Music-listening and Stress: The Effects of Music-Listening on Autonomic Nervous System Activation Prior To and During a Stress-inducing Task

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ABSTRACT

Music and the arts have played a fundamental role in human culture throughout history. In the field of rehabilitative therapy and integrative medicine, music-listening has been explored as an accessible, low-cost intervention regarding stress management and stress-related health issues. The proposed study seeks to add to our understanding of music, stress, and their physiological effects, using wearable BioHarness data logger devices in the medical student population. Eighteen medical students were randomized into two groups that studied with self-selected music or no music immediately prior to a stressful school exam. Participants recorded subjective measurements of stress and anxiety prior to the study period and after the exam. The BioHarness devices recorded objective data including respiratory rate and heart rate variability, which were further analyzed with OmniSense Analysis software to approximate parasympathetic and sympathetic nervous system activation in each participant. We found that music-listening was associated with a lower maximum heartrate during the exam, compared to the no-music group. These promising findings, while taken from a small sample size, point to a potential benefit of music-listening on alleviating stress activation among medical students.

INTRODUCTION

The beneficial effects of music on the human body is an expanding area of research in the fields of rehabilitative therapy and preventive medicine. The intersection of music and health is perhaps most notable in the field of music therapy, which promotes the use of music and rhythm training in areas ranging from stroke rehabilitation and dementia to developmental and behavioral disorders (Särkämo et al. 2008). Music has also been studied for its role in improving general quality of life, from mitigating everyday stress to alleviating pain in surgery and post-operative recovery (Kahloul et al. 2017; Knight and Rickard 2001; Thoma et al. 2013). In regard to chronic stress and its negative impact on the individual, family, and community, various researchers have approached music as an accessible, low-cost intervention for stress management and stress-related health issues.

While it is clear that the physiological responses activated by acute stress are beneficial to human survival, chronic exposure to stressful experiences leads to long-term damaging effects to the body. Bruce McEwen posed two factors that determined individual responses to potentially stressful situations: individual perception and individual state of physical health (McEwen 1998). While the strength of responses can vary from person to person, the actual response itself remains the same and is commonly known as the “fight-or-flight” response. The body’s adaptive systems, including the autonomic nervous system, hypothalamic-pituitary-adrenal (HPA) axis, and cardiovascular, metabolic, and immune systems, work together—raising heart rate and blood pressure, inhibiting digestion, and promoting glucose breakdown for energy via hormone release, notably cortisol, to protect the individual. However, the overworking of the HPA axis and sympathetic nervous system, as occurs in states of chronic stress, inhibits the body from returning to its ideal homeostatic state. This imbalance is associated with chronic fatigue, weight loss, compromised immunity, and increased risk for cardiovascular disease, in addition to other consequences for the individual, as well as greater impact on the community.

Quantitative measurements such as heart rate, heart rate variability, blood pressure, and finger pulse amplitude are promising markers of autonomic activity, particularly in relation to studying the negative health effects of chronic sympathetic activation (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996). Heart rate variability (HRV) is the variability between adjacent heartbeats, denoted by the temporal change between RR intervals on an electrocardiogram (Fohr et al. 2015, Schaffer et al. 2017). As it is non-invasively measured and regulated by both the parasympathetic and sympathetic components of the autonomic nervous system, HRV represents a simple, objective way to measure and assess an individual's state of stress. Specifically, HRV represents the robustness of an individual's stress response because it represents the presence of sympathetic activation in a process that is usually parasympathetically mediated via the vagal nerve. Thus, a healthy individual will have a high degree of irregularity or variability between RR intervals, though conversely chronically elevated HRV may indicate an overworked sympathetic nervous system.

HRV is primarily quantified via two methods: *time-domain,* based on statistical analysis of RR intervals, and *frequency-domain*, which separates HRV into ultra-low-frequency, very-low-frequency, low-frequency, and high-frequency components (Fohr et al. 2015, Papaioannou et al. 2013, Schaffer et al. 2017). These HRV-derived variables have been reported to more accurately reflect sympathetic and parasympathetic activity than HRV itself. For example, increases in high-frequency values are thought to reflect increased vagal tone and parasympathetic activity (Kemper et al. 2008; Iwanaga et al. 2005).

