function through strengthening multiple sensory pathways. This is especially beneficial for Parkinson's Disease (PD), as rhythmic auditory stimulation has been shown to improve gait in PD patients, but can also be applicable with other patients (e.g. cerebral palsy, chronic stroke).[22-25] Medicine has already proved to be open to integrating music, but there is a wide range of opportunity for improvement.

Medical Alarms

One opportunistic avenue in which to utilize music principles, such as pitch, rhythm and amplitude envelope, is in auditory alarms design. The acoustic environment of the hospital is a constant symphony of medical alarms, yet the lack of integration of basic music principles into auditory cues highlights a missed opportunity to utilize interoperability.[26, 27]

Current medical alarms are designed to adhere to the standard of the International Electrotechnical Commission (IEC) 60601-1-8, which has resulted in poor utilization of known acoustic features and uninformative alarms.[28-32] In accordance with this standard, medical alarms have a uniformed number of pulses, rhythm and octave.(33, 34) Although health care professionals are expected to learn and remember every signal and meaning, uniformity in sounds depletes the uniqueness of alarms, making it almost impossible to decode information of varying nature and importance.[34, 35] Wee and Sanderson found that alarms standardized to the IEC 60601-1-8 were only identified with 100% accuracy by 1 out of 22 nurses, even with mnemonics and training.[36] Additionally, Edworthy et al showed that new auditory icons outperform the IEC 60601-1-8 standard in both recognizability and localizability.[34] As such, the current alarms prove to be hard to learn and distinguish for healthcare professionals, yet there is room for improvement.

Structural changes to alarms, such as the amplitude envelope, may help decrease these deleterious effects. A sound's amplitude envelope is its change in amplitude over time. For example, clicking wine glasses will create an amplitude envelope with rapid onset and exponential decay. Currently, most medical alarms have a flat amplitude envelope characterized by rapid onset, a sustained period, and rapid offset. In contrast, most naturally occurring sounds, a yell or the previously described wine glasses clicking, have a percussive amplitude envelope characterized by a rapid onset, then continuous exponential decay. While the flat amplitude envelope presents a novel, synthetic warning sound, the auditory system is optimized to process a symphony of natural sounds – most consisting of percussive amplitude envelopes.[37] In fact, when utilizing percussive amplitude envelopes for alarms, researchers observed an improvement of recall in a memory task, as well as decreased perceived annoyance, when compared to flat amplitude envelopes. In addition, Schutz et al showed that amplitude envelope promoted learnability of tones.[28] These data suggest that structural adjustments to auditory alarms using music principles may result in alarms that are less aversive, easier to learn, and more recognizable; further leading to improved patient and provider outcomes.[28, 37]

The Operating Room (OR) is one area of the hospital that is not only saturated with alarms signals, but also music.[38] It has been shown that background music playing in the OR can relax the surgeon and improve their performance.[39-41] However, it has also been shown that this music can interfere with communication and overall performance of the room, specifically affecting anesthesiologists.[42-45] This is a prime example of where interoperability of medical devices can assist in ameliorating the interfering effects of music on communication and performance. For example, researchers have developed a device called the Canary Box (Figure 1) that is linked to both the music and a patient monitor during a patient's surgery. By using vital sign algorithms, the Canary Box mutes background music in times that require focus and clear communication.[42] The dynamic nature of this device linking technology allows for the incorporation of music's benefits and effective communication.

Figure 1. *The Canary Box Design [46]*

"Smart" Emotion

Beyond alarm design, music can play a role in relaxation and proactive care. One important concern in medicine is the risk of physician burnout, which not only affects the medical professional, but may also have residual effects on patient care and safety.[47] Since music activates neural pathways similar to those associated with euphoria and reward, it can be employed to improve mood and induce positive feelings, especially in stressful times.[48] For example, by using pre-recorded musical stimuli, physicians showed significantly reduced burnout symptoms after 5 weeks, which were maintained over a long time period.[19] Similarly, hospitals can be as stressful for patients, but when exposed to musical intervention while in the ICU, patients showed reduced systolic blood pressure and mean arterial pressure, as well as an increased sense of wellbeing.[49] Both examples show a clear improvement for emotional and physiological factors of providers and patients.

