Effects of Sound Immersion on Emotional Wellbeing and Homeostasis

Authors
D. Gentile
R. Geffen
N. Atassi
B. Farran*
N. Fellas
P. Oomen

Company
The Works Research Institute, Budapest, Hungary.

Version Published
17 September 2024

Corresponding Author
Dr. Bashar M. Farran
bfarran@theworks.info

ABSTRACT

Music and sounds evoke a wide range of emotions and activate numerous psychological and physiological effects. Since emotions involve the autonomic nervous system (ANS) associated with the maintenance of homeostasis, they play an important role in supporting human wellbeing. The aim of the present study is to further validate the mechanisms underlying the relationship between sound, emotions and homeostasis. To this end, the effects of spatial sound projection of two different singing bowls with fundamental frequencies at 73 Hz and 110 Hz were investigated by monitoring behavioural and emotional response in healthy subjects. Overall, we find that the spatial projection of singing bowl sounds elicits a highly significant increase in positive emotions. Exposure to both frequencies resulted in a significant improvement in emotional wellbeing and a significant reduction in negative emotions. We demonstrate frequency-dependent effects indicating a shift in arousal, where 73 Hz elicits feeling more wide awake while 110 Hz elicits sleepiness. These results indicate that non-invasive interventions, such as sound immersion with singing bowls, are effective means in restoring and maintaining homeostasis and underline the need for further research on the effect of discrete frequencies on human psychology and physiology, opening new perspectives on potential treatment of various disorders and conditions.

1. INTRODUCTION

1.1 Overview of theories on the definition and classification of emotions

It is well established that sounds, and music in particular, induce emotional responses in humans. Listening is a commonly integrated practice, from the earliest times of civilisations to the present day, to enhance spiritual dimension and restore emotional wellbeing. As demonstrated by various archaeoacoustic investigations, ancient men had a pronounced auditory sensitivity and experienced profound and multidimensional sensory effects from skilful manipulation of sound to amplify the spiritual dimension during rituals and ceremonies [1–4]. The dynamics underlying the relationship of sound and the emotions it elicits are subject of an increasing number of studies in various fields of research enhanced by technologies such as Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) that allow for a more in-depth investigation of the neurobiological responses triggered by emotions.

Emotion is one of the most pervasive aspects of human existence, related to every aspect of human behaviour. Scientific studies have focused on understanding the mechanisms of emotion as it is experienced and expressed by individuals, and these two factors have led to the conceptualisation of emotions and their differentiation. There are two main approaches to classifying emotions: (i) the categorical approach and (ii) the dimensional approach. According to the former approach, emotions are understood as discrete categories distinct from one another, biologically universal for all human beings. These innate emotions, expressively distinct and present from the earliest stages of human development contributing to human survival, are called 'basic emotions'. These are happiness, sadness, anger, fear, disgust, acceptance, surprise and anticipation [5, 6], from which all other emotional states defined as 'complex emotions' are derived. The latter approach identifies emotions as combinations along the dimensions of arousal - sometimes referred to as activation - and valence, rather than as distinct states [7–9]. The valence dimension expresses the state of pleasure–displeasure, while the arousal dimension expresses the state of low–high excitation. This dimensional classification is based on emotion's expressivity: for example, facial muscle responses recorded with an electromyogram (EMG) are indicators of valence [10–11], while skin conductance is an indicator of arousal [12].

Throughout the extensive body of literature defining emotion, especially in relation to auditory stimuli, one comes across a broad and heterogeneous background of research and theory (for an overview see [13–14]). What an emotion is can be found in the origin of the word itself: the Latin verb *emovère* - from *ex* (out) and *movere* (to move) -, which literally means 'to bring out'. This definition suggests the complexity of emotional responses, which are determined by a coherent manifestation of experiential, expressive and physiological components [15–17].

The peculiarity of emotions, therefore, is that they are a phenomenon involving a synchronisation of neural activity and physiological reactions [18]. As first argued by the psychologist William James [19] and later supported by Carl Lange [20], it is precisely the physiological responses that confer the distinct phenomenologies of emotions. Without these bodily manifestations, emotions are reduced to intellectual perceptions, thus bodily changes are essential to emotion. This approach, known as the James-Lange theory [14], emphasises the role of the Autonomic Nervous System (ANS) as a mediator of physiological responses in emotions, a theory subsequently supported, studied and implemented by leading neuroscientists specialising in emotion [21–23]. Since the ANS regulates various involuntary physiological processes including respiration, blood pressure (BP), heart rate (HR), heart rate variability (HRV), digestion and sexual arousal [24], it plays a key role in the manifestation of the specific bodily patterns caused by emotions [25]. Every human being has experienced, e.g., an increase or decrease in heart rate, blushing or turning pale (skin blood flow), increased sweating and so-called 'butterflies in the stomach' (gastrointestinal motility) during an emotion.

In contrast to James-Lange's theory, Walter B. Cannon and later Philip Bard postulated what is now known as the Cannon-Bard theory or thalamic theory of emotions. According to this theory, physiological arousal and emotional experience occur simultaneously, but independently: physiological arousal is controlled by the activity of the cerebral cortex while emotional experience is controlled by the thalamus [14].

1.2 Overview of the relationship between emotions and homeostasis

As emotions involve the ANS, associated with maintaining homeostasis, they play an important role in supporting human wellbeing. Experience of positive emotions enhances personal wellbeing and promotes physical health and longevity [26–27]. It also leads to expanding one's self, increasing control over one's life, developing greater self-confidence and higher degrees of optimism, which lead to greater social fulfilment and developing cooperative and prosocial behaviour [28–29].

In addition, positive valence emotions encourage goal achievement, improve professional performance and learning outcomes, and expand habitual ways of thinking or acting [30]. Moreover, recognition of negative valence emotions, as well as understanding the way in which they are expressed, are just as important for the individual in that they allow for the awareness, processing and acceptance of experiences necessary for balance and survival [31–33]. Repression of such emotions, in fact, is an attitude that often leads to various states of illness [34–36].

While early studies of emotion tended to focus only on autonomic responses, advances in human neuroscience have amply demonstrated the important role of the Limbic system in the experience and expression of emotion [37–39]. The Limbic system is one of the most complicated structures in the brain, which includes the Limbic cortex (Cingulate gyrus and Parahippocampal gyrus), Hippocampal formation (The Dentate gyrus, Hippocampus and Subicular complex), Amygdala, Septal area and Hypothalamus [40]. It is involved in several functions, including social and communicative behaviour, learning and memory processing [41–42], motivational processes and regulation of neuroendocrine functions [43–44]. Although emotions activate all brain circuits rather than just one distinct area [45–46], some regions appear to have greater importance in specific emotional processes. One of these is the amygdala, which plays a primary role in emotion regulation and modulation of complex functions and processes such as perception, cognition and motivation [14, 47–49], contributes to changes in short and long-term synaptic plasticity and activation of 'fight-or-flight' response via efferent projections from its central nucleus to cortical and subcortical structures [14]. Within the amygdala, GABAergic neurons that produce gamma-aminobutyric acid (GABA) exert effective control over excitatory neurons, modulating the response to anxiety-provoking stimuli [50–51]. GABAergic neurons hypoactivity leads to hyperexcitability of the amygdala which manifests as anxiety [52], while inhibition of GABAergic neurons in the central nucleus results in an enhancement of the physiological 'fight-or-flight' response of the amygdala. Negative valence emotions are associated with increased amygdala activity, while positive valence emotions, such as romantic love, are associated with amygdala deactivation [53]. Dysfunctions in amygdala activity are mainly associated with emotional alterations, such as fear, aggression, anxiety and stress disorders. Indeed, in various psychiatric disorders different morphological and functional characteristics of the amygdala are observed [54–57]. Other distinct areas of the limbic system, such as the subgenual anterior cingulate cortex, are thought to be important in experiencing sadness [58–59], while the Striatal system plays a central role in happiness events [60].

The limbic system influences ANS activities associated with emotional responses via the hypothalamic-brain pathway. The hypothalamus is involved in emotions through its role in the regulation of the stress response mediated by the Hypothalamic-Pituitary-Adrenal axis (HPA) involved in various psychological processes [61–62]. In addition to the HPA, the hypothalamus is closely interconnected with the sympathetic nervous system (SNS), another important system involved in the physiological components of stress response, through the activation of endocrine and autonomic responses such as cardiovascular activation. Together, the HPA axis and the SNS manage psychophysical activities with the aim of ensuring the maintenance of homeostasis in the human body [63]. The experience of emotional distress, also termed psychological distress, triggers various endocrine responses. Cortisol, known as the stress hormone, is linked to depression, stress, and anxiety and is released in the body as a result of activation of the HPA axis. Alpha-amylase (α-amylase), on the other hand, is the index correlating to sympathetic activity under conditions of stress [64]. A state of emotional distress is characterised by psychological symptoms and somatic complaints typical of depression and anxiety. It is well known that negative emotions, such as anxiety and stress, activate distinct physiological dynamics, such as heightened and prolonged cardiovascular activity, implicated in coronary heart disease [65]. Acute stress causes increases in the levels of norepinephrine, ACTH, cortisol, IL-6 and leptin [66].

Conversely, experiencing states of relaxation and emotional wellbeing has several direct positive effects on physiology, e.g. a decrease in heart rate (HR) and an increase in heart rate variability (HRV) [25], an increase in skin conductance response (SCR) amplitude which is indicative of the emotional arousal [67] and a reduction in respiratory rate (RR) [68]. In particular, positive emotions trigger numerous neuroendocrine responses important for maintaining wellbeing. It is widely documented that hormones such as oxytocin, serotonin, dopamine and endorphins - also classified as neurotransmitters - are released in the body during the experience of positive emotions. Oxytocin (OT), produced by the paraventricular and supraoptic nuclei of the hypothalamus, improves social contact between individuals and promotes social cohesion [17, 69], induces a general sense of wellbeing through its effects including calm, relaxation and anxiety alleviation [70–73]. OT, through specific receptors found within the amygdala [73], excites GABAergic neurons in response to fear [74]. GABAergic neurons produce gamma-aminobutyric acid (GABA), which is the main inhibitory neurotransmitter that improves mood, relieves anxiety and promotes sleep [75–77]. Serotonin or 5-hydroxy-tryptamine (5-HT) modulates variable physiological functions, such as sleep, arousal, feeding, temperature regulation, pain, emotions, and cognition [75, 78–79]. Like serotonin, dopamine is a neurotransmitter playing an important role in a number of body systems and functions, including sleep, learning, mood, memory and attention and mediates pleasure in the brain [75, 80–81]. Endorphins, which are endogenous opioid peptides that function as neurotransmitters, are released during a pleasure state, such as during continuous exercise, fear, love, music, laughter, food, and are a natural pain reliever in the body [82–83]. Some research suggested that emotions are also implied in the immune system responses. Positive emotional states increase the functioning of the immune system, whereas continuous negative emotional states decrease the functioning of the immune system and increase the chance of infectious diseases. Experiencing chronic negative valence emotions, for instance, is related to a higher lymphocyte cell count [84], higher basophilic granulocyte cell count and higher thrombocyte cell count [85–86]. This demonstrates that chronic negative moods trigger immune system responses and influence the thyroid hormone functioning [87].

In the following sections we will highlight the positive emotions induced by sounds and music and how they activate various physiological mechanisms that are considered important for maintaining and restoring psycho-physical wellbeing.