On the other hand, SDNN, the standard deviation of RR intervals over a period of time, is the most representative parameter of HRV as an adequate stress response, with higher values denoting a healthy response. Though there is currently little data regarding the effects of gender on HRV (Umetani et al. 1998), studies have shown that HRV decreases with normal aging. For example, for a 30-year-old individual, a mean SDNN >50 ms indicates a robust coping response to stress via the ANS while a mean SDNN of 20-30 ms indicates a weakened ANS. For a 60-year-old individual, a mean SDNN >40 ms is normal, 20-30 ms is low normal, and 15-20 ms is low. It is important to note that the length of recording period significantly affects time-domain and frequency-domain measurements, and that different mechanisms play a role in short-term vs long-term HRV. In the short-term, five-minute period, regulatory mechanisms controlling HR are respiratory sinus arrhythmia (RSA), baroreceptor reflex, and vascular tone; methodologically these recordings have been commonly used for gathering baseline HRV data. Over the 24-hour period, HRV is determined by circadian rhythm, core body temperature, metabolism, sleep cycle, and the HPA; most studies assessing the clinical utility of HRV, including the studies that determined the relationship between optimal SDNN and age, used 24-hour recordings (Schaffer et al. 2017). Short term values are not interchangeable with 24-hour values and in this study, our HRV measurements will be calculated from recordings lasting twenty minutes or less.

In the last five decades, HRV has been extensively studied as a potential clinical marker of cardiological and non-cardiological disease. In the 1970s and 1980s, several studies reported that reduced HRV was associated with increased risk of postinfarction mortality, and that HRV performed equally to left ventricular ejection fraction in predicting all-cause mortality, while performing better in predicting postinfarction arrhythmic complications (Wolf et al. 1977, Odemuyiwaet al. 1991). In 2002, Agelink et al. compared patients with major depressive disorder (MDD) to a control group and found reduced HRV, specifically reduced HRV-derived variables that represented vagal tone, in the MDD group (Agelink et al. 2002). They theorized that an imbalance of high sympathetic activity and decreased vagal tone may explain the higher cardiovascular mortality seen in severely depressed patients.

The effects of different kinds of music on HRV and other physiological responses have also been studied. In 2006, Etzel et al. observed cardiovascular and respiratory responses in participants while listening to "happy," "sad," and "fearful" music excerpts. While they found the fastest and slowest respiratory responses to be in the "happy" music group and "sad" music group, respectively, the researchers proposed that music tempo and rhythm may have a greater effect on respiration rate than the induced mood itself (Etzel et al. 2006). In 2008, Khalfa et al. investigated that theory by measuring physiological responses to three versions of happy/fast and sad/slow musical clips: a musical version, a rhythmic version without melodic pitches, and a tempo version without rhythm or pitches (Khalfa et al. 2008). Diastolic blood pressure and facial muscle activation were greater in participants listening to the happy/fast music clip; notably, those differences were not apparent in the rhythmic or tempo versions. Thus, the researchers concluded that musical tones played a role in participants' physiological responses to happy and sad music that could not be explained by tempo and rhythm alone.

There have been inconsistent findings regarding the effects of music on physiological indices of stress and subjective perceptions of stress. A meta-analysis showed that music interventions reduced levels of perceived anxiety as well as heart rate, respiratory rate, and blood pressure in cancer patients (Bradt et al. 2016). Another study reported similar results when looking at effects of music on the physiological stress response of healthy undergraduate students, finding that students listening to Pachelbel's Canon had smaller stress-induced increases in subjective anxiety, heart rate, and systolic blood pressure when preparing for an oral presentation (Knight and Rickard, 2001). However, other studies have found increased heart rate in music groups or no difference in physiological parameters between music and no-music groups (Knight and Rickard, 2001). Common methodological issues included small sample sizes and a variety of confounding factors that influence an individual's stress response and overall response to a particular piece of music. This includes familiarity towards a musical piece, preference for certain music or use of self-selected music, and history of music training.