With future research, smart, interoperable devices may be able to track and comprehend human emotions in real time. A possible "smart" device could utilize constant emotional and physiological monitoring and change music to match the needs of the patient or provider. For example, such a device may play serene music when the user's emotions register as stressed or upset. Research has shown to recognize emotion through EEG readings from the commercial Emotiv EPOC device (San Francisco, CA), making EEG a possible route of monitoring for a "smart" device.[50, 51] For some patients or austere settings, an EEG may be too invasive or expensive. Another possible physiologic sign to be used in this device could be heart rate variability (HRV), the physiological variation in the duration of intervals between sinus beats. HRV is considered an index of emotional regulation and self-regulatory strength, and can be measured by a simple heart rate monitor or pulse oximeter.[52-54] A device that is in tune for both patients' and providers' emotions may alleviate stress and improve patient outcomes.

From devices that work together, to devices that work with the user, there are various avenues of improvement that exist in the interoperable medical world.

Challenges of Health Information Exchange

While interoperability can seem to be an obvious improvement to medicine, there is some caution for companies to collaborate and create interoperable devices, both due to concerns of manufacturer and patient security.

From the economic standpoint, this reservation has resulted in a large proportion of relevant electronic health data to not be easily accessible, restricting the optimal integration and exchange.[20] As it is, biotechnology networks for data exchange are classified into two categories – commercial and free; however, the networks in the "free" category are usually financed indirectly through institutions, ultimately classifying those as commercial as well.[55] Fortunately, connecting healthcare data has been facilitated by the 2009 Health Information Technology for Economic and Clinical Health Act (HITECH Act) and the 2010 Patient Protection and Affordable Care Act (PPACA) by encouraging the use of the EHR – opening the doors for data exchange and interoperability.[56,57] Additionally, groups such as MDPnP, mentioned earlier, are working to increase their cooperation with devices of various manufacturers. With optimal implementation, the EHR allows a medical professional to understand a patient's medical history and provide effective medical treatment, regardless of provider or location. As such, the EHR is one crucial step toward health information interoperability.

However, there are many concerns and limitations beyond business boundaries for the use of the EHR and other interoperable devices. One concern is the lack of standardized data implementation into the EHR (e.g. different codes to be used in different hospitals). Fortunately, the HL7 Common Terminology Service and Fast Healthcare Interoperability Resources, two resources that normalize terminology across the EHR and improve the process of aggregating and sharing clinical data.[58]

Additionally, the main concern that medical information faces is maintaining the security of patient health information (PHI), which is any information that can be tied to an individual. This importance is enforced under Health Insurance Portability and Accountability Act (HIPAA). There are many requirements that HIPAA enforces, but the overall goal is to safeguard PHI, usually resulting in all medical technology to be encrypted.[59] HIPAA is essential to ensuring proper patient safety, and should be considered for all medical technologies.

While HIPAA is important, it brings many challenges to the development of technologies that seek to open exchange of data between devices and healthcare networks. To ensure security and adopt interoperable technology, it is important to include, among other key features, a third-party certification of compliance and a secure network that will verify and protect all PHI and other clinical information.[60] These considerations will be imperative for all device developers and collaborators to incorporate into their design.

With the necessary restrictions and enforcements to protect PHI, the exchange of information in the biotechnology sector can be difficult to change and innovate. In just one case, HIPAA was found to have increased confidentiality and privacy, but also adding uncertainty, cost, and delay to human subjects health research.[61] With these technologies, clinical data approaches a more standardized and distributable structure, but many improvements are still needed to ensure proper data exchange and patient security.[62]

Conclusion

Technologies that enable interoperability across health care networks will likely provide for improved medical treatment and clinical research. Research groups have successfully created interoperable devices and platforms, such as the Canary Box and MDPnP, yet barriers to widespread data exchange remain. While patient privacy and outcomes should remain as critical concerns, developing new technologies and devices that promote interoperability can bridge gaps in communication – between both individual providers and large scale networks. Interoperable technology incorporating music with medicine can serve as an example of the successful and opportunistic innovations working to improve and advance the practice of medical care.