1.3 Effects of music on emotions and associated physiological states

Listening to music and sounds evokes a wide range of emotions. This is related, on the one hand, to the aesthetic experience of the individual who chooses to listen to music and sounds after an evaluation of the emotions aroused, according to parameters such as beauty, preference, harmony, identification, evocativeness and complexity. On the other hand, it relates to the hedonistic value derived from it, i.e. the profound state of pleasure experienced while listening, such that it is an important aspect of the individual person and adopted as a frequent activity in daily life [88–89]. A substantial body of research on hearing-induced emotions has focused on determining positive emotional responses to various acoustic parameters. It has been shown that musical parameters, such as changes in tempo, tone and harmony, induce different emotional arousals [90–92]. Juslin et al. [93] and Asutay et al. [94] have further suggested that the emotional responses induced by auditory stimuli depend not only on the physical properties of the sound, but also on the listener and the context.

For example, one well-documented physiological phenomenon that causes peaks of pleasure in response to listening to music, are ‘chills’ or ‘shivers down the spine’ [18, 95–97]. Various studies suggest that changes in rhythm lead to corresponding changes in respiratory rate [98–99]. Other physiological phenomena in response to listening to music include increases in electrodermal activity, heart and respiratory rate, and decreases in temperature and blood volume amplitude (BVP) [18, 100]. Listening to music has been shown to have a positive impact on health through its stress-reducing effects, positively affecting cognitive [101], physiological [102–103] and emotional processes [18].

Contemporary neuroscientific findings have confirmed that music and sounds influence the activity of various regions of the limbic system and several cortical regions, structures involved in emotions [18, 38–39, 104–105]. The emotional response of joy provoked by music is triggered by the connectivity between the hypothalamus and the hippocampus [106], supporting the idea that the hippocampus is involved in the positive emotions provoked by music by inducing endocrine responses such as reduced cortisol levels [66]. Listening to music affects the endocrine, ANS and salivary biomarkers such as cortisol, chromogranin A and oxytocin, which are indices of stress reduction [107]. Ooishi et al. [108] have shown that listening to music causes changes in salivary cortisol levels that indicate significant emotional arousal and relaxation [103]. Cortisol levels have been shown to decrease with listening to music during surgery and reduce the need for sedation [109].

Several studies using fMRI have shown that learning musical skills influences the functionality and plasticity of grey and white matter in the hippocampus [110]. In contrast to the past, in which the auditory cortex was credited with a purely functional role in the processing of music and sound, it has recently been shown that its role in the processing of emotion is broader than previously thought. Interestingly, the anterior and posterior regions of the auditory cortex are involved in the processing of feelings such as joy and fear, as they have functional connectivity with limbic and paralimbic, somatosensory, visual, motor and attentional structures [111]. The ability of music to modify the activity in the hippocampus [38] gives rise to new methods for treating the symptoms of various disorders and inducing functional changes in several neurodegenerative conditions, such as Alzheimer and Parkinson diseases [112–114], depression [115–117], post-traumatic stress disorder and personality disorder [118–119].

1.4 Effects of sounds on emotions and associated physiological states

Previous research on emotional responses to sound has primarily focused on the relationship between physical parameters of sound such as loudness, frequency [94], or soundwave type in relation to basic emotional responses on the two dimensions of arousal and valence. Listening to static, fixed and meaningless sounds has shown that the valence dimension was mainly affected by intensity, while arousal was affected by the sharpness of the sound [120]. These findings are in line with other studies showing that tonal sounds reduce wakefulness and that Sound Pressure Level (SPL) is correlated with annoyance (for an overview see [121]). Sounds were also found to trigger basic emotional classes, such as Happy–Sad and Calm–Anger. Kumar & Abhayapala investigated the relationship between 12 pure tones generated by Solfeggio frequencies (174 Hz, 285 Hz, 396 Hz, 417 Hz, 528 Hz, 639 Hz, 741 Hz, 852 Hz and 963 Hz) and the frequency of standard tuning and its octaves (110 Hz, 220 Hz and 440 Hz) and primary emotion classes (Happy–Sad, Calm–Anger). The study found that the crossover point for all four primary emotions has been shown to lie in the frequency range of 417-440 Hz. In particular, the dominance of the emotion class Anger has been found in the higher frequency range and increases exponentially with increasing pure tone frequency up to 440 Hz, while for the emotion class Calm, it remained almost constant for both the lowest and highest class frequencies, decreasing sharply in the frequency range from 285-528 Hz. The emotion class Happy is emphasised in the frequency range of 210-528 Hz, while the emotion class Sad decreases exponentially with increasing pure tone frequency and vice versa [122].

For the present study, two samples of singing bowls with a fundamental frequency of 73 Hz and 110 Hz were used as sound stimuli. It was found in prior studies that singing bowls have a significant effect on decreasing tension, anger, fatigue and depressed mood, while feelings of spiritual wellbeing increased significantly in all subjects [123]. On the other hand, Imbriani [124] hypothesised that it is the mechanical vibration emitted by the singing bowls that causes the relaxation effect and not the sound itself. Cooper [125] reported statistically significant effects of relaxation, imagination, ineffability, positive mood, insightfulness, disembodiment and unity in both live and recorded sessions with singing bowls. Kim & Choi [126] suggested that the pulsating sound of a singing bowl synchronises and activates brain waves, with a significant increase in high-Alpha and low-Beta waves, which indicate relaxation [127]. It has been shown that 20 minute sessions with singing bowls provide a greater depth of relaxation than supine silence (SS), based on the monitoring of physiological parameters such as the stress index and HRV. Trivedi & Saboo [128] demonstrated a significant decrease every five minutes in the mean stress index, an increase in HRV and an increase in the standardised mean square deviations of the Respiratory Rate (RR) interval, which is hyperbolically correlated with HR. These changes indicate an improvement in parasympathetic activity, confirming the subjects' depth of relaxation. The positive effect of singing bowls has also been reported by participants dealing with more acute conditions: a pilot study of patients with metastatic cancer who underwent 6 sessions of Tibetan singing bowls reported a significant decrease in the level of tonic and phasic skin conductance indicating a lower level of arousal, a reduction in anxiety and involuntary mental activity, a significant increase in HRV indicating greater flexibility of the autonomic system to stressors, a significant improvement in resting heart rate (RHR), RR and oxygenation. EEG recordings in the anterior-frontal areas reported changes in beta and alpha frequencies and inter-hemispheric coherence, suggesting reduced arousal and reduced mental fatigue that correlate with states of mindfulness and information processing [129].

The choice to use 73 Hz as one of the frequencies in this study was motivated by the work of the French physician Paul Nogier (1908-1996) on auriculotherapy, a treatment based on the stimulation of points in the auricle using acupuncture needles, lasers or sound waves. Nogier observed that the outer ear was connected to specific parts of the body: the lower part of the auricle (the lobule) corresponds to the head, the middle part (the concha) to the chest and abdomen, and the cartilaginous part (the antihelix) corresponds to the spine. These reflex properties of the ear were determined by him after numerous observations of patients who experienced pain in one part of the body that corresponded to a specific point on the ear when pressure was applied to it [130]. Nogier was eventually able to locate the positions of the organs on the outer ear, shown in detailed cartographies, which laid the foundation for auriculotherapy [131]. By stimulation of electromagnetic waves, Nogier determined a division of the ear's surface into 7 zones, each sensitive to a specific frequency, known today as Nogier Frequencies. Among these, the frequency D2 (73 Hz) stimulates subcortical areas, especially the hypothalamus [130], which indicates that 73 Hz can elicit hormonal balance and emotional reactions since the hypothalamus is involved in emotions through the regulation of the HPA axis and the SNS, and is the producer of OT, as previously described. Some studies of auriculotherapy have reported its positive effects on various health disorders [132–134] and on the reduction of anxiety, stress and depression [135–137].

Numerous investigations into the acoustics of prehistoric megalithic structures have identified resonance of such spaces at the frequency of 95-120 Hz, specifically 110-112 Hz [1–4], [138]. The dominant resonance frequency most frequently found at archaeological sites of acoustic interest is 110 Hz [1–4], [138] and this frequency may be involved in mediating changes in cognitive processing and the induction of altered states of consciousness experienced in association with various sacred sites [2]. One study measured brain activity with a quantitative electroencephalography (QEEG) of subjects listening to a binaurally recorded soundscape derived from one of these sacred sites and found increased frontal gamma activity, modulation of cingulate activity in the alpha, beta and gamma bands, and improved coherence between left and right frontal temporal regions [139]. Some studies investigated the effects of 110 Hz on physiological mechanisms and neuronal activity. Kumeta et al. [140] studied the properties of sound as a mechanical stimulus for cultured T2, NIH3T3, C2C12 and NB2a cells. A sine wave of 110 Hz was used as a stimulus with four different SPLs, and the observations indicate a suppression of these genes compared to control genes derived from frequency, waveform and pressure level of the stimulation, demonstrating how audible sound is an important factor in sound-induced gene regulation. In addition, alternating capacitive electric field (ACEF) stimulation at 110 Hz has been shown to significantly promote the proliferation of human dermal fibroblasts (HDF) and human epidermal keratinocyte cells (HaCaT), promoting wound healing [141]. Research conducted on the effects of sound stimuli with a frequency of 110 Hz on brain activity monitored by EEG showed significantly lower activity in the left temporal lobe and an asymmetrical shift of the prefrontal cortex from left to right hemispheric dominance compared to the other frequencies analysed, which may be related to emotional processing [2]. Furthermore, the neuronal activation triggered by 110 Hz induces calcium efflux [142], a biomolecule important for cellular homeostasis, and it has been shown that 110 Hz is a fundamental frequency of activity within the hippocampal CA3 region of the brain in rats [143–144], an important structure involved in memory and also implicated in abnormal subjective experience [145–147]. A study on the effects of acoustic and visual stimuli and their synergistic effects on HRV in eyes-closed conditions (CEC) and eyes-open conditions (OEC) found that cardiac autonomic function during listening to a 110 Hz sine wave under eyes-closed conditions (CEC) was significantly greater than the values for sine waves at other frequencies and for the 110 Hz sawtooth waves. The value for 110 Hz under CEC and OEC was significantly greater than that of white noise under OEC [148].

In the present study, geometrically shaped virtual sound sources, also called Geometrical Sound (GS), were used to further examine potential effects on human emotional wellbeing and homeostasis. In a recent study carried out by Geffen & Braun [149] behavioural and physiological changes were monitored in 50 healthy subjects in response to three GS conditions (Pyramid, Cube, Sphere) and control (Stereo). Results showed that GS positively affected brain wave topology, power amplitude and connectivity patterns in the subjects. Furthermore, participants reported an increase in positive feelings and a decrease in negative feelings in conjunction with a decrease in blood pressure and heart rate in response to GS compared to control. This demonstrates the potential efficacy of spatial sound on improving human physiology and emotional wellbeing, laying the foundation for further investigations, such as the present study, into the use of spatial-geometric modelling of sound as an alternative and non-invasive method to restore physiological balance and emotional wellbeing in humans [150–151].

Further understanding of the dependency between sounds, frequency and emotions is critical for various applications, such as the adoption of sounds and music for non-invasive interventions to maintain and improve homeostasis and induction of emotions to restore wellbeing. This further demonstrates the need for more rigorous research into the effects of sound and music on human psychology and physiology.

2. RESEARCH METHODOLOGY

The present study investigated the effects of spatial sound projections of two different singing bowls with fundamental frequencies at 73 Hz and 110 Hz on emotional wellbeing as reported by POMS2 and MDMQ questionnaires. The study serves to further validate associated effects of the sounds on the Autonomic Nervous System (ANS) and its role in maintaining homeostasis, as reported by Oomen et al [152]. Changes in physiological parameters were not investigated in this study.