The purpose of this present study was similarly to study the effects of music on objective and subjective measures of stress. Our first objective was to explore whether music-listening promotes "protective" parasympathetic activation in the midst of a stressor, shown by smaller stress-induced increases in heart rate and respiratory rate in the music-listening group. We used non-invasive, wireless BioHarness devices that recorded biometric data via a data logger embedded in a smart fabric sensing strap. While we also recorded and analyzed HRV between music and no-music group, several factors precluded our ability to assess sympathetic or parasympathetic activation via HRV changes. Firstly, short-term HRV values were not interchangeable with clinically relevant 24-hour values, so in this study, our HRV measurements were calculated from recordings lasting twenty minutes or less. Secondly, HRV-derived frequency variables were shown to more accurately predict parasympathetic or sympathetic activation, an analysis which is beyond the scope and resources of this study. Our second objective was to assess qualitative measures of stress before and after music-listening and explore whether music is a common resource used by medical students while studying or coping with stress and anxiety in general.

We will focus on a population of medical students and record their qualitative and quantitative data prior to an exam, while listening to self-selected music or no music, and during an exam. We hypothesize that students who are exposed to music prior to a stress-inducing task will have autonomic physiological responses indicative of higher parasympathetic activation over sympathetic activation, indicative of reduced stress, and that overall medical students will employ a variety of coping methods, including music-listening, to manage their stress on a regular basis.

METHODOLOGY

For quantitative data collection, we obtained ten non-invasive, wireless BioHarness devices that would comfortably and reliably transmit data to a central computer via Bluetooth. For qualitative data collection, we designed a pre-test and post-test survey with several objectives: to assess changes in stress and anxiety via visual analogue scales, assess baseline stress and anxiety using the Perceived Stress Scale, explore students' coping mechanisms, and to assess whether music was used as a primary coping mechanism.

This study protocol was approved by an independent review body. Written informed consent from all subjects was obtained.

Participants

Second year medical students attending the University of Arizona College of Medicine – Phoenix were recruited for the study. The stressor was their STEP 1 diagnostic exam in October 2018. The diagnostic exam was given over a period of four and a half hours. The inclusion criteria were any second-year medical student at UACOMP; the exclusion criteria were any second-year student not taking the STEP 1 diagnostic exam in October 2018. We recruited eighteen students via email, ten of which signed up to take their diagnostic on Thursday, October 25, 2018, and eight of which signed up for Friday, October 26, 2018.

Questionnaires

The Perceived Stress Scale (PSS) was used to measure perceived stress during the preceding month. The 10-item PSS has consistently been shown to be reliable and valid across countries, different languages, and age groups, since the 1990s (Cohen et al. 1983, Cohen, 1988, Baik et al., 2019). Pre-test and post-test surveys were used to obtain information about participants' age, gender, subjective stress before and after the exam, and subjective stress after music-listening. The surveys also included supplemental questions regarding participants' experience with listening to music while studying, listening to music when feeling stressed or anxious, and preferred ways of dealing with stress and anxiety.

Procedure

On the day of the diagnostic, students were asked to arrive at 7am, one hour prior to check-in at 8am, with a music playlist, headphones, and study material if needed. The participants signed the informed consent document and filled out a pre-test qualitative survey. Then, all participants put on non-invasive BioHarness chest straps and were randomized into control (no music) or experimental (music) groups and directed to two rooms. After five minutes of baseline data collection of respiratory rate, heart rate, and heart rate variability in a silent room, the respective groups were instructed to begin listening to music or continue to sit in silence for a period of twenty minutes. Both groups were allowed to study during this period.