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Full-Length Article

Multidisciplinary Perspectives on Music Perception and Cognition for Cochlear Implant Users

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Abstract

For over 30 years, cochlear implants (CIs) have been successfully providing sound and speech perception to individuals who suffer from severe-to-profound sensorineural hearing loss. Despite many recent advances in CI technology, significant challenges remain for users, including speech perception in noisy environments, identifying vocal emotion, and perhaps most notably, music perception and appreciation. Moreover, pediatric cochlear implant users often demonstrate a slower and more variable language development trajectory compared to their normal hearing peers, which is in part due to the imperfect hearing restoration by these devices. In this brief report, we discuss multidisciplinary perspectives on music perception and cognition for CI users, as well as how they can be employed to improve the cochlear implant listening experience. We divide these strategies into two categories—a top-down approach (e.g., employing therapeutic measures to help train the CI user's brain to fully reap the benefits of cochlear implantation) and a bottom-up approach (e.g., improving the auditory input through developing new technology, creating individualized programming strategies, and developing music specifically tailored for CI users). These individualized, yet multidirectional approaches will help create a functionally-integrated system that supports robust processing of complex sounds, which is essential for many everyday tasks.

Keywords*:* *cochlear implant, hearing loss, music cognition, music perception* multilingual abstract | **mmd.iammonline.com**

Introduction

Cochlear implants (CIs) are a surgical intervention for severe-to-profound sensorineural hearing loss, and with over half a million users worldwide, they are by far the world's most successful neuroprosthetics. Over the past few decades, advances in CI processing systems have yielded substantial gains in speech perception such that most CI users are able to achieve satisfactory—or even near perfect—speech recognition scores in quiet environments.[1]

However, despite considerable technological and surgical advances in the field, significant limitations remain for CI users, including speech understanding in noisy environments, detection of vocal emotion, and notably, music perception and enjoyment. Such tasks require processing of spectrally-complex sounds that are ineffectively conveyed by CIs. Moreover, children with cochlear implants often demonstrate a slower and more variable language development trajectory compared to their normal-hearing peers.[2] This may be due to several reasons, including spectrally-impoverished acoustic signals provided by CIs, as well as lack of access to auditory speech signals for prelingually deafened children until their CIs are activated.

In this review, we highlight technological limitations of CIs, the challenges that users face, and recent research that may improve the CI experience via multidisciplinary approaches spanning the fields of music composition/production, biomedical engineering, otolaryngology, audiology, and neuroscience (Fig. 1). These potential advancements and therapies are broadly organized from "bottom-up" to "top-down" strategies, meaning they can improve either the quality of ascending auditory information or the higher cognitive processes that shape perception.

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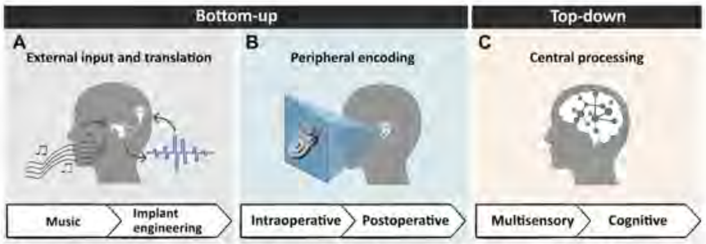

Figure 1. Multidisciplinary approaches to improving music perception and cognition with a cochlear implant. *We organize possible interventions from external factors to those involving the inner ear and finally, higher cognitive processes. In other words, from "bottom-up" to "top-down" approaches.*

How hearing works

The auditory pathway is composed of two parts, the peripheral auditory system and the central auditory system. The peripheral auditory system is made up of several components. The outer ear is composed of the auricle (or pinna) and external auditory canal, which serve to funnel and focus sound waves onto the tympanic membrane (or eardrum). The tympanic membrane, which separates the outer and middle ear, then vibrates, transmitting the acoustic energy from sound waves to the three tiny bones of the middle ear - the ossicles. These three ossicles (malleus, incus, and stapes) then further transmit this vibration, thus efficiently transferring sound waves from air to a fluid medium (perilymph) in the inner ear through an area advantage (i.e., hydraulic amplification) and a lever effect. The cochlea of the inner ear receives this mechanical signal through vibratory pressure from the stapes footplate applied to the oval window, which creates a traveling fluid wave that causes hair cell deflection along the base to the apex of the cochlea, stimulating bipolar neurons of the spiral ganglion that form the auditory nerve (part of the eighth cranial nerve). Thus, the inner ear helps convert this mechanical signal into an electrical signal that can be carried by the auditory nerve through the central auditory system to the brain. The central auditory system begins at the cochlear nuclei in the brainstem, which receive spiral ganglion axons of the auditory nerve. From there, auditory fibers from bilateral cochlear nuclei synapse at the superior olivary complex, followed by the lateral lemniscus, inferior colliculus, and medial geniculate body of the thalamus. Projections from the medial geniculate body then proceed to the primary auditory cortex of the temporal lobe of the brain (see Fig. 2A).[3]

