Short Running Title: The Effect of Music & Binaural Beats on Anxiety
Short Informative Title: The Effect of Music & Auditory Beat Stimulation on Anxiety

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Abstract

Background: Music and auditory beat stimulation (ABS) in the theta frequency range (4-7 Hz) are sound-based anxiety treatments that have been independently investigated in prior studies. Here, the anxiety-reducing potential of calm music combined with theta ABS was examined in a large sample of participants.

Method: Participants taking anxiolytics (n = 318) were randomly assigned to a single session of sound-based treatment: combined (music & ABS), music-alone, ABS-alone, or pink noise (control). Pre- and post-intervention somatic and cognitive state anxiety measures were collected along with trait anxiety, personality measures and musical preferences.

Results: Among participants with moderate trait anxiety, we observed reductions in somatic anxiety that were greater in combined and music-alone conditions than in the pink noise condition; and reductions in cognitive state anxiety that were greater in the combined condition than in the music-alone, ABS-alone, and pink noise conditions. While we also observed reductions in somatic and cognitive state anxiety in participants with high trait anxiety, the conditions were not well differentiated.

Conclusions: Sound-based treatments are effective in reducing somatic and cognitive state anxiety. For participants with moderate trait anxiety, combined conditions were most efficacious.

1 | Introduction

Anxiety has been steadily increasing in occurrence particularly in the adolescent and young adult populations in the past 24 years (Phillips & Yu, 2021). COVID-19 pandemic lockdowns have further increased the prevalence of anxiety with U.S. adults being three times more likely to screen positive for anxiety disorders in April/May 2020 compared to 2019 (Twenge & Joiner, 2020).

Many anxiety treatments exist, including anti-anxiety medications (selective serotonin re-uptake inhibitors, serotonin-norepinephrine reuptake inhibitors, benzodiazepines) (Bachhuber, Hennessy, Cunningham, & Starrels, 2016; Baldwin, Woods, Lawson, & Taylor, 2011; Baldwin, Ajel, & Garner, 2010; Brett & Murnion, 2015), cognitive strategies, behavioural approaches (cognitive behavioural therapy, exposure, relaxation), mindfulness and acceptance-based approaches (Gunter & Whittal, 2010; Otte, 2011; Stewart & Chambless, 2009). However, many anxiety sufferers do not respond to these standard approaches, and many others face barriers to treatment (Gunter & Whittal, 2010). Therefore, it is important to identify other approaches that may be useful as an alternative or supplement to mainline treatments. Many people already use music to manage their mental health and sound-based anxiety treatments involving music show promise in fulfilling this need (Zoteyeva, Forbes, & Rickard, 2016).

Music listening can reduce anxiety (Buffum et al., 2006; Bulfone, Quattrin, Zanotti, Regattin, & Brusaferro, 2009; Davis & Thaut, 1989; Nguyen, Nilsson, Hellström, & Bengtson, 2010; Wu, Huang, Lee, Wang, & Shih, 2017) and some evidence suggests that it may do so more effectively than anti-anxiety drugs such as midazolam (Bringman, Giesecke, Thörne, & Bringman, 2009). This may be due to the neurochemical effects of music which include increased levels of endogenous opioids and dopamine (Chanda & Levitin, 2013; Mallik, Chanda, & Levitin, 2017; Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011). Furthermore, the mood regulating properties of music may be enhanced if the mood of the music is matched to an individual's initial emotional state before being changed to the target state (Heiderscheit & Madson, 2015). This approach to sequencing music selections follows the iso principle, first proposed as a system of mood regulation supported by music (Altshuler, 1948). The music recommendation system used in this research is supplied by LUCID Inc. (https://www.thelucidproject.ca) and employs the iso principle along with affective classification and reinforcement learning to cultivate affect-driven personalized music sequences (Labbé, McMahon, & Z., 2021). The sequences consist of instrumental music integrated with nature sounds and were composed by LUCID's music director/composer.