After the twenty-minute period, participants proceeded to the lecture hall to take the exam while still wearing the BioHarness device. We noted the time at which students walked over to the lecture hall and the time at which they actually began the exam. We also noted the approximate times at which participants took their optional breaks, though it was difficult to account for some students because they took their breaks while sitting in front of their computer. After completing the diagnostic exam, participants returned to their initial room for five minutes of post-test data collection. During that time, the participants filled out a second post-test qualitative survey that similarly assessed their anxiety and stress levels. This post-test survey also included supplemental questions regarding the participants' chosen music playlist and their thoughts on listening to music while studying. When the five-minute period was over, participants removed their BioHarness devices. Test scores were not accessed at any time.

Measurements

Objective stress was determined by recordings of beat-to-beat RR intervals from the beginning of the baseline period throughout the testing period. The data was then analyzed using Omnisense Analysis software (version 5.0.0), which displayed second-by-second heart rate, respiratory rate, and heart rate variability calculated as SDNN.

Statistical analysis

Heart rate, heart rate variability, and respiratory rate were reported as means and standard deviations between participants in the no-music vs music groups. The Wilcoxon rank sum test was used to assess differences between those two groups. The Wilcoxon sign rank test was used to compare outcome measures within the overall no-music and music groups, respectively, between each time point (baseline, pretest, stressor). Finally, the linear mixed model was used to estimate the mean difference in outcome measures between the no-music and music groups across time. Intervention status, time points, and the day in which the participant entered the study were included into the model for adjustment. All p-values were 2-sided and $p<0.05$ was considered statistically significant. All data analyses were conducted using Stata 15 (College Station, Texas).

RESULTS

Over the course of two days, we collected data from a total of 18 participants, with an equal number of males and females in both groups (6 females and 3 males). The ages ranged from 23 years old to 37 years old, with an average age of 26 years old. Due to battery issues, biometric data was missing from one participant in the non-music group, so quantitative analysis only included eight participants in the non-music group. Additionally, post-test data was missing from several participants in both the non-music and music group primarily due to battery issues. Therefore, we did not conduct an analysis of post-test data and instead analyzed data from three time periods: a three- to five-minute baseline period, twenty-minute study period, and the first twenty minutes of the exam. Eighteen responses were included in the qualitative thematic analysis and assessment of baseline stress and anxiety using the Perceived Stress Scale.

Objective results

For our analysis, we looked at minimum and maximum values of three parameters over three time periods: heart rate (HR), heart rate variability (HRV), and respiratory rate (RR) during the three- to five-minute baseline period (Period 1), a twenty-minute study period with music-listening or silence (Period 2), and twenty-minutes of the exam period (Period 3).

Between music and no-music groups, we noticed an overall trend: the mean minimum and maximum HR was lower in the music group than the non-music group during Period 2 and Period 3 (figure 1.1). However, the only statistically significant result was the maximum HR during Period 3; HRmax (bpm) was 88.4 bpm in the music group compared to 101.8 bpm in the no-music group during the exam ($p=0.008$). The difference in maximum HR during Period 2 was close to statistical significance; HRmax in the music group was 90.9 bpm vs 100.6 bpm in the no-music group ($p=0.059$). Using a linear mixed model analysis, we found that on average, HRmax in the music group was 9.75 bpm lower than the no-music group (p=0.008) across all 3 time points. HRmin was also lower during Period 2 (p=0.13) and Period 3 (p=0.22). On average, HRmin was 5.02 bpm lower in the music group across all 3 time points (p=0.08).

		Period 1 mean (SD)	p-value	Period 2 mean (SD)	p-value	Period 3 mean (SD)	p-value
HR min	No music (n=8)	76.6 (6.67)	$p < 0.19$	72.8 (7.97)	$p < 0.13$	73.6 (12.2)	$p < 0.22$
	Music (n=9)	72.8 (5.09)		67.8 (6.69)		67.4 (6.76)	
HR max	No music (n=8)	96.8 (7.56)	$p < 0.21$	100.6 (9.91)	$p < 0.059$	101.8 (11.3)	$p < 0.008$
	Music (n=9)	90.9 (12.4)		90.9 (9.10)		88.4 (7.10)	

Table 1.1 Two sample analysis of mean minimum and maximum heart rate

For HRV, the maximum and minimum HRV were greater in the music group compared to non-music group during the study period and the exam, but these results were not statistically significant. For RR, there was no significant difference between music group and no music group during either of the three time periods. This was true for both minimum RR and maximum RR.