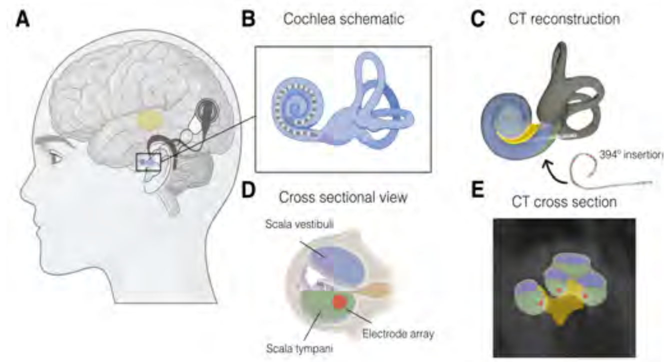

Figure 2. An overview of electrode placement within the cochlea. *(A) The external processor (gray) transmits electrical pulses to an internal receiver and an electrode array within the cochlea (blue), which causes auditory spiral ganglion cells to fire action potentials and ultimately transmit information to the auditory cortex (yellow). (B) Depending on the manufacturer, the electrode array in the cochlea can have up to 22 channels. (C) For a patient with a Cochlear™ Nucleus® CI532 electrode array, a CT reconstruction indicates full insertion just over 360º. (D) A cross sectional view of the cochlea indicates the ideal placement of the electrode array within the scala tympani. (E) For this patient, the electrode array (red) is indeed within scala tympani (green) throughout multiple turns in the cochlea as depicted in this labeled section of a high resolution temporal bone CT scan. Figure panels C and E were created using the methods described in Noble et al.[4] CT= computed tomography*

How cochlear implants work

Though CIs and hearing aids (HAs) are both medical devices used to treat hearing loss, they are very different. HAs amplify (i.e., increase the volume of) sounds and send them to the brain through the entire auditory pathway, as described above. HAs may benefit individuals with a wide range of mild to severe hearing loss. On the other hand, CIs bypass damaged portions of the ear and directly stimulate auditory spiral ganglion cells (Fig. 2B); CIs are typically used by individuals with severe-to-profound sensorineural hearing loss who derive minimal benefit from HAs.

A CI consists of several components (Fig. 2A). Sound from the environment is detected by a microphone near the opening of the ear canal. The adjacent processor translates the frequency and amplitude of sound waves into electrical pulses. These digital signals are sent by the transmitter to an internal receiver/stimulator implanted under the skin. Lastly, the electrical pulses are delivered to the inner ear where auditory spiral ganglion cells are excited in a tonotopic manner (i.e., from high to low frequencies spiraling inward from the base to the apex of the cochlea) via the electrode array (Fig. 2B). This entire process takes place on the scale of about 10 ms and establishes a rudimentary sense of hearing.

Why music perception is difficult with an implant

Processing an acoustic signal (e.g., speech or music) involves both temporal and spectral cues. Temporal envelope processing is the ability to resolve signal changes over time; it helps us distinguish words, speech rhythm and stress, as well as musical rhythm. Spectral information is the fine structure of the frequency composition of sounds. Therefore, spectrotemporal processing is the ability to resolve component frequencies over time. This is analogous to how a Fourier transform is used to resolve a time-domain function into a frequency spectrum. While spectral resolution helps us distinguish some aspects of speech (e.g. voice quality and intonation), words themselves can by conveyed quite well via temporal cues. In contrast, crucial aspects of music like pitch and timbre are encoded by spectral cues. The discrete number of electrodes in a CI limits spectral resolution in part due to the excessive spread of intracochlear electric current around each electrode contact. This phenomenon of "channel interaction" causes interference between channels and the inability to resolve more than 8-10 independent channels of information.[5–7] See Figure 3 for an example of how cochlear implant processing degrades a melody. We also provide a supplementary video illustrationg the phenomenon.