ABS is a non-invasive neuromodulatory technique which uses sound waves to produce combination tones, binaural beats, or monoaural beats in the alpha (8-13 Hz), beta (14-30 Hz), theta (4-8 Hz), gamma (30-50 Hz) or delta (1-4 Hz) frequency ranges with the intention of producing a neural frequency following response (Pastor et al., 2002; Schwarz & Taylor, 2005; Vernon, Peryer, Louch, & Shaw, 2014). Combination tone signals can be generated by superposing two sine waves of neighboring frequencies. Monaural beat refers to the presentation of amplitude modulated beat signals to a single ear, or to both ears simultaneously. When the individual sine waves are presented dichotically, a binaural beat percept is produced (Chaieb, Wilpert, Reber, & Fell, 2015). For example, a two-tone exposure of 400 and 405 Hz presented to each ear separately will be experienced as a modulated wave of 5 Hz by the listener (Moore, 2012).

ABS in the theta and delta frequency range may reduce anxiety and promote increased self-reported relaxation (Isik, Esen, Büyükerkmen, Kilinç, & Menziletoglu, 2017; McConnell, Froeliger, Garland, Ives, & Sforzo, 2014; Padmanabhan, Hildreth, & Laws, 2005; Wahbeh, Calabrese, & Zwickey, 2007a).

In this study, 318 participants taking anxiolytics were recruited using Prolific, an online participant pool platform. Participants were randomly assigned to one of the following four treatments: 1) Combined (music & ABS), 2) Music-alone, 3) ABS-alone, and 4) Pink noise (control). Music preferences, trait anxiety and personality traits have been confounding factors in previous studies involving music, ABS and mental health (Garcia-Argibay, 2019; Hanser, 1985; Miranda, Gaudreau, Debrosse, Morizot, & Kirmayer, 2012; Wang, Kulkarni, Dolev, & Kain, 2002). Therefore, before their treatment session, participants completed the Short Test of Music Preferences (STOMP), the short form of the Eysenck Personality Questionnaire (EPQR) and the trait version of the State Trait Inventory for Cognitive and Somatic Anxiety (STICSA). The participants completed the following measures pre and post treatment: the state version of the STICSA, Positive and Negative Affect Scale (PANAS).

Our hypotheses were that the combined, music alone and ABS alone conditions would experience a greater reduction in somatic and cognitive state anxiety compared to the pink noise control condition. These hypotheses were pre-registered using the Open Science Framework (Registration DOI: https://doi.org/10.17605/OSF.IO/VHCA5) and were based upon previous studies showing that ABS and listening to music reduce anxiety (Bringman et al., 2009; Buffum et al., 2006; Bulfone et al., 2009; Davis & Thaut, 1989; Isik et al., 2017; McConnell et al., 2014; Nguyen et al., 2010; Padmanabhan et al., 2005; Parodi et al., 2020; Wahbeh et al., 2007a;

Wiwatwongwana et al., 2016; Wu et al., 2017; Yusim & Grigaitis, 2020) . We did not make specific predictions for moderate and high trait anxiety participants, but our preregistration noted our intention to recruit from both of these populations. Trait anxiety may be a confounding factor in studies involving music (Hanser, 1985; Wang et al., 2002). Therefore, we separated the participants into moderate and high trait anxiety conditions according to prior criteria to determine whether moderate and high trait anxiety participants differ in their responses to the treatments (Roberts, Hart, & Eastwood, 2016). This experimental protocol received approval from the Ryerson Research Ethics Board (REB 2020-068) and was conducted in accordance with the ethical principles stated in the Declaration of Helsinki (Association, 2013). All participants gave their informed consent prior to their inclusion in the study.

2 | Method

2.1 | Participants

An *a priori* power analysis based on two previous studies that examined how anxiety levels were affected by music and binaural beats (Le Scouranec, Poirier, Owens, & Gauthier, 2001; Wang et al., 2002) indicated that to achieve a power of 0.80 at a significance of p = 0.05, expected effect size (Cohen's d) of 0.84, we would need to sample a minimum of 68 participants each from moderate and high trait anxiety populations.