The experiment included 44 participants (19 male; 25 female) aged 18 years or older, healthy, sober, non-pregnant, with normal hearing and without a history of neurological or psychiatric illnesses, e.g., no seizures, epilepsy and in particular sound-induced epilepsy, nor claustrophobia, or other problems that could interfere with the research setting. Participants who have artificial cardiac pacemakers, brain shunts and/or joint replacements were excluded from the study. Participants were recruited via local platforms and were informed that the purpose of the experiment was to observe the effects of sound on their psycho-physical state by giving their written consent. The experiment was conducted on site at The Works Research Institute in Budapest, Hungary, according to the guidelines of The United Ethical Review Committee for Research in Psychology (EPKEB).

2.2 Acoustic Test Environment

A sound-proofed spherical enclosure (Sphere) was utilised as an acoustic test environment (Fig 1) with an integrated omnidirectional loudspeaker configuration (Fig 2A-B). A custom designed chair to support subjects in seated position is centered inside the Sphere (Fig 3).

Fig 1. The Sphere at The Works Research Institute, Budapest, Hungary.

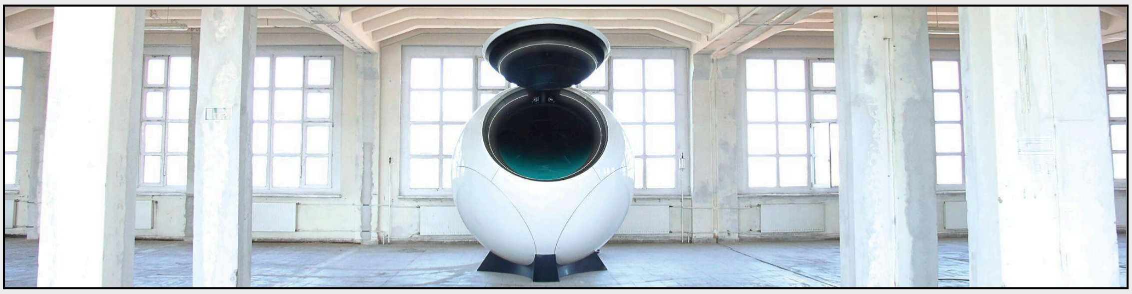


Fig 2A-B: Loudspeaker configuration inside the Sphere. 9 omnidirectional loudspeakers (OmniDrive Pro v2) are situated within a 0.2m air gap behind a part sound-transparent, part sound-absorbing inner shell (A), encapsulated by a sound-insulating and sound-absorbing outer shell (B). Loudspeakers are positioned at equal radial angles and equidistant from the centre of the Sphere [width (x), depth (y), height (z) = 0, 0, 0; in m].

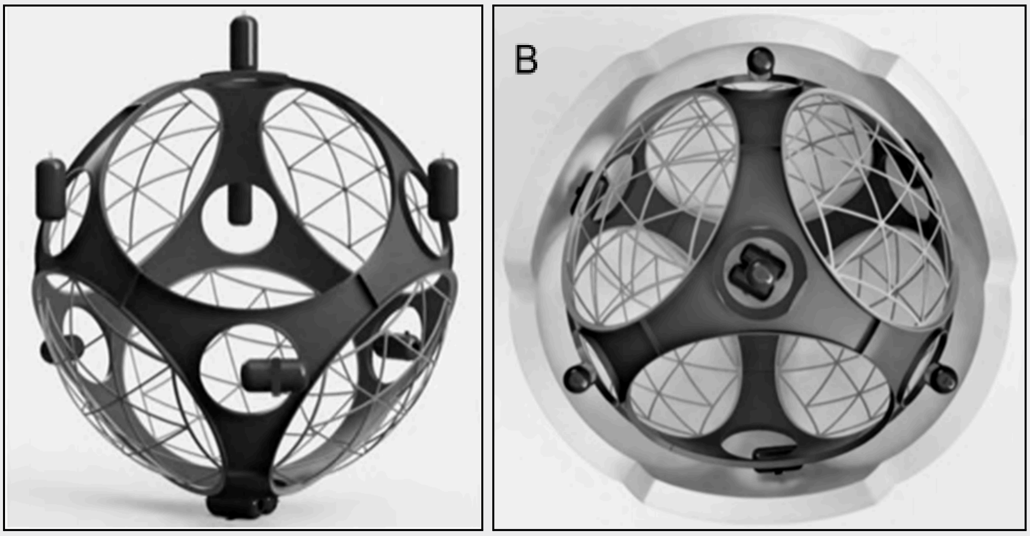
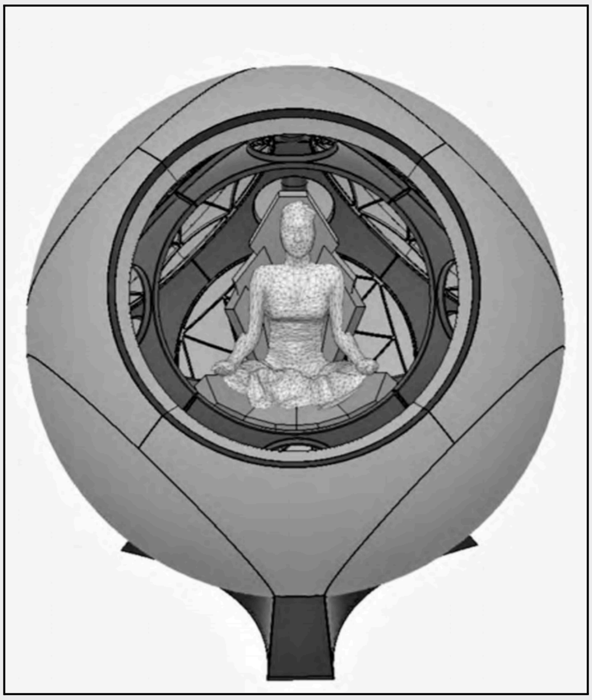


Fig 3: Subject situated in seated position inside the Sphere.



2.3 Sound stimuli

The sound stimuli projected inside the Sphere comprise pre-recorded samples of a singing bowl with a fundamental frequency of 73 Hz and the most prominent harmonics at 221 Hz, 443 Hz and 879 Hz (Fig 5A); and a singing bowl with a fundamental frequency of 110 Hz and the most prominent harmonics at 111 Hz, 333 Hz, and 973 Hz (Fig 5B). The sound samples of the singing bowls have a total decay time of 19.56 seconds and 14.22 seconds, respectively. For each experimental trial, the sample is repeated 15 times and 21 times, respectively, providing a total duration of ~5 minutes for each trial (Fig 6A-B).

Singing bowl recordings were projected in nine different virtual shape configurations: Pyramid (C1); Tetrahedron (C2); Cube (C3); Octahedron (C4); Icosahedron (C5); Dodecahedron (C6); Cuboctahedron (C7); Sphere (C8); and Stereo (C9). Each spatial sound projection consisted of a virtual source: a sound object identified by the vertices of each geometric shape; and a virtual space: a reverberating field comprising the reflections of the source within a space of the same geometric shape (Fig 7A-D). All virtual sources have a circumference of 2m base width and all virtual spaces have a circumference of 8m base width. Any other variations in spatial parameters were engineered to accommodate optimal sound performance per frequency while maintaining the highest performance proximity between conditions. (For further specification of the projected sound parameters, see Appendix 1).

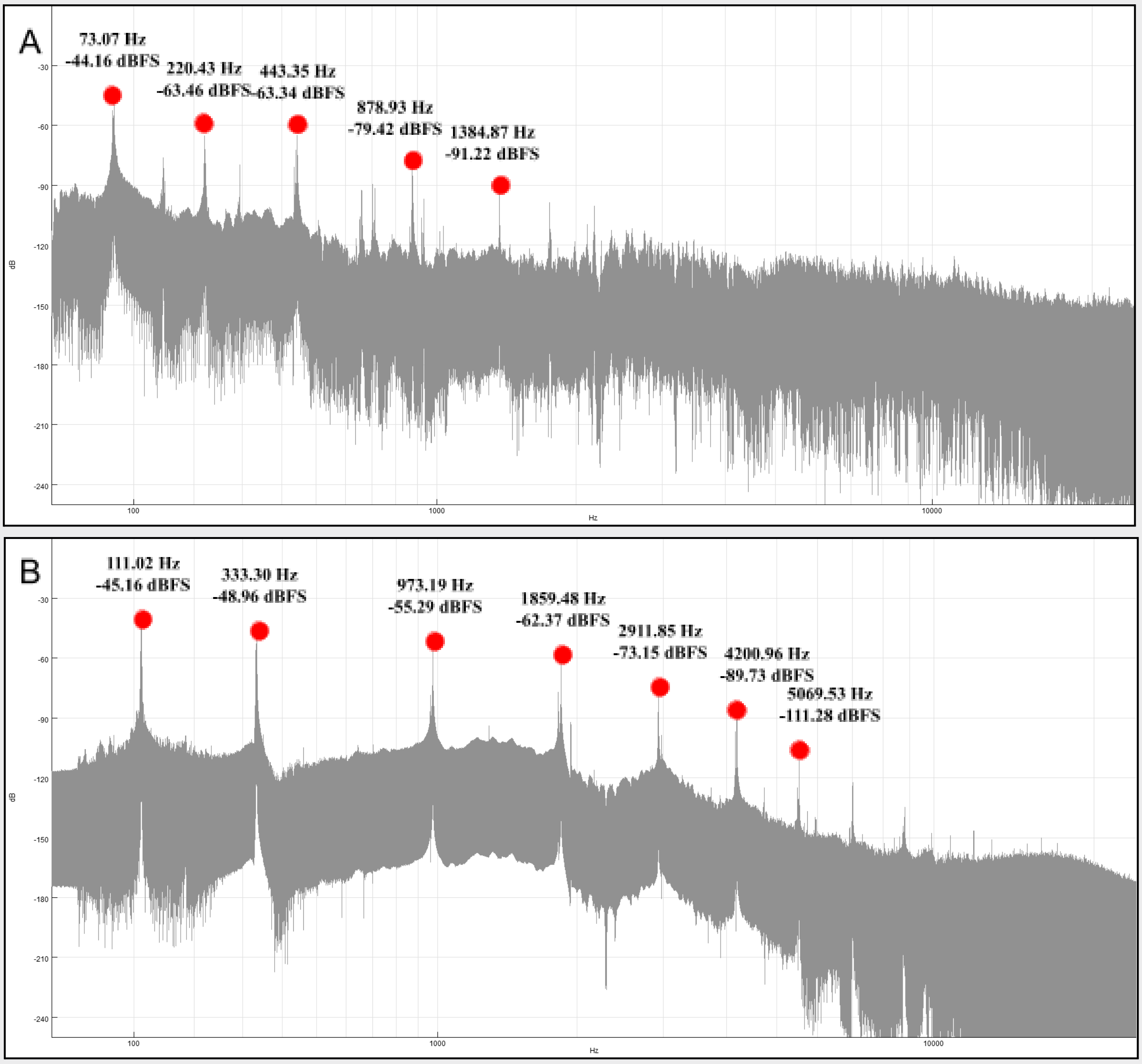


Fig 5A-B. Fast Fourier Transform (FFT) of stimuli at (A) 73 Hz and (B) 110 Hz with the peaks indicating the most prominent harmonics of each stimulus.