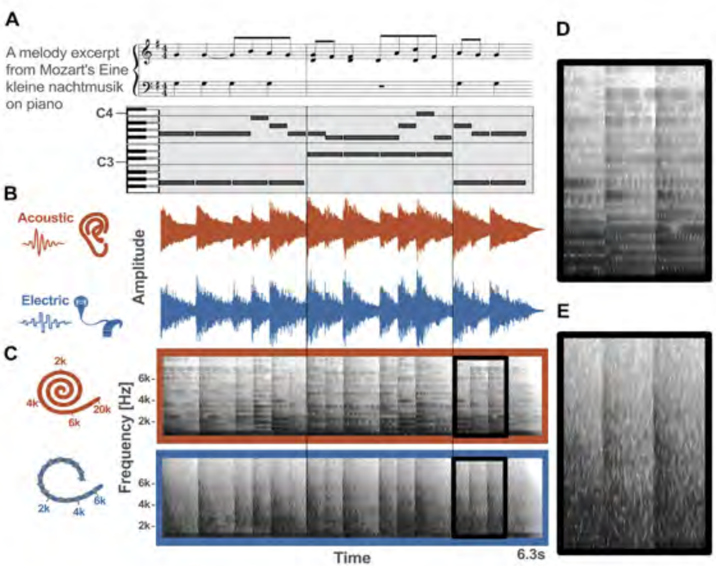

Figure 3. An example of how cochlear implant processing degrades a melody. *(A) We selected a short classical melody for its simple structure and recognizability in its original form, which we demonstrate using a sampled piano sound via GarageBand software. (B) Though CIs accurately convey the overall waveform of music via high temporal resolution, the harmonics, timbre, and other crucial spectral components are absent (C), which drastically affects how this melody sounds to users. For a better view of the acoustic spectrogram (D), a segment (C, black box) is expanded to show the visual patterns of stacked lines that represent overtones (including harmonics) and define the timbre of an instrument. In the expanded view of the CI simulation spectrogram (E), these visual patterns are largely absent. To fully appreciate the importance of this missing spectral information, we recommend downloading the supplementary video to take a listen.*

Click HERE for video

https://drive.google.com/open?id=1jAJ_LTmP-QkJ9d72lSR24wje2Yb2z4aV

Bottom-up approaches to improving music perception for CI users

Tailored music composition and production

One possible intervention is to better design music for the known limitations of cochlear implant processing. For instance, melody is an important aspect of music; however, standard melodies typically consist of neighboring notes with such small differences in pitch that several may be filtered to the same electrode for a CI user. This means that very obvious differences between notes for acoustic listeners—such as A7 to B7 (i.e., 3,520 Hz to 3,951 Hz)—may be filtered to the same electrode within the cochlea (e.g., electrode 14, Fig. 3C inset). As a result, these two notes will sound identical to CI users and will be less melodic. Although the minimum perceptible difference in pitch varies between CI users, a difference of 3 to 8 semitones is typically required for discrimination.[9–11] This range is much larger than normal hearing listeners' ability to resolve differences of less than one semitone. Furthermore, polyphonic melodies with overlapping notes are far too complex and cacophonous for CI users. Instead, utilizing simple, monophonic melodies (i.e., with only individual notes in sequence) can sound more melodic with electric hearing via CIs.

This limitation in spectral resolution affects melody perception for CI users as well as timbre discrimination. Timbre describes the difference in instrument sound qualities when, say, a piano and violin play the same note at the same volume and for the same duration. Although the sources of these overlapping notes can be clearly distinguished by typical listeners, CI users may only perceive a single, ambiguous sound. In fact, timbre discrimination can be so poor that it is possible for even a flute and a snare drum to sound the same. In contrast, simple synthesized sounds such as square waves that contain regular harmonics and no reverb may be more preferable for CI users than the complex, yet indistinguishable timbres of acoustic instruments like pianos and violins.

Rhythm and lyrics are much more accessible musical components for CI users. Similar to speech, they rely more on temporal information that implants can better encode. Therefore, music that emphasizes rhythm and lyrics while simplifying timbre and melodies is more likely to sound "musical" to CI users[12]. Additionally, creating short loops within a song can better synchronize neural firing in the auditory brainstem and enhance musicality, even for typical listeners. This so-called "sound-to-song" effect can be illustrated by listening to a short loop (~1 s long) of a sound, which becomes increasingly more musical over time.[13] In the same way, looping otherwise difficult-to-perceive musical motifs could be perceptually enhanced for CI users' listening enjoyment.