Participants (n = 318, mean age: 28.95 years, age range: 18-63 years, 232 females, 86 males) that were taking anxiolytics were recruited using the online participant pool platform Prolific (www.prolific.co). From this participant population, moderate trait anxiety participants (n = 93) were classified as having a STICSA trait somatic score between 16.9 and 22.4, and a STICSA trait cognitive score between 17.1 and 26.6 (Roberts et al., 2016). High trait anxiety participants (n = 70) were classified as having a STICSA trait somatic score above 22.4 and a STICSA trait cognitive score above 26.6 (Roberts et al., 2016).

2.2 | Self-report measures

The State Trait Inventory for Cognitive and Somatic Anxiety (STICSA) was used to determine somatic and cognitive trait and state anxiety of the participants. The STICSA was chosen as an anxiety measure as it has good reliability and validity as a measure of state and trait cognitive and somatic anxiety (Bados, Gómez-Benito, & Balaguer, 2010; Grös, Antony, Simms, & McCabe, 2007).

The Positive and Negative Affect Scale (PANAS) was used to assess the mood of the participants before and after their randomly assigned treatment. The PANAS has good reliability and validity and has been widely used in many studies to assess mood (Gray, 2007; Watson, Clark, & Tellegen, 1988).

The Short Test of Music Preferences (STOMP) was used to assess the musical preferences of the participants. The STOMP has good reliability and has been validated as a good measure of musical preferences (Rentfrow & Gosling, 2003).

The short form of the Eysenck Personality Questionnaire (EPQR) was used to determine the personality traits of participants, specifically their introversion, extraversion and neuroticism and is shown to have good reliability and validity (Rocklin & Revelle, 1981).

2.3 | Treatment conditions

The music sequences in the music conditions were curated by the affective music recommendation system described in the introduction. All participants received 24 minutes of treatment and followed the same procedure independent of the experimental condition they were assigned to. The participants were randomly assigned to one of four treatment conditions: combined (music with ABS); music-alone, ABS-alone, or pink noise.

2.4 | Procedure

After consenting to the study, participants downloaded the LUCID Research Application on their iOS device. Participants then completed the pre-treatment survey consisting of the STICSA trait, the Eysenck Personality Questionnaire (EPQR), the Short Test of Music Preferences (STOMP), the Positive and Negative Affect Scale (PANAS), and the STICSA state. Participants then listened to their assigned treatment for 24 minutes. Participants then completed the post-treatment survey consisting of the STICSA state and the PANAS.

2.5 | Data analysis

According to the Shapiro Wilks normality test, our data were not normally distributed. Permutation methods control false positives, allow the use of non-standard statistics and make only weak assumptions regarding the data (Winkler, Ridgway, Webster, Smith, & Nichols, 2014). Therefore, we decided to conduct a multiple linear regression using the permutation package Permuco in R (Frossard & Renaud, 2019). STICSA state somatic anxiety was the dependent variable. Independent variables were STICSA trait cognitive, STICSA trait somatic, the STOMP music preferences factors (Reflective & Complex, Intense & Rebellious, Upbeat & Conventional, Energetic & Rhythmic) and the EPQR factors (Extraversion, Neuroticism, Psychoticism, Lie scale).

Participants were separated into moderate and high trait anxiety conditions according to previously established thresholds described in the Participants section (Roberts et al., 2016). Somatic and cognitive state anxiety reduction was calculated by subtracting the post-treatment

STICSA state score from the pre-treatment STICSA state score for each participant. Pairwise Fisher Randomization Resampling tests (5000 iterations) also known as permutation tests were done comparing the treatment conditions for both somatic and cognitive state anxiety reduction. Permutation tests are a good way to control the type I error rate for multiple comparisons, it is non-parametric and so makes no assumptions about the underlying distribution of the data that are common in other inferential statistical tests (Camargo, Azuaje, Wang, & Zheng, 2008; Good, 1994; Kuehl, 2000). For the PANAS, for each participant, the pre-treatment positive affect was subtracted from the post-treatment positive affect. The post-treatment negative affect was subtracted from the pre-treatment negative affect for each participant. Pairwise Fisher Randomization Resampling tests (FRT) (5000 iterations) also known as permutation tests were done comparing the treatment conditions for both positive and negative affect.