When looking at changes in HR, HRV, and RR across time, we found that the HRmin and HRVmin were highest during Period 1, decreased during Period 2 and remained relatively unchanged during Period 3 (figure 1.1–1.2). For HRmin, this was true for the total population, the music group, and no-music group, though the change in HRmin for the no-music group was not statistically significant. On average, HRmin in the music group was approximately 4.00 bpm lower than the control group during the study period (p=0.02) and exam (p=0.02). HRVmin was approximately 12.0 bpm lower in the music group during the study period (p<0.0001) and exam (p<0.0001).

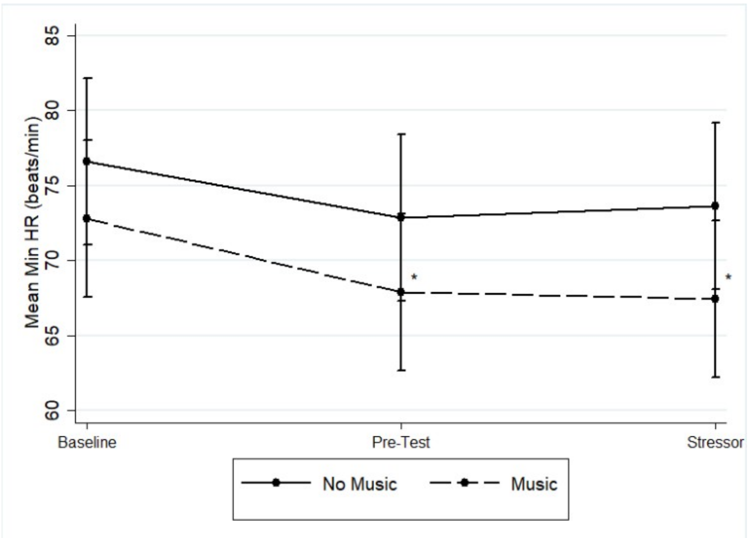

Figure 1.1 Change in mean minimum heart rate over time

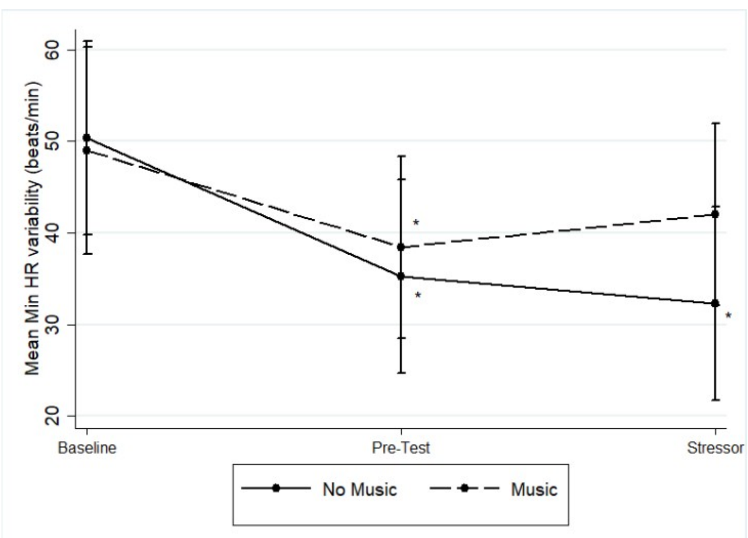

Figure 1.2. Change in mean minimum heart rate variability over time

In the no-music group, HRmax was lowest in Period 1 and increased during Period 2 and Period 3; HRVmax was highest in Period 1 and decreased during Period 2 and Period 3. However, these data in the no-music group were not statistically significant.

While there was no statistically significant change in RRmin between time periods for either group, there was a decrease in RRmax that was close to statistical significance (p=0.08) between Period 2 and Period 3 (figure 1.3). This was present in the overall population and the music group.