Intraoperative, surgical considerations

Surgical considerations can also be made to optimize spectral fine structure processing. Typically, a CI is blindly inserted into the scala tympani (one of the bony cavities of the inner ear) through either the round window (a membrane that separates the middle ear from the inner ear) or through a cochleostomy (the creation of a hole adjacent to the round window in the cochlea, as seen in Figure 4).

In recent years, there has been an increasing emphasis on minimizing intracochlear trauma and optimizing electrode contacts closer to spiral ganglion cell targets. These surgical factors are known to affect post-implantation outcomes, so it is important to establish techniques and strategies that provide real-time, intraoperative feedback regarding CI insertion and positioning. For example, recent studies have investigated the utility of real-time, intraoperative electrocochleography (ECochG) in providing information regarding intracochlear trauma[14] and the location of the electrode array within the cochlea.[15,16] Proper insertion of the electrode array into the scala tympani (i.e., without crossover into scala vestibuli; see Figure 2D and 2E) has been associated with better hearing outcomes and decreased intracochlear trauma, which may facilitate residual hearing preservation.[17] Use of a flexible, shorter electrode array may also cause less harm to the healthy portion of the cochlea in individuals with residual low frequency hearing because this segment is farthest away from the round window (or cochleostomy) insertion site. Studies have shown a correlation of both intracochlear damage[18] and worse hearing preservation[19] with increased depth of insertion.

These strategies help preserve residual low frequency hearing, which enable patients to take advantage of electroacoustic stimulation (EAS), where high-frequency information is provided by a CI and low frequencies can be delivered with acoustic amplification with a HA in the same ear.[20] EAS has been shown to be beneficial for tasks that require a relatively high spectral resolution, including speech perception in noise[21] and pitch perception.[22]

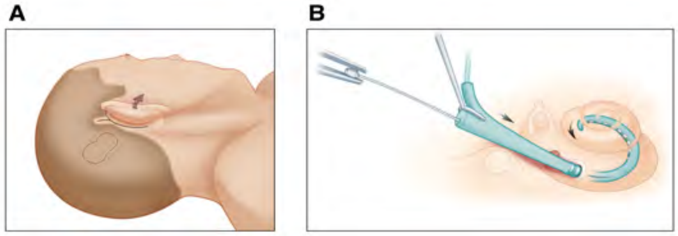

Figure 4. Patient positioning and electrode array insertion during cochlear implantation. *(A) The patient is placed supine with the head tilted towards the contralateral shoulder. A postauricular incision is made, through which a mastoidectomy is performed to grant the surgeon access to the middle ear via the facial recess. The facial recess is a surgical approach to access the round window. (B) Traditionally, the electrode array was inserted through a cochleostomy (as depicted); however, the round window approach has been gaining popularity in recent years. In this illustration, the round window can be seen immediately left of the cochleostomy.*[23]

Postoperative, audiological programming

After CI surgery, patients see their audiologist who activates and programs the device. This individualized program involves several parameters including frequency allocations and stimulation levels. Programming optimizes the CI user's listening experience by fitting acoustic input into the reduced dynamic range of electric hearing through an implant. Electrode arrays are designed so each electrode stimulates nerve pathways corresponding to a spectral bandwidth of frequencies. However, a one-size-fits-all approach results in decreased programming efficiency, since there are patient-to-patient variations in final electrode placement.

High resolution CT imaging can help characterize electrode positions in vivo, and thus facilitate an individualized image-guided mapping strategy that has been shown to enhance spectral fine structure processing via selective deactivation of electrodes to reduce channel interaction[5] and also improve pitch perception outcomes by reducing place-pitch mismatch.[24] Another precision medicine strategy being investigated is the Fitting to Outcomes eXpert (FOX) trial; this investigates the utility of FOX, an artificial intelligence software tool, in individualized CI programming for each patient based on specific outcome measures.[25] Such tools will enable audiologists to better customize CI programming parameters to optimize CI pitch discrimination.