3 | Results

Among participants with moderate trait anxiety, the combined and music-alone conditions had significantly higher somatic state anxiety reduction than the pink noise condition (Figure 1A). The combined condition also had a significantly higher somatic state anxiety reduction compared to the ABS condition (Figure 1A) and a significantly higher cognitive state anxiety reduction than the music-alone, ABS-alone and pink noise conditions (Figure 1B).

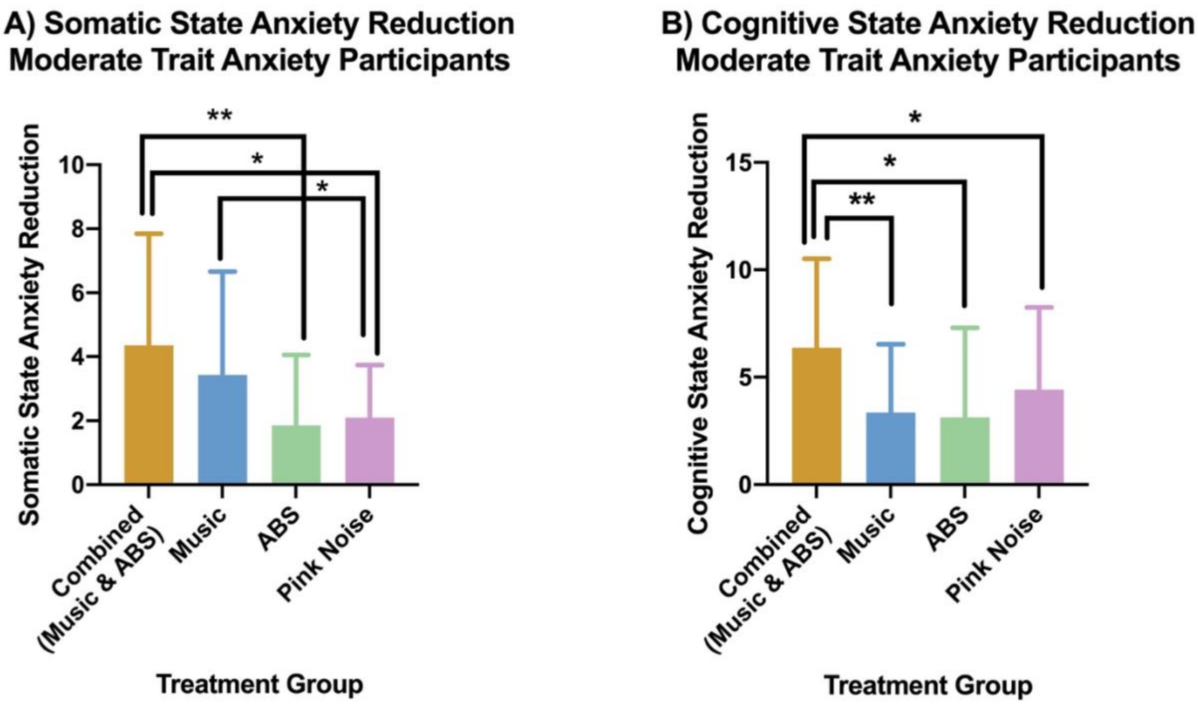

Figure 1: Mean somatic (A) and cognitive (B) state anxiety reduction in moderate trait anxiety participants. * indicates $p < 0.05$ (FRT, 5000 iterations), ** indicates $p < 0.01$ (FRT, 5000 iterations). Error bars are standard deviations. Please see Tables 1A and 1B for exact p values, effect sizes, power and degrees of freedom for each significant comparison.

Table 1A: Additional statistical information for Figure 1A significant comparisons

Comparison	Tail of Test	Exact p-value	Effect size (Cohen's d)	Power	Degrees of Freedom
Combined vs. ABS	Two-tailed	0.009	0.86	0.79	41
Combined vs. Pink Noise	One-tailed	0.04	0.83	0.84	41
Music vs. Pink Noise	One-tailed	0.05	0.52	0.52	40

Table 1B: Additional statistical information for Figure 1B significant comparisons

Comparison	Tail of Test	Exact p-value	Effect size (Cohen's d)	Power	Degrees of Freedom
Combined vs. Music	Two-tailed	0.01	0.82	0.72	39
Combined vs. ABS	Two-tailed	0.03	0.78	0.72	42
Combined vs. Pink Noise	One-tailed	0.05	0.49	0.50	45

Among participants with high trait anxiety, the music-alone condition had significantly higher somatic (Figure 2A) and cognitive (Figure 2B) state anxiety reductions compared to the ABS-alone condition. There were no other significant differences between any of the other treatments.