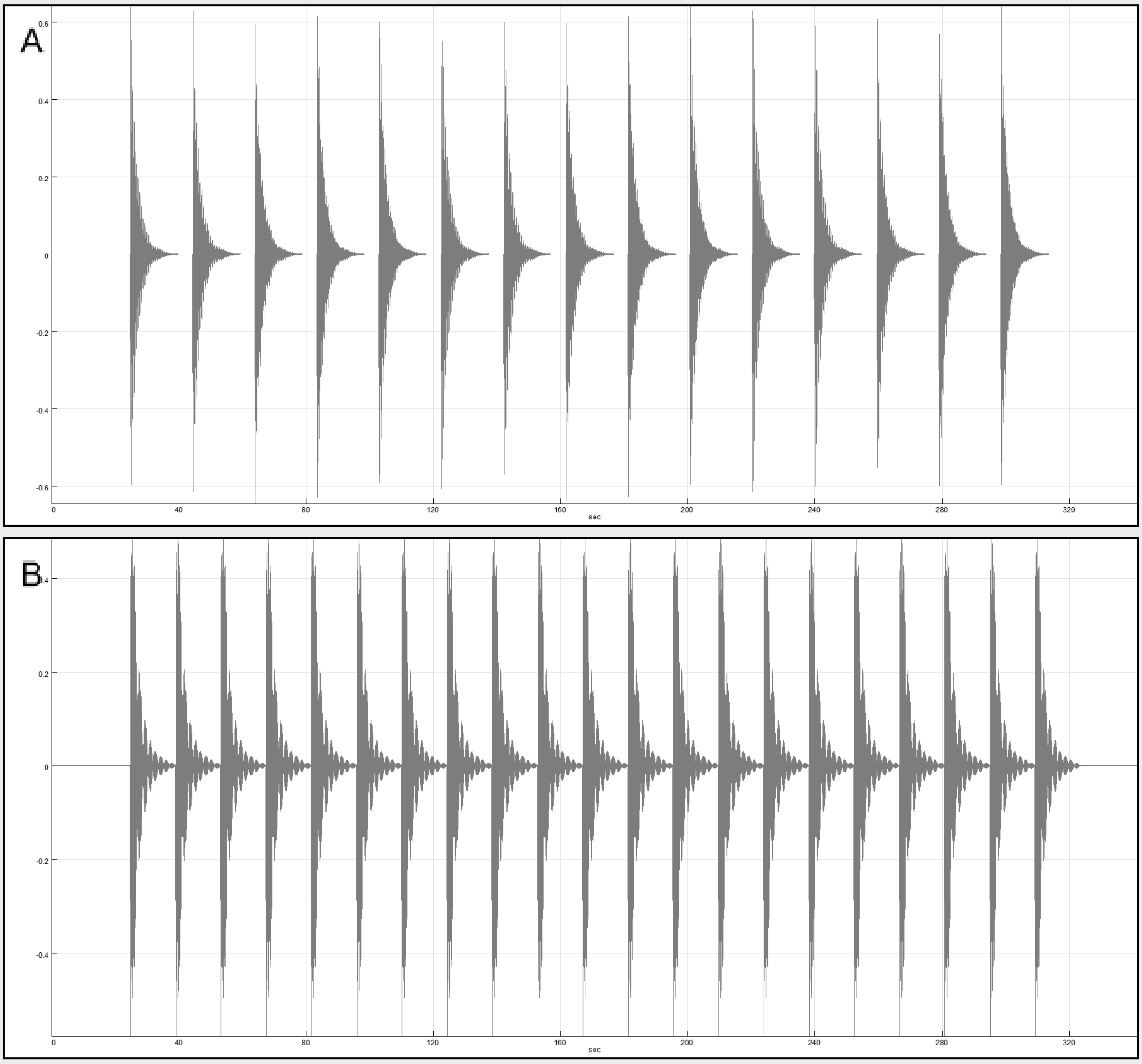


Fig 6A-B. Waveform of stimuli at (A) 73 Hz showing 15 consecutive hits and (B) 110 Hz showing 21 consecutive hits.

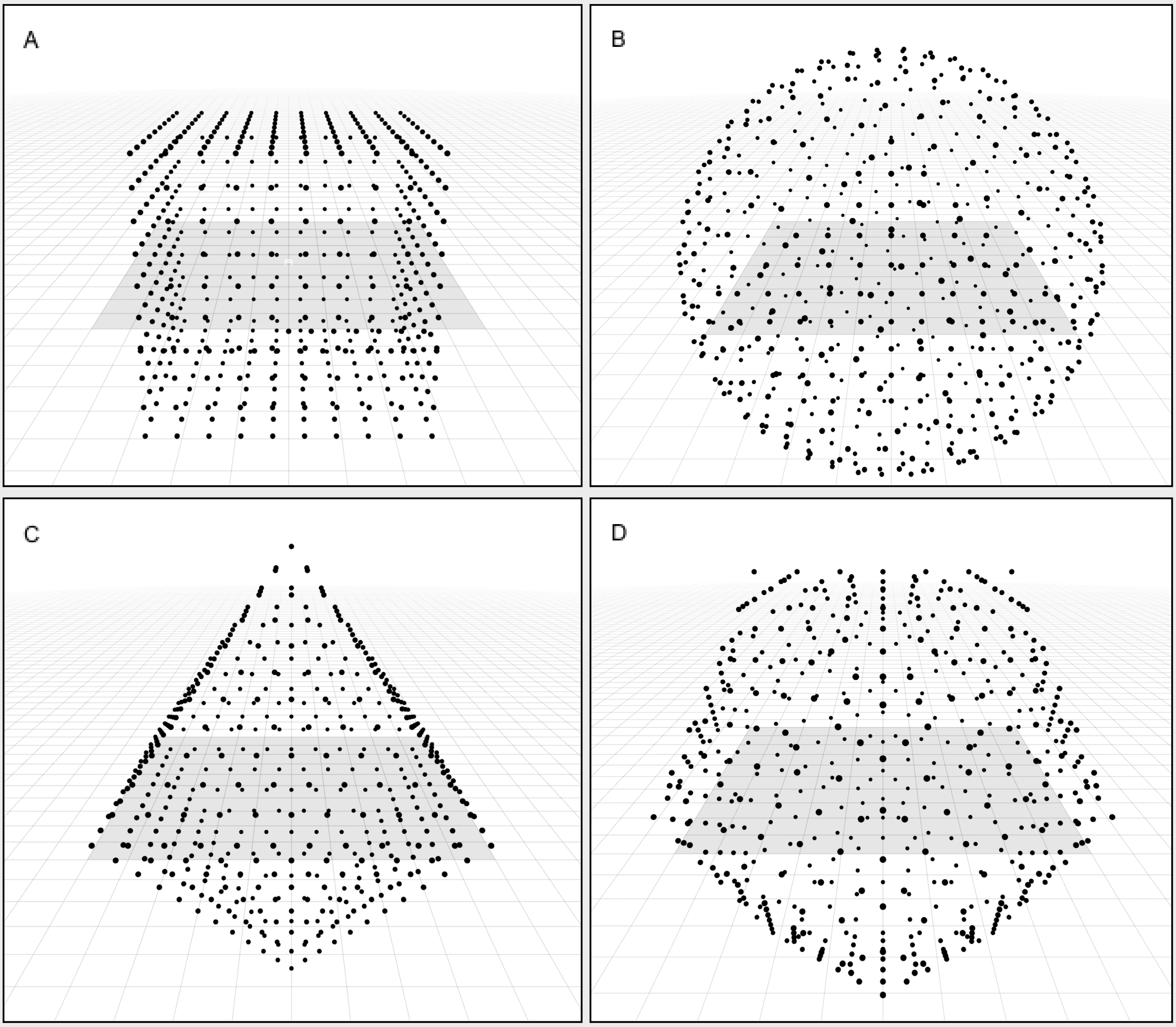


Fig 7A-D. Examples of spatial sound projections of virtual spaces with a geometric shape defined by a plurality of virtual points: Cube (C3); Sphere (C8); Octahedron (C4); and Dodecahedron (C6). The center of each virtual shape is positioned relative to the center of the Sphere, so that the center of each projected shape also coincides with the position of the seated subject. The spatial sound projections are generated by acoustic simulation software (built in 4DSOUND v2.0 audio framework) comprising audio signal components determined by the positions of the associated virtual points such that the virtual source is perceived by a subject as reverberating within the virtual space at said position relative to the subject [153]. The reverberation of the virtual spaces was computed using recursive absorption of the sound energy per octave bands: 67.5 Hz = 0.02; 125 Hz = 0.02; 250 Hz = 0.02; 500 Hz = 0.03; 1k Hz = 0.04; 2k Hz = 0.05; 4k Hz = 0.05; 8k Hz = 0.05; 16k Hz = 0.05 comprising the absorption characteristics of limestone walls [154], adding a generated total reverberation to the sound source of ~8 seconds for each respective shape.

2.4 Experimental Procedure

Subjects (*N=44*) were divided into two groups: 26 subjects (16 female; 10 male) were exposed to the 73 Hz stimulus, while 18 subjects (9 female; 9 male) were exposed to the 110 Hz stimulus. Subjects were comfortably seated on the chair in the Sphere, in complete darkness with their eyes closed, their sternum approximately located at the centre of the Sphere and centered within the projected virtual sound space. During the experimental procedure, subjects were exposed to the stimulus in 9 different conditions (C1-C9) each lasting 5 minutes, adding to a total experiment duration of 45 minutes per participant. The order of sound stimuli was randomly alternated between participants and recorded as a single blind paradigm.

2.5 Questionnaires

To study emotional responses to the sound stimuli, all subjects in both groups were monitored before and immediately after exposure to the sound stimuli by means of two questionnaires. For this study we used, in order, the POMS2 and the MDMQ questionnaire.

The Profile of Mood States Second Edition (POMS2) [155] is a validated psychological test that assesses people's moods (for individuals aged 13 and older). For this experiment, the POMS2 was used in the short version for adults, consisting of 35 items to which the participant answers with the following rating scale: 0 = not at all; 1 = little; 2 = moderately; 3 = enough; 4 = extremely. As the meaning of the evaluation score varies from one scale to another, the score is converted into a standard score, i.e. a *t*-score. The Multidimensional Mood Questionnaire (MDMQ) [156] is a widely used and thoroughly validated questionnaire to assess a respondent's mental state. The English version comprises 30 items divided into 6 response categories.

Data analysis was performed using IBM SPSS statistical software (version 29.0.0). A paired-sample *t*-test was used to compare the means of the responses related to mood and emotional states as reported by the POMS2 and MDMQ questionnaires before and after exposure to the sound stimuli. A paired sample *t*-test was also used to analyse the results from the two questionnaires by comparing the results from groups exposed to 73 Hz and 110 Hz stimuli combined and separately, and the groups in relation to each other.

The statistical significance threshold was set at $p<0.05$, while the high significance threshold was set at $p<0.005$. We plotted the results obtained in order to visualise the responses related to emotional states (as shown in Figs 8-13) reporting mean values and standard error means (SEM) for those items that had a significant to highly significant variation between the two different time points.