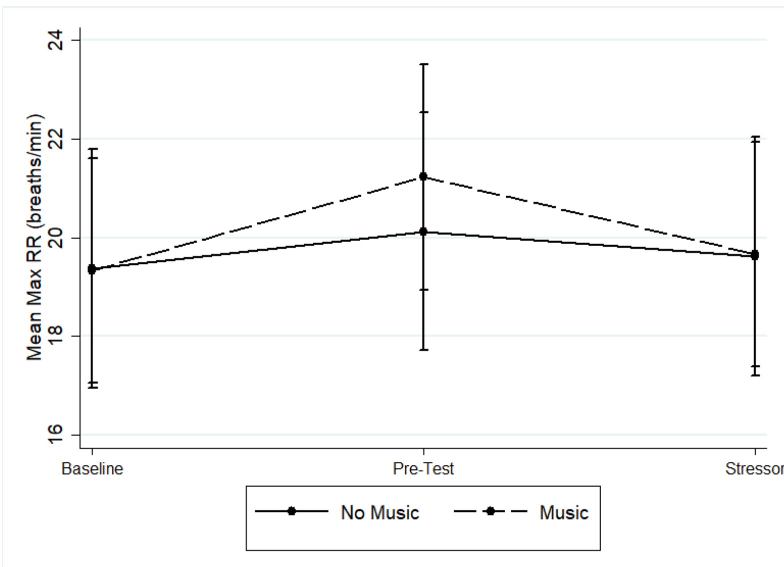

Figure 1.4. Mean maximum respiratory rate over time

Differences between days

On average, physiological parameters were lower among Day 2 participants compared to Day 1 participants. However, these differences were not statistically significant.

Music Preferences

Among the music-listening group, the most popular genres of music used were pop, alternative/ indie, rock, classical/ piano, and rap.

Subjective results

Overall subjective stress levels among participants were assessed via the Perceived Stress Scale, which asks ten questions about individual thoughts and feelings over the last month, using a 5-point Likert scale (0-never, 1-almost never, 2-sometimes, 3-fairly often, 4-very often). For 4 of the 10 questions, the scores are reversed such that a score of 0=4, 1=3, 2=2, 3=1, and 4=1. The scores are then added up, with individual scores ranging from 0 to 40. Scores ranging from 0-13 are considered low perceived stress, scores ranging from 14-26 are considered moderate perceived stress, and scores ranging from 27-40 are considered high perceived stress. Among 18 participants, the mean, median, and mode was 15. The scores ranged from 7 to 23.

Questions	Mean Responses (0 = never, 1 = almost never, 2 = sometimes, 3 = fairly often, 4 = very often)	SD
In the last month, how often have you been upset because of something that happened unexpectedly?	1.6	0.86
In the last month, how often have you felt that you were unable to control the important things in your life?	1.9	1.11
In the last month, how often have you felt nervous and “stressed”?	2.7	0.96
In the last month, how often have you felt confident about your ability to handle your personal problems?	3.1	0.68
In the last month, how often have you felt that things were going your way?	2.6	0.50
In the last month, how often have you found that you could not cope with all the things that you had to do?	1.3	0.96
In the last month, how often have you been able to control irritations in your life?	2.8	0.73
In the last month, how often have you felt that you were on top of things?	2.4	0.51
In the last month, how often have you been angered because of things that were outside of your control?	1.5	1.10

In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?	1.3	1.02

There were several objectives of the pre-test and post-test survey: to assess participants' subjective anxiety levels before and after listening to music, to assess the use of music as a study aid and a form of stress relief, and more broadly, to identify the most common coping mechanisms employed by medical students.

Subjective anxiety levels

The first objective was answered by the question: "What improvement did listening to music have on your stress level prior to the exam?" Participants answered according to a Likert scale: 0=no improvement, 1=borderline improvement, 2=mild improvement, 3=moderate improvement, 4=marked improvement, and 5=exceptional improvement. Of the nine students who listened to music, there was one answer each for "1=borderline improvement," "2=mild improvement," "4=marked improvement" and "5=exceptional improvement." The remaining five students selected "3=moderate improvement." The student who responded "4=marked improvement" also added a written response: "Studying and music helped me warm up and meditate before the exam."