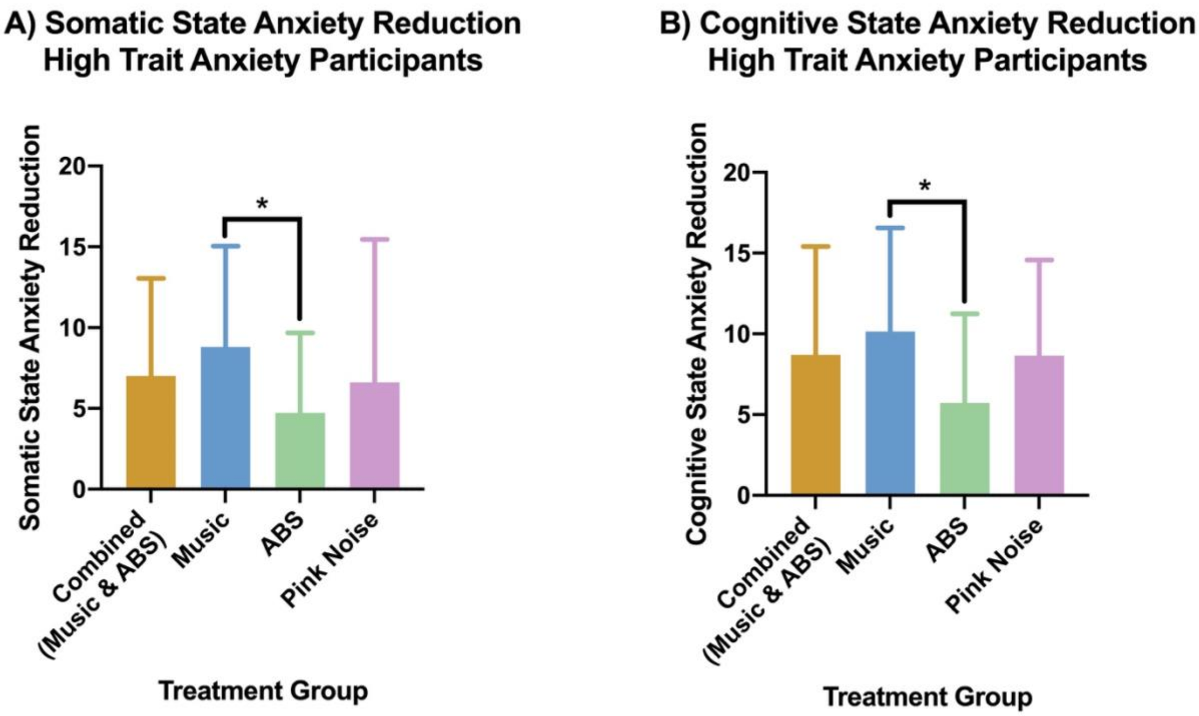

Figure 2: Mean somatic (A) and cognitive (B) state anxiety reduction in high trait anxiety participants. * indicates $p < 0.05$ (FRT, 5000 iterations). Error bars are standard deviations. Please see Tables 2A and 2B below for exact p values, tail of test, effect sizes, power and degrees of freedom for each significant comparison.

Table 2A: Additional statistical information for Figure 2A significant comparisons

Comparison	Tail of Test	Exact p-value	Effect size (Cohen's d)	Power	Degrees of Freedom
Music vs. ABS	Two-tailed	0.04	0.72	0.52	31

Table 2B: Additional statistical information for Figure 2B significant comparisons

Comparison	Tail of Test	Exact p-value	Effect size (Cohen's d)	Power	Degrees of Freedom
Music vs. ABS	Two-tailed	0.04	0.74	0.53	31

In moderate anxiety participants, the combined condition also had significantly higher increase in positive affect compared to the pink noise condition (Figure 3A) and a significantly higher decrease in negative affect compared to the ABS-alone condition (Figure 3B).