3. RESULTS

3.1 Results from POMS2 and MDMQ for 73 Hz and 110 Hz combined

From both questionnaires a decreasing trend in all negative mood scores of all participants after exposure to the sound stimuli at both frequencies was reported (Fig 8-9; Table 1). In particular, the results from the POMS2 show a significant decrease in the mean values of the items: worn out ($p<0.011$); hopeless ($p<0.048$); fatigued ($p<0.008$); helpful ($p<0.047$); uncertain about things ($p<0.010$); considerate ($p<0.054$); and exhausted ($p<0.055$); and a highly significant decrease in the items: tense ($p<0.000$); angry ($p<0.003$); sad ($p<0.001$); grouchy ($p<0.002$); uneasy ($p<0.001$); nervous ($p<0.000$); and anxious ($p<0.001$). Similarly, the MDMQ results show a significant decrease in the mean value of the item: worn out ($p<0.012$); and a highly significant decrease in the items: tense ($p<0.004$); and nervous ($p<0.000$).

Furthermore, both questionnaires reported an increase in all positive mood scores after exposure to the sound stimuli at both frequencies. In particular, the POMS2 results show a significant increase in the mean value of the item: trusting ($p<0.017$); , while the MDMQ results show a significant increase in the mean values of the items: rested ($p<0.016$); relaxed ($p<0.005$); highly activated ($p<0.007$); fresh ($p<0.010$); happy ($p<0.032$); and wonderful ($p<0.005$); and a highly significant increase in the items: great ($p<0.000$); superb ($p<0.002$); calm ($p<0.001$); and deeply relaxed ($p<0.002$).

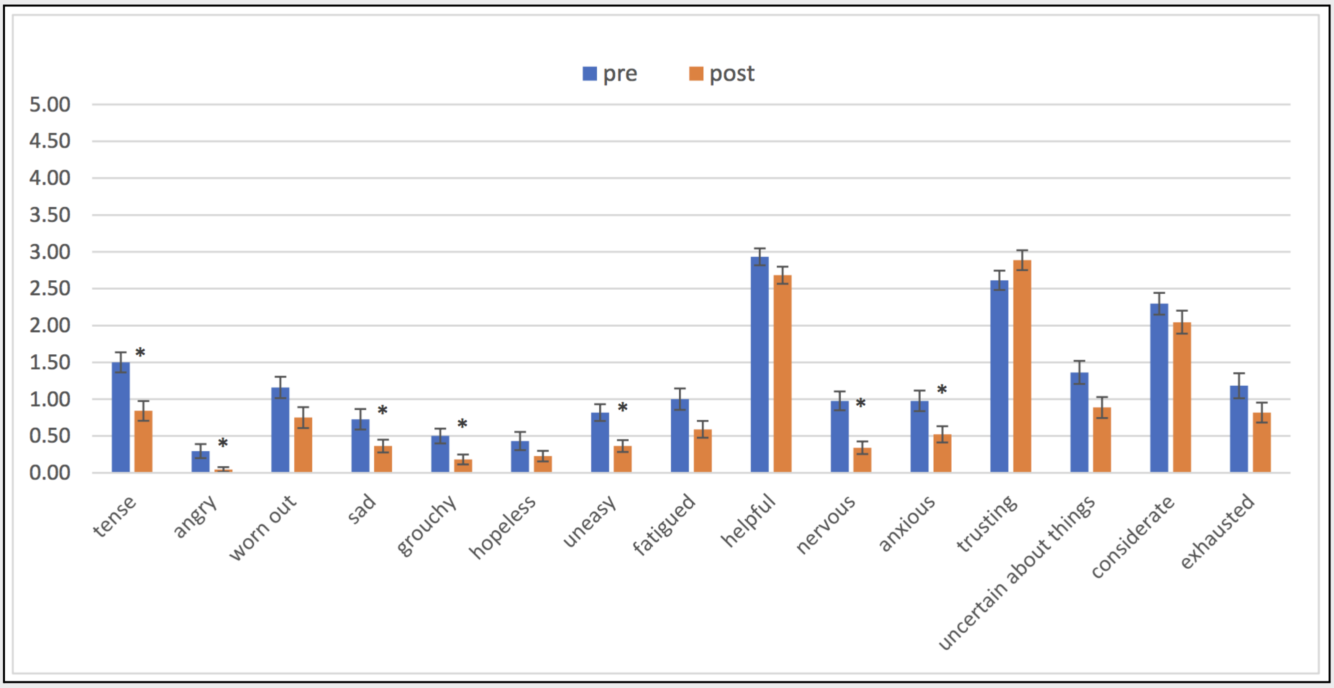


Fig 8. Items from the POMS2 questionnaire with significant (p<0.05) and highly significant (*p<0.005) differences between pre- and post-exposure to all sound stimuli for all participants in both groups (73 Hz and 110 Hz). Error bars represent standard error means (SEM).

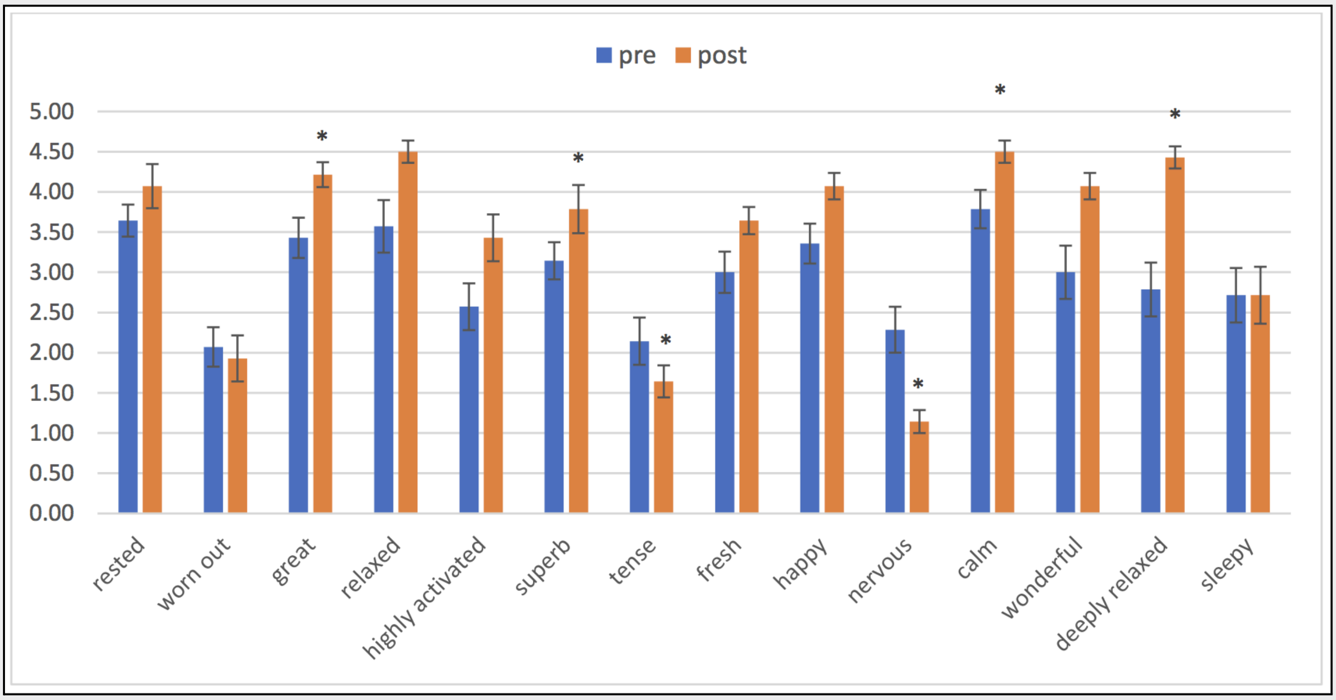


Fig 9. Items from the MDMQ questionnaire with significant (p<0.05) and highly significant (*p<0.005) differences between pre- and post-exposure to all sound stimuli for all participants in both groups (73 Hz and 110 Hz). Error bars represent standard error means (SEM).

POMS2			MDMQ		
	Pre-Exposure	Post-Exposure		Pre-Exposure	Post-Exposure
Items	Mean ± SEM	Mean ± SEM	Items	Mean ± SEM	Mean ± SEM
tense	1.50 ± 0.136	0.84 ± 0.134*	rested	3.64 ± 0.199	4.07 ± 0.275
angry	0.30 ± 0.095	0.05 ± 0.032*	worn out	2.07 ± 0.245	1.93 ± 0.286
worn out	1.16 ± 0.145	0.75 ± 0.142	great	3.43 ± 0.251	4.21 ± 0.155*
sad	0.73 ± 0.139	0.36 ± 0.087*	relaxed	3.57 ± 0.327	4.50 ± 0.139
grouchy	0.50 ± 0.100	0.18 ± 0.067*	highly activated	2.57 ± 0.291	3.43 ± 0.291
hopeless	0.43 ± 0.123	0.23 ± 0.072	superb	3.14 ± 0.231	3.79 ± 0.300*
uneasy	0.82 ± 0.114	0.36 ± 0.080*	tense	2.14 ± 0.294	1.64 ± 0.199*
fatigued	1.00 ± 0.145	0.59 ± 0.114	fresh	3.00 ± 0.257	3.64 ± 0.169
helpful	2.93 ± 0.114	2.68 ± 0.116	happy	3.36 ± 0.248	4.07 ± 0.165
nervous	0.98 ± 0.128	0.34 ± 0.086*	nervous	2.29 ± 0.286	1.14 ± 0.143*
anxious	0.98 ± 0.140	0.52 ± 0.110*	calm	3.79 ± 0.239	4.50 ± 0.139*
trusting	2.61 ± 0.131	2.89 ± 0.135	wonderful	3.00 ± 0.331	4.07 ± 0.165
uncertain about things	1.36 ± 0.156	0.89 ± 0.143	deeply relaxed	2.79 ± 0.334	4.43 ± 0.137*
considerate	2.30 ± 0.147	2.05 ± 0.143	sleepy	2.71 ± 0.339	2.71 ± 0.354
exhausted	1.18 ± 0.170	0.82 ± 0.135			

Table 1. Results from the POMS2 and MDMQ questionnaires reporting mean values and standard error of the mean (Mean±SEM) for items with significant ($p<0.05$) and highly significant (*$p<0.005$) differences between pre- and post-exposure to 73 Hz and 110 Hz sound stimuli combined for all participants.

3.2 Results from POMS2 and MDMQ for 73 Hz

The results from the POMS2 questionnaire (Fig 10; Table 2) showed a significant decrease in negative mood states after exposure to the 73 Hz sound stimuli for the items: angry ($p<0.011$); worn out ($p<0.024$); sad ($p<0.032$); grouchy ($p<0.010$); uneasy ($p<0.005$); fatigued ($p<0.035$); anxious ($p<0.025$); hopeless ($p<0.048$); and a highly significant decrease for the item: nervous ($p<0.000$).

A similar trend is reported by the results from the MDMQ questionnaire (Fig 11; Table 2) which indicate a significant decrease in the items: bad ($p<0.026$); tense ($p<0.014$); nervous ($p<0.008$); and exhausted ($p<0.030$). Furthermore, the results from the MDMQ questionnaire reported a significant increase in positive mood states for the items: great ($p<0.006$); wide awake ($p<0.048$); deeply relaxed ($p<0.006$) and superb ($p<0.054$); and a highly significant increase in the items: relaxed ($p<0.004$); calm ($p<0.002$); and wonderful ($p<0.003$).