Top-down methods for improving music perception for CI users

Musical training-induced benefits in music perception

Since most CI users today can obtain good speech perception in quiet, there has been a shift towards more complex auditory rehabilitation paradigms, including musical training. For example, benefits in melodic contour identification, as well as pitch and timbre perception have been observed with longitudinal training interventions.[26] This type of intervention can be implemented to potentially improve music perception and appreciation in CI users, regardless of their musical abilities, type of device, or experience with the CI.[26]

Rhythmic priming effect on language

Children with cochlear implants often demonstrate a slower and more variable language development trajectory compared to their normal peers;[2] this may be due to several reasons, including phonological impairments as a result of the spectrally-impoverished acoustic signals provided by CIs (e.g., impaired identification of short grammatical morphemes), as well as lack of access to auditory speech signals for prelingually deafened children until their CIs are activated.

A large body of literature has explored shared neural resources for music and language, notably in rhythm/timing and grammar (i.e., syntactic) processing. Behavioral studies conducted in children have also demonstrated the positive influence of rhythmically regular musical stimulation on grammar task performance in children with normal development and developmental language delay.[27,28] Bedoin et al.[29] showed that this observed improved language processing state (i.e., short-term benefits in language processing induced by rhythmically regular musical stimulation in the laboratory) can be extended to a permanent trait (i.e., long-term effect) when incorporated into language training/rehabilitation programs in pediatric CI users, a population known to have language deficits. Thus, regular musical stimuli may enhance grammar processing when incorporated into language therapy in pediatric CI users.

Multisensory enhancements for music listening

Degraded auditory input is common to all CI processors and, like hearing loss, prompts attentional focusing on other sensory modalities. Fortunately, speech is typically an audiovisual experience wherein coincident orofacial articulations can considerably boost intelligibility over auditory-alone listening.[30] This is also true for typical listeners who can benefit from visual speech cues to communicate in otherwise unintelligible auditory signal-to-noise ratios. For many CI users, communication by phone is only possible through audiovisual formats such as FaceTime. When faced with impaired auditory inputs for speech as well as music, the incorporation of visual cues is an intuitive and effective compensatory strategy. Practically, this can mean live music may be more enjoyable for CI users than recorded music that lacks any visual cues from the musicians' gestures. Furthermore, designing concurrent visual cues for music listening via new software designs could also improve listening enjoyment for CI users. In short, paired visuals and/or haptics with auditory listening could prove useful for facilitating the natural enhancement that multisensory listening affords.

Discussion and future directions

Historically, CI research has been focused on optimizing CI processing systems, types of electrode arrays, and surgical approaches for implant placement. Complex auditory processing (e.g., music perception and speech in noise) remains a challenge for patients, and will continue to be addressed through a variety of approaches such as the external input/translation of acoustic sounds, peripheral encoding within the cochlea, as well as more central processing interventions. Such strategies require collaboration across disciplines including (A) music composition/production, biomedical engineering, (B) otolaryngology, audiology, and (C) neuroscience (Figure 1). Given a broad trend towards precision medicine (e.g., targeted cancer therapy), taking an individualized approach in optimizing the CI experience (e.g., CT-guided CI mapping, tailoring music composition to a CI user) may prove beneficial for improving spectral fine structure processing and possibly music perception and appreciation. Moreover, shared neural pathways for music and language processing may mean that improvements in music perception may generalize to also improving the CI linguistic experience.

Considering that we all live and work in complex listening environments, improving speech-in-noise perception has many practical benefits. For example, in a busy clinical environment like in the intensive care unit or in the operating room, our brains are saturated with noises and other complex sounds such as alarms with varying degrees of urgency. For CI users, communicating in this environment may be particularly challenging due to the low spectral resolution of CI-mediated sounds. As a result, we must be conscious of how complex sounds are frequently present in day-to-day life, yet may be inaccessible for CI users.

It should be noted that while the strategies discussed in this article may benefit music perception and appreciation, not all have been validated through objective measures that assess musical (e.g., pitch or timbre) perception. Clearly, musical perception is required for music appreciation, and it is important to also establish whether these strategies have further clinical significance to everyday listening environments.

Conclusion

Interdisciplinary, individualized approaches are necessary for improving music listening for cochlear implant users. Collectively, we should explore external factors of music composition and production as well as implant design and processing, and intraoperative surgical considerations for optimizing placement of the electrode array within the cochlea. Finally, as the neural representation of music is centrally processed by the brain, there are potential strategies in integrating auditory information with other sensorimotor information (e.g. visuals and haptics), as well as training the brain through auditory rehabilitation to to more fully benefit from CI-mediated hearing.

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