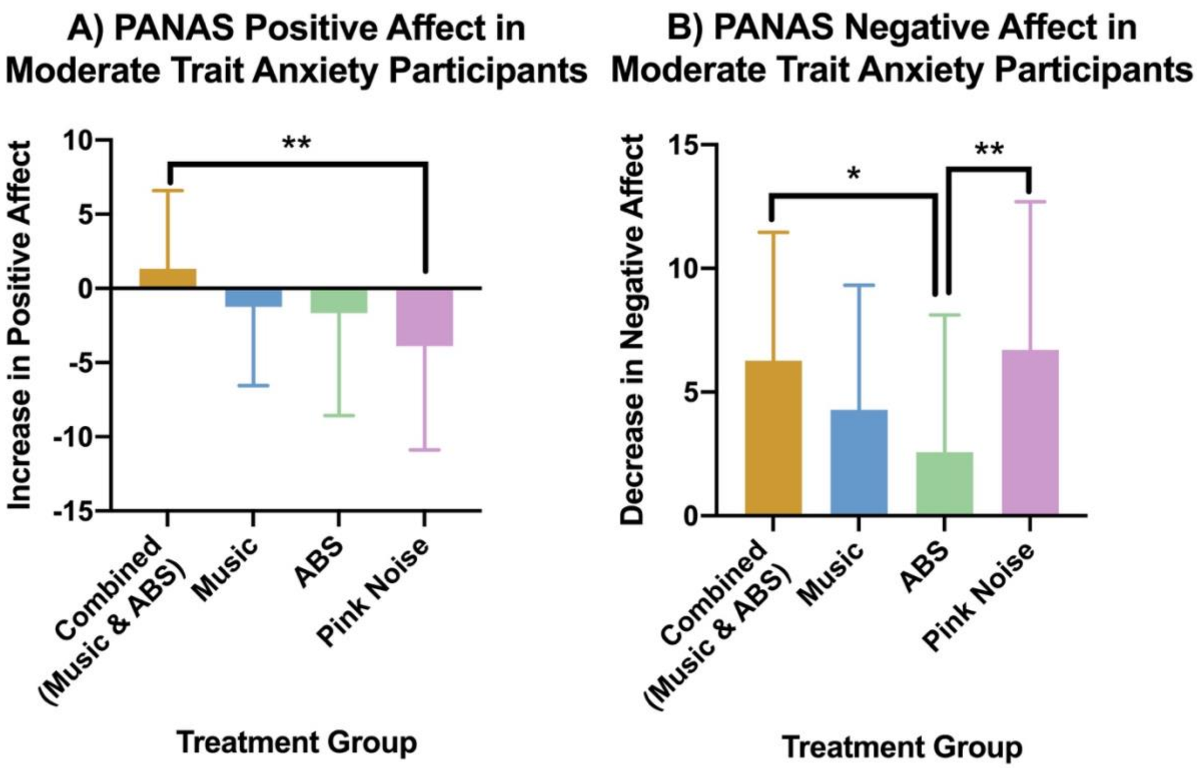

Figure 3: Mean positive affect increase (A) and negative affect decrease (B). ** indicates $p < 0.01$ (two tailed FRT, 5000 iterations). Error bars are standard deviations. Please see Tables 3A and 3B in supplementary information for exact p values, effect sizes, power and degrees of freedom for each significant comparison.

Table 3A: Additional statistical information for Figure 3A significant comparisons

Comparison	Tail of Test	Exact p-value	Effect size (Cohen's d)	Power	Degrees of Freedom
Combined vs. Pink Noise	Two-tailed	0.005	0.48	0.35	43

Table 3B: Additional statistical information for Figure 3B significant comparisons

Comparison	Tail of Test	Exact p-value	Effect size (Cohen's d)	Power	Degrees of Freedom
Combined vs. ABS	Two-tailed	0.016	0.69	0.62	43
Pink Noise vs. ABS	Two-tailed	0.01	0.72	0.70	48

Among participants with high trait anxiety, the combined condition had a greater decrease in negative affect compared to the ABS-alone condition ($p < 0.05$). There were no other significant differences in any other pairwise comparisons for either positive or negative affect.