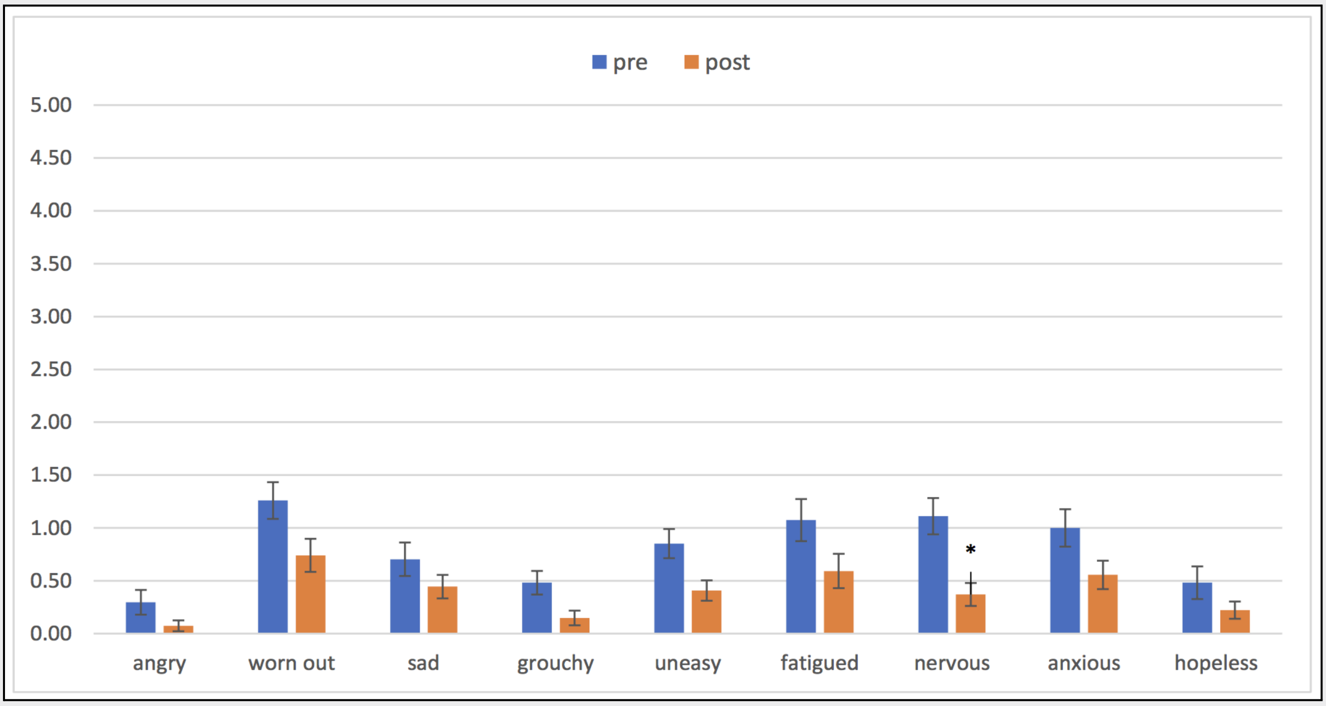


Fig 10. Items from the POMS2 questionnaire with significant (p<0.05) and highly significant (*p<0.005) differences between pre- and post-exposure to 73 Hz sound stimuli for in-group participants. Error bars represent standard error means (SEM).

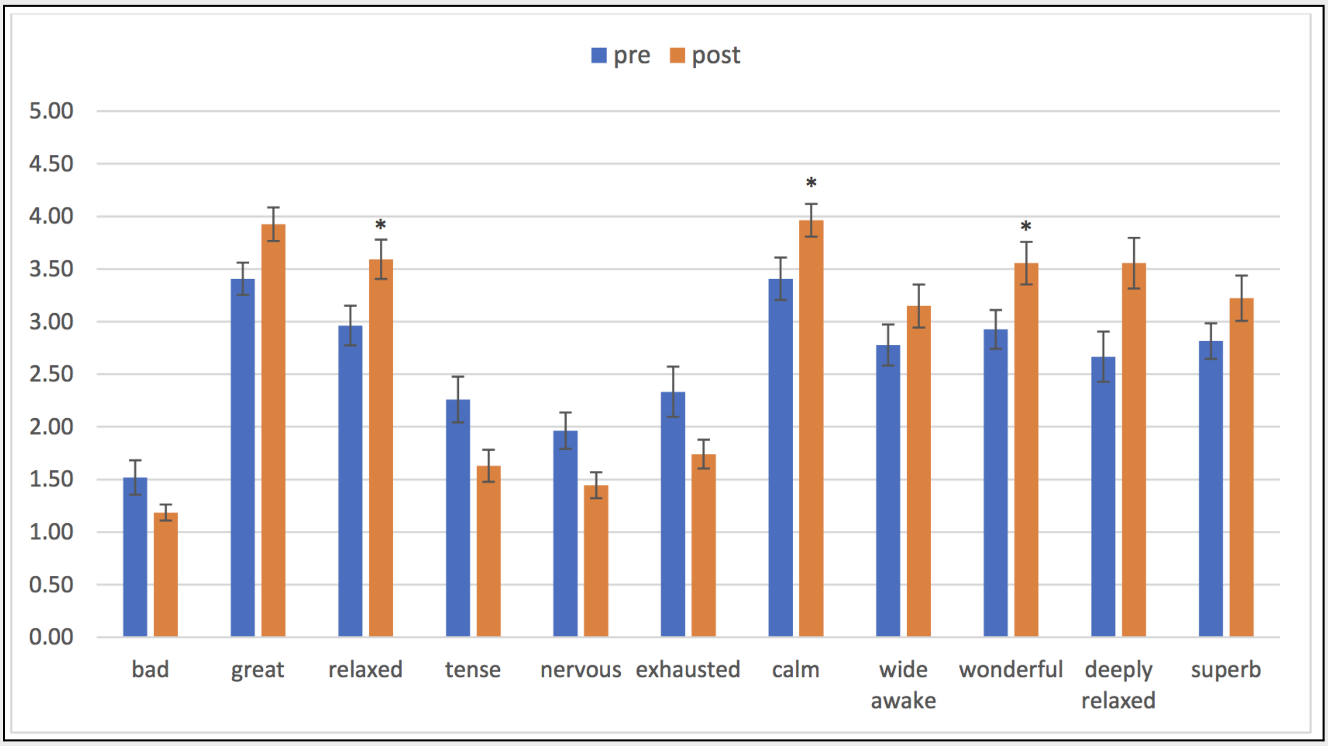


Fig 11. Items from the MDMQ questionnaire with significant (p<0.05) and highly significant (*p<0.005) differences between pre- and post-exposure to 73 Hz sound stimuli for in-group participants. Error bars represent standard error means (SEM).

POMS2			MDMQ		
	Pre-Exposure	Post-Exposure		Pre-Exposure	Post-Exposure
Items	Mean ± SEM	Mean ± SEM	Items	Mean ± SEM	Mean ± SEM
angry	0.30 ± 0.117	0.07 ± 0.051	bad	1.52 ± 0.163	1.19 ± 0.076
worn out	1.26 ± 0.174	0.74 ± 0.156	great	3.41 ± 0.153	3.93 ± 0.159
sad	0.70 ± 0.158	0.44 ± 0.111	relaxed	2.96 ± 0.189	3.59 ± 0.187*
grouchy	0.48 ± 0.112	0.15 ± 0.070	tense	2.26 ± 0.217	1.63 ± 0.152
uneasy	0.85 ± 0.138	0.41 ± 0.096	nervous	1.96 ± 0.173	1.44 ± 0.123
fatigued	1.07 ± 0.199	0.59 ± 0.162	exhausted	2.33 ± 0.239	1.74 ± 0.137
nervous	1.11 ± 0.172	0.37 ± 0.109*	calm	3.41 ± 0.202	3.96 ± 0.155*
anxious	1.00 ± 0.177	0.56 ± 0.134	wide awake	2.78 ± 0.195	3.15 ± 0.205
hopeless	0.48 ± 0.154	0.22 ± 0.082	wonderful	2.93 ± 0.184	3.56 ± 0.202*
			deeply relaxed	2.67 ± 0.239	3.56 ± 0.241
			superb	2.81 ± 0.169	3.22 ± 0.216

Table 2. Results from the POMS2 and MDMQ questionnaires reporting mean values and standard error of the mean (Mean±SEM) for items with significant (p<0.05) and highly significant (*p<0.005) differences between pre- and post-exposure to 73 Hz sound stimuli for in-group participants.

3.3 Results from POMS2 and MDMQ for 110 Hz

The results from the POMS2 questionnaire (Fig 12; Table 3) showed a significant decrease in negative mood states after exposure to the 110 Hz sound stimuli for the items: sad ($p<0.008$); unable to concentrate ($p<0.034$); nervous ($p<0.041$); anxious ($p<0.016$); and uneasy ($p<0.056$); and a highly significant decrease in the items: tense ($p<0.000$); and uncertain about things ($p<0.001$). A similar trend is reported by the results from the MDMQ questionnaire (Fig 13; Table 3) which indicate a significant decrease in the items: nervous ($p<0.023$); worn out ($p<0.056$); and sleepy ($p<0.056$) and a significant increase in positive mood states: great ($p<0.017$); highly activated ($p<0.034$); superb ($p<0.013$); and happy ($p<0.014$).

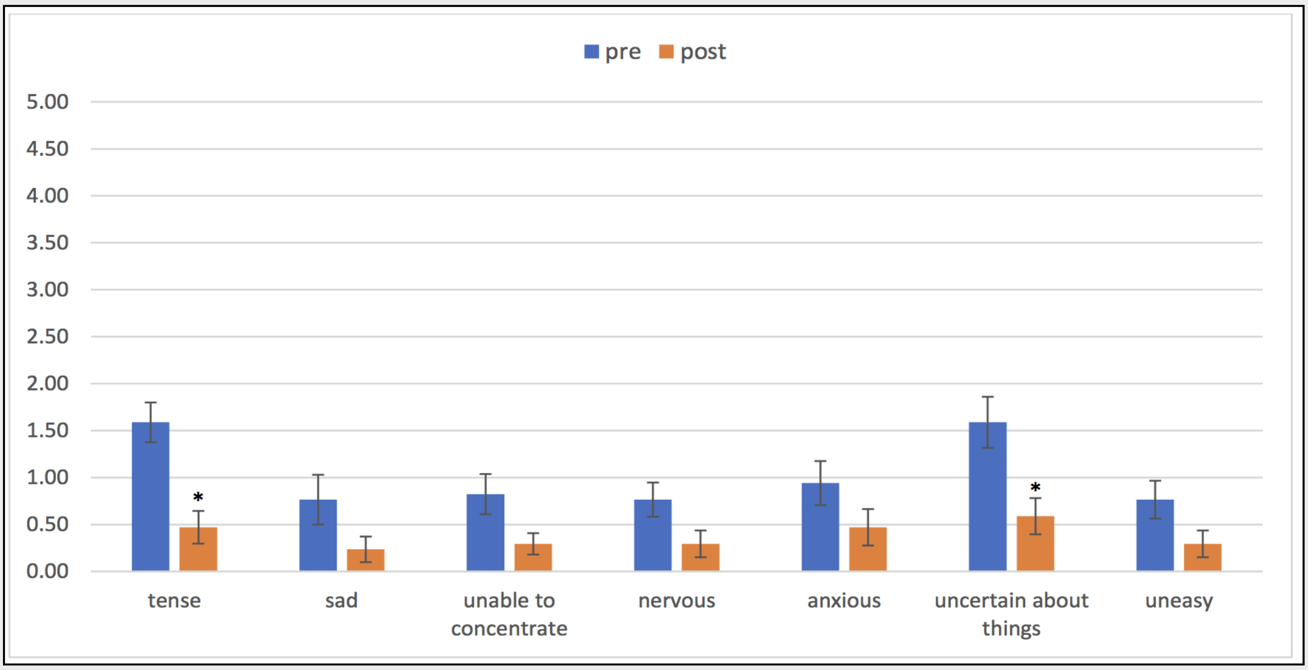


Fig 12. Items from the POMS2 questionnaire with significant (p<0.05) and highly significant (*p<0.005) differences between pre- and post-exposure to 110 Hz sound stimuli for in-group participants. Error bars represent standard error means (SEM).