Music as a study tool and a form of stress relief

To answer the second objective, we asked these yes/no questions with room for a written explanation: "Do you typically listen to music while studying?" and "Do you typically listen to music when feeling stressed/ anxious?" In response to the first question, nine participants (50%) reported listening to music while studying, citing benefits like increased stamina, better focus, improved mood, and reduced stress. Eight participants (44%) reported that they did not typically listen to music while studying, the most common reason being that it was distracting and made it harder to focus. One participant did not answer yes or no, stating instead that the use of music depended on the type of studying. This was a common theme among the written responses of other participants as well. Participants were less likely to listen to music if they were learning a new subject or listening to lectures and videos, and more likely to listen to music if they were reviewing material, drawing, or making charts. The genre of music also played a role. Two of the participants who answered "No" stated that if they did listen to music, they preferred classical or instrumental music because they found lyrics to be distracting.

Fourteen participants (77.7%) reported yes and four participants (22.2%) responded no to the question: "Do you typically listen to music when feeling stressed/ anxious?" The most common reported benefits were improved relaxation, improved mood, and distraction from the stressor. The most common reason for not listening to music was that it was not as effective as other methods of relieving stress.

To summarize, roughly half of the group found music-listening to be beneficial while studying and half of the group did not, based on several factors—the type of studying method needed, the type of music available, and past experience with being distracted or more focused when listening to music. Additionally, the majority of the group found music-listening to be helpful when feeling stressed or anxious.

Coping methods used by medical students

To identify what kinds of coping mechanisms were commonly employed by medical students: we asked these yes/no questions with room for written responses: "How do you typically deal with exam-related stress and anxiety?" and "How do you typically deal with overall stress and anxiety?" Reported methods of coping with both exam-related and overall stress and anxiety fell into three broad categories: *social resources, physical resources,* and *psychological resources*. The most common social resources were spending time or talking with friends and family, reading, listening to music or podcasts, watching YouTube videos and Netflix. Eleven participants (61%) mentioned exercise, whether walking, running, working out, or going outdoors, as a form of stress relief. Psychological coping mechanisms included thinking motivational thoughts, using breathing techniques, meditation, and power poses. Examples of motivational self-talk included:

> "I try to keep in mind…that I know more than I think I know."
>
> "Remind myself that failure is okay, and it can get better from here."
>
> "I try hard to remind myself that if I do my best that is all that is within my control."

In our small group of participants, a variety of coping mechanisms were utilized to deal with stress and anxiety related to medical school exams as well as outside of medical school.

DISCUSSION

The purpose of this study was to examine whether music-listening during a stress-inducing task would affect the physiologic stress response brought on by that task. We hypothesized that medical students listening to music while studying for an immediate exam would have a different stress response, measured by heart rate, heart rate variability, and respiratory rate, compared to medical students who did not listen to music. We also hypothesized that the different stress responses would persist during the exam that followed, thus measuring data across three time points, a short baseline period, an experimental study period with music or no music, and an exam period. Our results supported both hypotheses: during the exam, the music group had a mean maximum heartrate of 88.4 bpm compared to 101.8 bpm (p=0.008), and across three time points, the mean maximum heartrate in the music group was 9.75 bpm lower than the no-music group (p=0.008). Other supportive findings were a lower minimum heartrate during the experimental study period and exam period, though these were not statistically significant.