The multiple linear regression with state anxiety as the dependent variable and trait anxiety as an independent variable revealed a significant positive relationship between state anxiety reduction and trait anxiety of participants ($p < 0.05$) and a significant negative relationship between state anxiety reduction and a preference for Intense & Rebellious music preference factor ($p < 0.05$).

4 | Discussion

We found that the combined condition and music-alone condition had greater somatic state anxiety reduction compared to the pink-noise control condition in participants with moderate trait anxiety (Figure 1A). This may be due to the fact that music treatments with slow tempo show reductions in respiration rate, heart rate, sweat production, body temperature and muscle tension, the same physiological changes associated with reducing somatic anxiety (Bernardi et al., 2009; Chanda & Levitin, 2013; Chapados & Levitin, 2008; Ree, French, MacLeod, & Locke, 2008; Sandstrom & Russo, 2010). Interestingly, we found no significant difference in somatic state anxiety reduction between the ABS and pink noise conditions in moderate trait anxiety participants (Figure 1A). Pink noise has been shown to increase relaxation and sleep quality (Suzuki, Kawada, Ogawa, & Aoki, 1991; Zhou et al., 2012). This coupled with the fact that theta ABS has been shown to in some cases to increase negative affect (Lane, Kasian, Owens, & Marsh, 1998; Wahbeh, Calabrese, Zwickey, & Zajdel, 2007b), may help explain this result.

With regard to moderate trait anxiety participants, although the music condition did not lead to a significant reduction in cognitive anxiety compared to the pink noise control, the combined (music & ABS) condition did (Figure 1B). We can speculate that theta ABS component of the combined condition may have contributed to reductions in cognitive anxiety by entraining endogenous oscillations that are characteristic of relaxation (McConnell et al., 2014; On, Jailani, Norhazman, & Zaini, 2013). In order to verify these speculations, future studies should incorporate EEG and self-report methods.

Prior studies have demonstrated that ABS integrated with special carrier tones and algorithmic audio generation methods reduce general anxiety either with music or within the context of meditation (Parodi et al., 2020; Wiwatwongwana et al., 2016; Yusim & Grigaitis, 2020). However, these prior studies did not differentiate between somatic and cognitive anxiety, so it is difficult to determine the specific impact that the ABS may have had on cognitive anxiety.

In moderate trait anxiety participants, there was increased positive affect in the combined condition compared to the pink-noise condition (Figure 3A). Music listening tends to increase positive affect which may help explain this result (Fredenburg & Silverman, 2014; Merry & Silverman, 2021). There was a larger decrease in negative affect in the combined and pink noise conditions compared to the ABS-alone condition (Figure 3B). Theta ABS increases the Profile of Mood States depression subscale compared to pink noise and increases negative affect compared to beta ABS (Lane et al., 1998; Wahbeh et al., 2007b). These prior studies did not specifically examine a moderate or high trait anxiety population and since trait anxiety may affect physiological responses to music (Hanser, 1985; Wang et al., 2002), this could be one reason for the mixed results across our outcome measures.

In high trait anxiety participants, the music condition had a larger somatic and cognitive state anxiety reduction compared to the ABS condition (Figures 2A and 2B). But there were no significant differences in somatic or cognitive anxiety reduction between combined, music-alone and pink noise conditions. Pink noise deepens and improves sleep quality (Suzuki et al., 1991; Zhou et al., 2012). This combined with the fact that theta ABS has been shown to in some cases to increase negative affect (Lane et al., 1998; Wahbeh et al., 2007b), may be the reason that the music with ABS condition and music conditions did not have larger anxiety reductions compared to the pink noise condition. For high trait anxiety participants, transitioning from beta to alpha ABS within the first 5 minutes of the treatment may not cause the increase in negative affect seen with theta ABS, but does not appear to reduce anxiety compared to music alone (Wiwatwongwana et al., 2016). High trait anxiety participants may require longer and multiple sessions to achieve a reduction in anxiety.