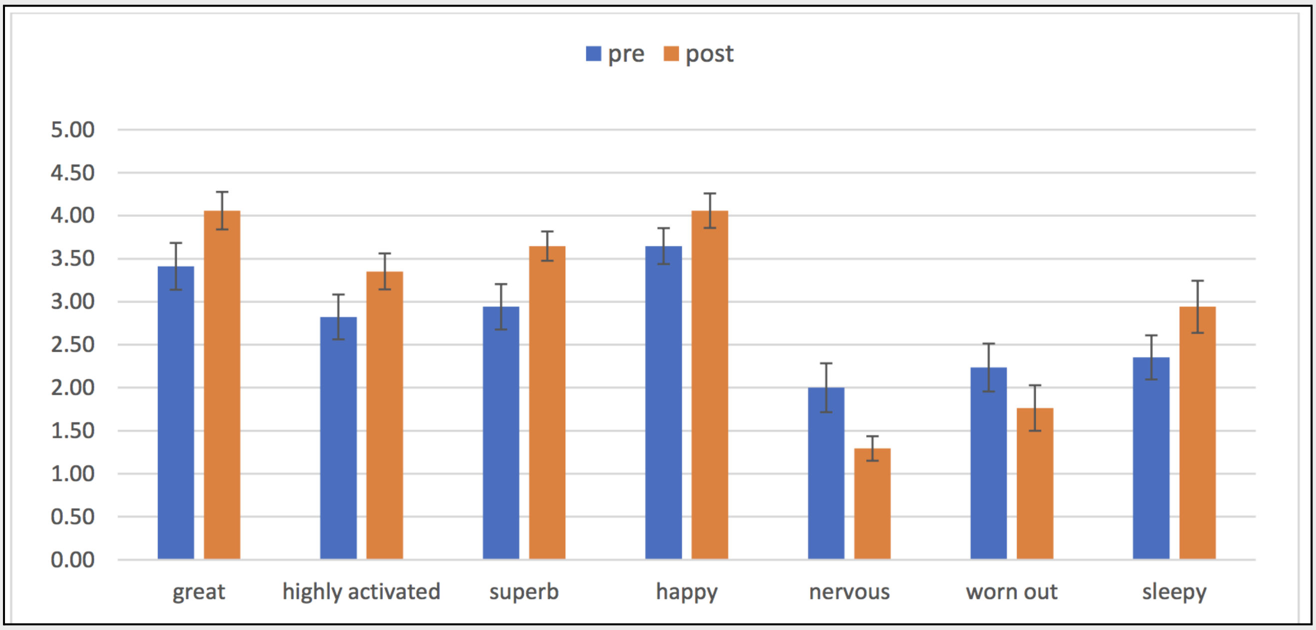


Fig 13. Items from the MDMQ questionnaire with significant (p<0.05) and highly significant (*p<0.005) differences between pre- and post-exposure to 110 Hz sound stimuli for in-group participants. Error bars represent standard error means (SEM).

POMS2			MDMQ		
	Pre-Exposure	Post-Exposure		Pre-Exposure	Post-Exposure
Items	Mean ± SEM	Mean ± SEM	Items	Mean ± SEM	Mean ± SEM
unable to concentrate	0.82 ± 0.214	0.29 ± 0.114	**superb**	2.94 ± 0.264	3.65 ± 0.170
nervous	0.76 ± 0.182	0.29 ± 0.143	**happy**	3.65 ± 0.209	4.06 ± 0.201
anxious	0.94 ± 0.234	0.47 ± 0.194	**nervous**	2.00 ± 0.284	1.29 ± 0.143
uncertain about things	1.59 ± 0.272	0.59± 0.193	**worn out**	2.24 ± 0.278	1.76 ± 0.265
uneasy	0.76 ± 0.202	0.29± 0.143	**sleepy**	2.35 ± 0.256	2.94 ± 0.303

Table 3. Results from the POMS2 and MDMQ questionnaires reporting mean values and standard error of the mean (Mean±SEM) for items with significant (p<0.05) and highly significant (*p<0.005) differences between pre- and post-exposure to 110 Hz sound stimuli for in-group participants.

3.4 Comparison of results for 73 Hz and 110 Hz combined and separately

The comparative results from the POMS2 and MDMQ questionnaires for all groups are summarised in Table 4 and Table 5. Comparing the results of emotional responses obtained by combining the groups (see Table 1) to the results obtained for the groups separately (Table 2-3) we found the items: helpful; and considerate were significantly decreased for the groups combined but not for the groups separately.

Furthermore, we found items that were significantly increased for the groups combined but not for the groups separately: trusting; rested; and fresh. A highly significant increase for both groups combined compared to the groups separately was observed in the items: great (*Combined – 73 Hz: p*<0.000; *Combined – 110 Hz: p*<0.040); relaxed (*Combined – 73 Hz: p*<0.000); highly activated (*Combined – 110 Hz: p*<0.000); happy (*Combined – 110 Hz: p*<0.000); calm (*Combined – 73 Hz: p*<0.000); wonderful (*Combined – 73 Hz: p*<0.001); and deeply relaxed (*Combined – 73 Hz: p*<0.000).

Comparing the results of the emotional responses obtained for the group exposed to 73 Hz to the group exposed to 110 Hz and the groups combined, we found that the items: hopeless; fatigued; grouchy; angry; and exhausted were significantly decreased for the group exposed to 73 Hz, but not for the group exposed to 110 Hz. The item: bad was significantly decreased for the group exposed to 73 Hz, but not for the group exposed to 110 Hz and for both groups combined. The item: wide awake was significantly increased for the group exposed to 73 Hz, but not for the group exposed to 110 Hz and in the groups combined. A significant decrease for the group exposed to 73 Hz compared to the group exposed to 110 Hz and the groups combined was observed in the item: hopeless (*Combined – 73 Hz: p*<0.028).

Comparing the results of the emotional responses obtained for the group exposed to 110 Hz to the results obtained for the group exposed to 73 Hz and the groups combined, we found the item: unable to concentrate was significantly decreased for the group exposed to 110 Hz, but not for the group exposed to 73 Hz and the groups combined. We found a highly significant decrease in the item: uncertain about things (*Combined – 110 Hz: p*<0.000) for the group exposed to 110 Hz compared to the groups combined and this item was not found to be significantly decreased for the group exposed to 73 Hz. A highly significant decrease for the group exposed to 110 Hz compared to the group exposed to 73 Hz and the groups combined was observed in the item: sad (*Combined – 110 Hz: p*<0.001; *73 Hz – 110 Hz: p*<0.000). The item: great (*73 Hz – 110 Hz: p*<0.044) was found to be significantly increased for the group exposed to 110 Hz compared to the group exposed to 73 Hz, but significantly decreased compared to the groups combined. A highly significant increase for the group exposed to 110 Hz compared to the group exposed to 73 Hz was observed in the item: superb (*73 Hz – 110 Hz: p*<0.000); and a highly significant increase for the group exposed to 110 Hz compared to the group exposed to 73 Hz and the groups combined was observed in the items: sleepy (*Combined – 110 Hz: p*<0.000).

As for general effects equally distributed across all groups, a highly significant decrease was observed for the items: worn out (POMS2: *Combined – 73 Hz: p*<0.006; MDMQ: *Combined – 110 Hz: p*<0.000); and tense (POMS2: *Combined – 110 Hz: p*<0.000; MDMQ: *Combined – 73 Hz: p*<0.026) for the groups exposed to 73 Hz and 110 Hz separately compared to both groups combined, with variance in significance across the POMS2 and MDMQ questionnaires. The item: nervous (POMS2: *Combined – 73 Hz: p*<0.002; *Combined – 110 Hz: p*<0.000; *73 Hz – 110 Hz: p*<0.000; MDMQ: *Combined – 73 Hz: p*<0.000; *Combined – 110 Hz: p*<0.000; *73 Hz – 110 Hz: p*<0.002) was decreased with high significance across all groups, with variance in significance across the POMS2 and MDMQ questionnaires. The items: uneasy; and anxious were decreased with high significance across all groups and without significant differences between the 73 Hz and 110 Hz stimuli, both combined and separately.

	POMS2					
	Combined – 73 Hz		Combined – 110 Hz		73 Hz – 110 Hz	
Items	Mean Difference Pre – Post	Pooled ± SEM Pre – Post	Mean Difference Pre – Post	Pooled ± SEM Pre – Post	Mean Difference Pre – Post	Pooled ± SEM Pre – Post
tense	-	-	0.46	± 0.153*	-	-
worn out	0.11	± 0.152	-	-	-	-
sad	-0.11	± 0.121*	0.15	± 0.143*	0.26	± 0.164*
hopeless	0.06	± 0.106				
nervous	0.10	± 0.120*	-0.17	± 0.125*	-0.27	± 0.150*
uncertain about things	-	-	0.53	± 0.177*	-	-

Table 4. Comparative results from the POMS2 questionnaires reporting mean difference pre- and post-exposure and pooled standard error of the mean (±SEM) for items with significant (p<0.05) and highly significant (*p<0.005) differences between the groups exposed to 73 Hz and 110 Hz combined and separately.

	MDMQ					
	Combined – 73 Hz		Combined – 110 Hz		73 Hz – 110 Hz	
Items	Mean Difference Pre – Post	Pooled ± SEM Pre – Post	Mean Difference Pre – Post	Pooled ± SEM Pre – Post	Mean Difference Pre – Post	Pooled ± SEM Pre – Post
worn out	-	-	0.34	± 0.267*	-	-
great	0.26	± 0.187*	0.13	± 0.216	-0.13	± 0.197
relaxed	0.30	± 0.218*	-	-	-	-
highly activated	-	-	0.33	± 0.276*	-	-
superb	0.24	± 0.241*	-	-	-0.30	± 0.203*
tense	0.13	± 0.226	-	-	-	-
happy	-	-	0.3	± 0.206*	-	-
nervous	-0.63	± 0.193*	-0.44	± 0.214*	0.19	± 0.177*
calm	0.16	± 0.185*	-	-	-	-
wonderful	0.44	± 0.229*	-	-	-	-
deeply relaxed	0.75	± 0.237*	-	-	-	-
sleepy	-	-	-0.59	± 0.329*	-	-

Table 5. Comparative results from the MDMQ questionnaires reporting mean difference pre- and post-exposure and pooled standard error of the mean (±SEM) for items with significant ($p<0.05$) and highly significant ($*p<0.005$) differences between the groups exposed to 73 Hz and 110 Hz sound stimuli combined and separately.