The relationship between music-listening and reduced heartrate during a stressor is notable, though not totally understood, especially given inconsistent findings in this area of research. Contributing factors to those inconsistencies include difficulty controlling for musical properties like tempo, genre, appeal to the individual listeners and familiarity with the selected music. Additionally, heart rate is governed by multiple systems and in any moment can be influenced by the respiratory system, endocrine system, cardiovascular system, as well as age and gender. It is not as useful as heart rate variability in understanding sympathetic and parasympathetic stress activation, where increased heart rate variability after a health stressor has been associated with improved clinical outcomes. However, the findings in our study were consistent with past studies that similarly measured heart rate indices during a stress-inducing task with music exposure (Knight and Rickard 2001). If the sympathetic nervous system is one of several factors affecting heart rate indices during a stressful situation, then this study supports the conclusion that listening to music reduces sympathetic nervous system indices of stress (Knight and Rickard 2001).

Regarding heart rate variability, the minimum and maximum heart rate variability were highest during the baseline period, decreased during the study period and remained relatively unchanged during the exam for all participants. While clinical studies using 24-hour measurements of heart rate variability have been used to delineate “ideal” heart rate variability ranges by age and gender, those ranges are not applicable to short-term measurements of heart rate variability, such as the five or ten-minute long measurements of HRV used in this study. Further analysis of the maximum and minimum heart rate variability data is required, using software programs with time-domain or frequency-domain capabilities, in order to understand how music-listening or test-taking might have affected the overall decrease in heart rate variability during the entire study. Regarding respiratory rate, there was no statistically significant difference in respiratory rate between groups or across time periods. This was not a surprising finding, given the association between musical properties (tempo, genre) and respiratory rate, and the fact that participants were allowed to use self-selected music.

The secondary objective of this study was to assess the types of coping mechanisms that medical students use when dealing with subjective anxiety and stress. We found that they employed a variety of known beneficial resources, such as investing in social relationships, completing some form of exercise or physical activity, or engaging in positive thinking. Moreover, half of the participants found music-listening to be beneficial while studying, while several specified that music-listening was beneficial depending on the situation. The majority of the group found music-listening to be helpful when feeling stressed or anxious. Among our small group of participants, these students seemed to be largely capable of handling the stresses and rigors of medical school, with a good understanding of available resources and methods to stay mentally healthy and avoid burn-out.

Confounding factors and limitations

There were several significant limitations to the study that affected the breadth and depth of our investigation of music's effect on stress activation. Regarding the type of exam or stressor to use, we considered several factors. Our budget allowed for ten BioHarnesses, which limited the number of students that could participate at one time. In order to include more than ten students in the study, we needed multiple exams on different days, while ideally controlling for the exam material and overall stress-inducing experience. Perhaps the most prominent limitation was the measurement and analysis of heart rate variability. After data collection, it became more apparent that the clinical applicability of HRV measurements is dependent on the duration of recording, age, and gender of participants. Not only are short-term HRV recordings not interchangeable with 24-hour HRV recordings, but both short-term and long-term recordings require more detailed analyses that were beyond the scope of this project. An option to improve reliability of HRV analysis and provide more information regarding medical student stress levels would be to record HRV during a longer exam. Board exams are often 7-8 hours and present one option, though feasibility is an issue.

Inevitably we had issues with the BioHarness technology. Biometric data was missing from one participant in the non-music group and post-test data was missing from the majority of participants in both the non-music and music group. Other limiting factors included a small sample size and variety in musical experience and preference. Our size was limited by the number of Bioharness devices available over an exam period, and we chose to allow self-selected music, instead of choosing the same musical clip for the participants, to maximize interest in the study. Among participants, there were differences in age, medical history, and overall varied life experiences that could affect how well each individual could cope with exam-based stressors, subjectively and objectively. Additionally, students' prior habits of music-listening during studying would affect their responses; someone who usually studies in silence might consider studying with music to be stressful right before an exam and vice versa. Finally, we did not restrict coffee intake prior to the exam, in efforts to maximize recruitment, though this could have affected heart rate and respiratory rate.

In conclusion, while music has long been used as a source of enjoyment and celebration in human history, its role in healing, alleviating pain, and relieving stress, continues to be an ongoing subject of investigation. This study provides promising support of the physiologic benefits of listening to music during a stressor. For medical students, physicians, and patients, music is an encouraging non-invasive, easily accessible and cost-effective intervention in the realm of physical health and mental wellbeing.

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