In high trait anxiety participants, the combined condition had a significantly higher reduction in negative affect compared to the ABS condition. Music decreases negative affect (Fredenburg & Silverman, 2014; Merry & Silverman, 2021), whereas theta ABS alone may increase negative affect (Lane et al., 1998; Wahbeh et al., 2007b). Therefore, combining music with ABS may cause a decrease in negative affect when compared to the ABS-alone condition. Some individuals may also find the persistent hum of the ABS-alone condition irritating compared to the combined condition where this ABS hum is masked with the music. The pink noise condition also had a significantly higher reduction in negative affect compared to the ABS condition. This may be explained by the fact that pink noise increases sleep quality and relaxation

(Suzuki et al., 1991; Zhou et al., 2012) and participants may have found the persistent hum of the ABS only condition irritating.

Although much of the research involving ABS points to anxiety reduction, increased relaxation and improved cognition and attention, the effectiveness of ABS has not been supported in all studies (Chaieb & Fell, 2017; Crespo, Recuero, Galvez, & Begoña, 2013; Kennel, Taylor, Lyon, & Bourguignon, 2010; López-Caballero & Escera, 2017; Pluck & López-Águila, 2019). This inconsistency in experimental results is likely due to several factors which include frequency used, type of sound used to mask the binaural beat, trait anxiety, personality factors such as extraversion and duration of exposure (Garcia-Argibay, 2019; Hanser, 1985; Rammsayer, Netter, & Vogel, 1993; Reedijk, Bolders, & Hommel, 2013; Reedijk, Bolders, Colzato, & Hommel, 2015; Wang et al., 2002). In this study we accounted for these factors statistically and through experimental design which should help increase the reproducibility of this study. Specifically, we took into account personality traits and trait anxiety of our participants. Personality traits such as extraversion are related to mesostriatal dopamine levels which have been found to determine the effectiveness of gamma ABS in improving cognition (Garcia-Argibay, 2019). In this study, we used theta ABS and found no significant effects of extraversion on the anxiety reduction effectiveness of our music with ABS or ABS conditions, but we did see a significant effect of trait anxiety on anxiety reduction effectiveness.

Participants in all conditions experienced pre-post reductions in somatic and cognitive state anxiety suggesting the presence of demand/expectancy characteristics. However, given that some conditions (Combined and music) resulted in significantly greater anxiety reduction than others (pink noise control), this suggests that experimental condition plays a significant role over the presence of demand characteristics. Nevertheless, in future studies the Credibility and Expectancy Questionnaire (Devilly & Borkovec, 2000) may be administered to further examine the role of demand characteristics. The sample population of this study were on anxiolytics with the majority being on SSRIs (Tables S1 & S2, Supplementary Information). SSRIs may inhibit emotional responses (Opbroek et al., 2002) which in turn may impact the responsiveness to music/sound based treatments. This limits the generalizability of our findings to those taking anxiolytics. However, we hope to address this in a future study examining the anxiety-reducing potential of sound-based treatments on both anxiolytic and non-medicated populations.

5 | Conclusion

We found that in moderate trait anxiety participants, combined and music-alone conditions led to significant reductions in somatic anxiety compared to ABS-alone and pink noise conditions. Similarly, we found that the combined condition significantly reduced cognitive anxiety compared to the ABS-alone and pink noise conditions. In high trait anxiety participants, the music treatment significantly reduced somatic and cognitive anxiety compared to the ABS treatment, however, the pattern of results was difficult to interpret because of the lack of differences with the pink noise condition. We hypothesize that high trait anxiety participants may require longer and more frequent music treatments over time in order to achieve the same reductions in anxiety as moderate trait anxiety participants. We hope to examine this in a future longitudinal study. The implications of this work are immense as many people who suffer from anxiety do not respond to standard treatments and fail to seek treatment and this simple and easily distributable method of potentially reducing anxiety may help serve this segment of the population.

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Conflict of Interest

Dr. Frank Russo has served as an advisor for LUCID (the company which supplied the music curation system) since 2018. He has been granted stock options that represent 1.7% of the total stock option pool.

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