4. DISCUSSION

The present study examined the effects of spatial sound projections of two different singing bowls with fundamental frequencies at 73 Hz and 110 Hz on the emotional wellbeing of participants. The study supports to further demonstrate ANS activation in response to sound as observed in previous studies, e.g. see [149, 152, 157]. Overall, we find that after exposure to both stimuli, stress and negative moods decrease significantly, while feelings of emotional wellbeing and relaxation increase significantly. The reported positive psychological effects are in line with the findings of other studies. For example, Goldsby et al. [123] reported significant effects on decreasing tension, anger, fatigue and depressed mood ($p<0.001$ for all listed emotions) and an increasing feelings of wellbeing after treatment with singing bowls in all healthy subjects. A study by Walter and Hinterberger [158] on the neurophysiological effects of a singing bowl massage reported positive effects on the participants' emotional state after the treatment, in particular 82.4% of the participants felt calmer, 79.4% happier, 88.2% more satisfied, 82.4% more confident and 88.2% more connected. Trivedi & Saboo [128] reported that 20-minute sessions with singing bowls provided greater depth of relaxation than supine silence (SS) in participants, indicated by a significant decrease in the stress index and an increase in HRV. Both stimuli used in the present study induce a reduction in anxiety levels, findings also observed in a study which found that treatment based on Tibetian singing bowl (TSB) induces significant reductions in anxiety and psychological and physiological relaxation in a non-clinical anxious adult population [159].

We find that the results for the groups combined show predominantly a highly significant increase in moods associated with positive valence, compared to the results of both groups separately. Participants felt more trusting, more rested, more fresh, greater, more relaxed, more highly activated, more happy, more calm, more wonderful and more deeply relaxed, as depicted in Fig 14. The visual representation of emotions along the valence–arousal axes like Fig. 14 follows the model of emotions in two-dimensional circumplex space and provides a better understanding of emotion recognition. The set of emotions is displayed on a 2D plane as a point that has two coordinates i.e. valence and arousal [160]. These findings suggest that a general increase in positive valence is attributed to the effect of immersion in singing bowl sounds, rather than being a discrete effect of the frequencies that were monitored in this study.

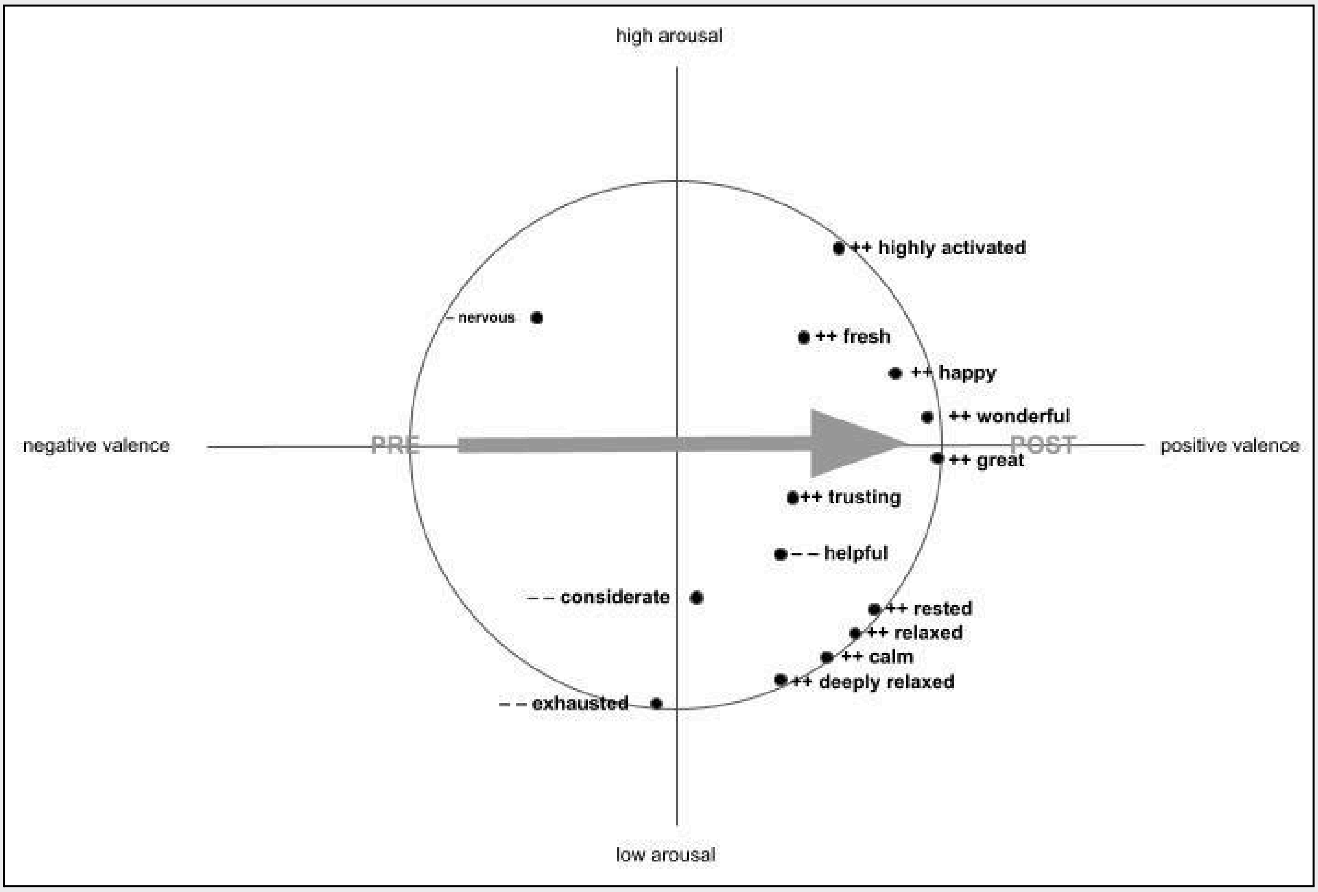


Fig 14. 2D plane showing items with significant decrease (–), highly significant decrease (––) and highly significant increase (++) post-exposure for the groups combined compared to the groups post-exposure to 73 Hz and 110 Hz separately.

Other significant differences in the emotional response of participants can be observed in comparing the results obtained for the groups separately. The frequency of 73 Hz was chosen based on its importance in auriculotherapy, while no rigorous scientific studies have previously investigated its effects on emotional health and physiological mechanisms in humans. The results from the present study show, for the first time, that exposure to 73 Hz primarily elicits a significant decrease in moods associated with negative valence compared to the results of both groups combined.

The results further suggest that the frequency of 73 Hz elicits higher arousal in participants, an effect that was not observed for 110 Hz. In response to 73 Hz, participants felt particularly less bad, less worn out, and less exhausted, while at the same time they felt much more wide awake, as depicted in Fig 15. These findings resonate with previous findings of Dr. Paul Nogier, who postulated that the frequency of 73 Hz acts positively on subcortical areas, specifically on the hypothalamus, resulting in similar emotional reactions [130].

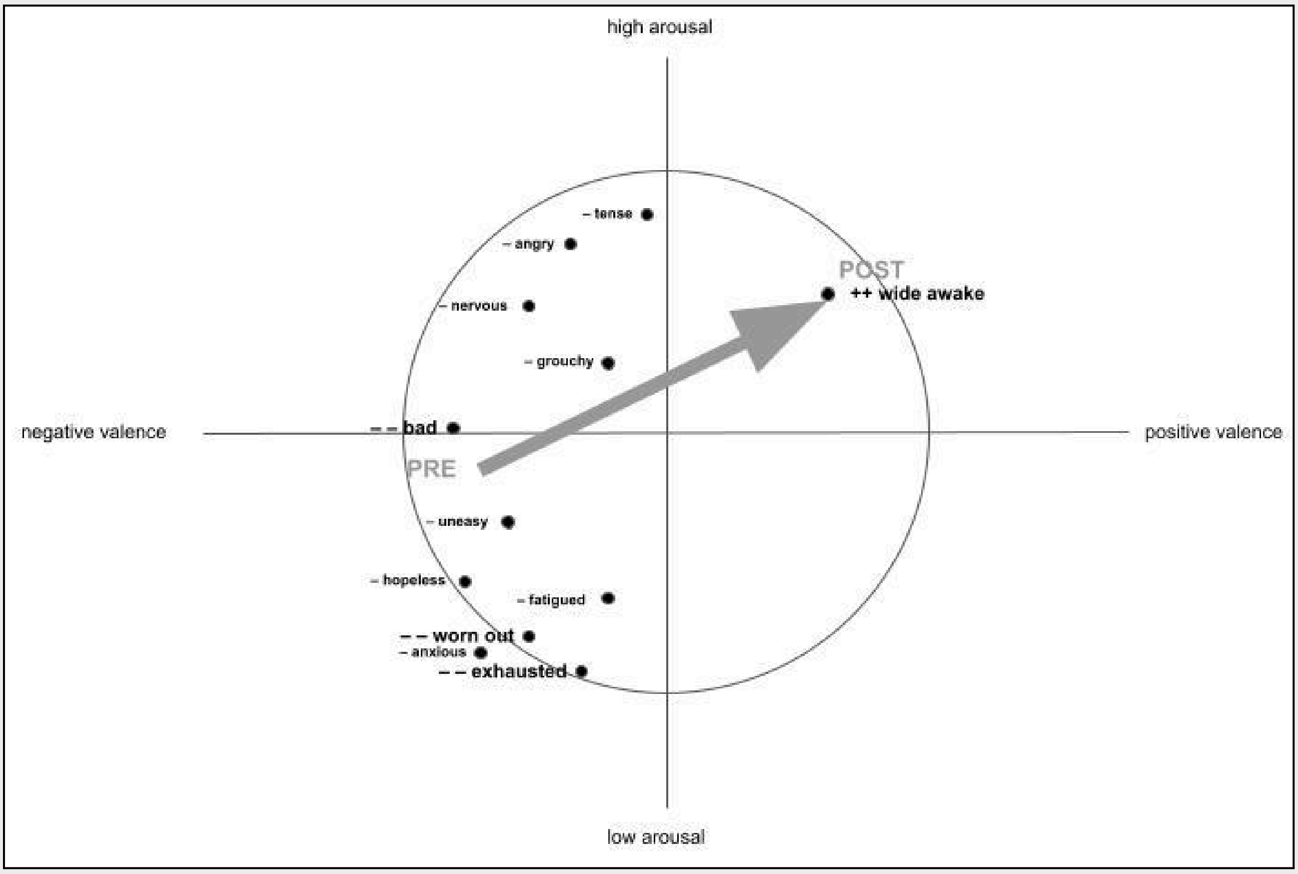


Fig 15. 2D plane showing items with significant decrease (–), highly significant decrease (––) and highly significant increase (++) for the group post-exposure to 73 Hz compared to the group post-exposure to 110 Hz and the groups combined.

We find that the results for the group exposed to 110 Hz show a significant decrease in moods associated with negative valence, compared to the results of both groups combined. A similar effect was observed for the group exposed to 73 Hz, although with significance for predominantly different items. Participants exposed to the frequency of 110 Hz felt particularly less sad, less uncertain about things and less unable to concentrate, while at the same time feeling more superb and more great, as depicted in Fig 16. These results are in line with the POMS2 results observed by Goldsby et al. [123] which show a significant reduction in post-treatment tense in participants in response to singing bowl sound, indicating the decrease of negative emotions with higher arousal.

Interestingly, participants monitored in the present study also felt particularly more sleepy after exposure to 110 Hz. This finding is contrary to the results of a recent study on the effects on sleepiness of subjects lying in a hammock over a singing bowl before and after being hit seven times, which reported significantly lower sleepiness after relaxation with the singing bowl [161]. We conclude that the increase of sleepiness is not discretely associated with the sound of singing bowls, and thus it is suggested that the frequency of 110 Hz may specifically elicit an effect of sleepiness, associated with a shift towards lower arousal.

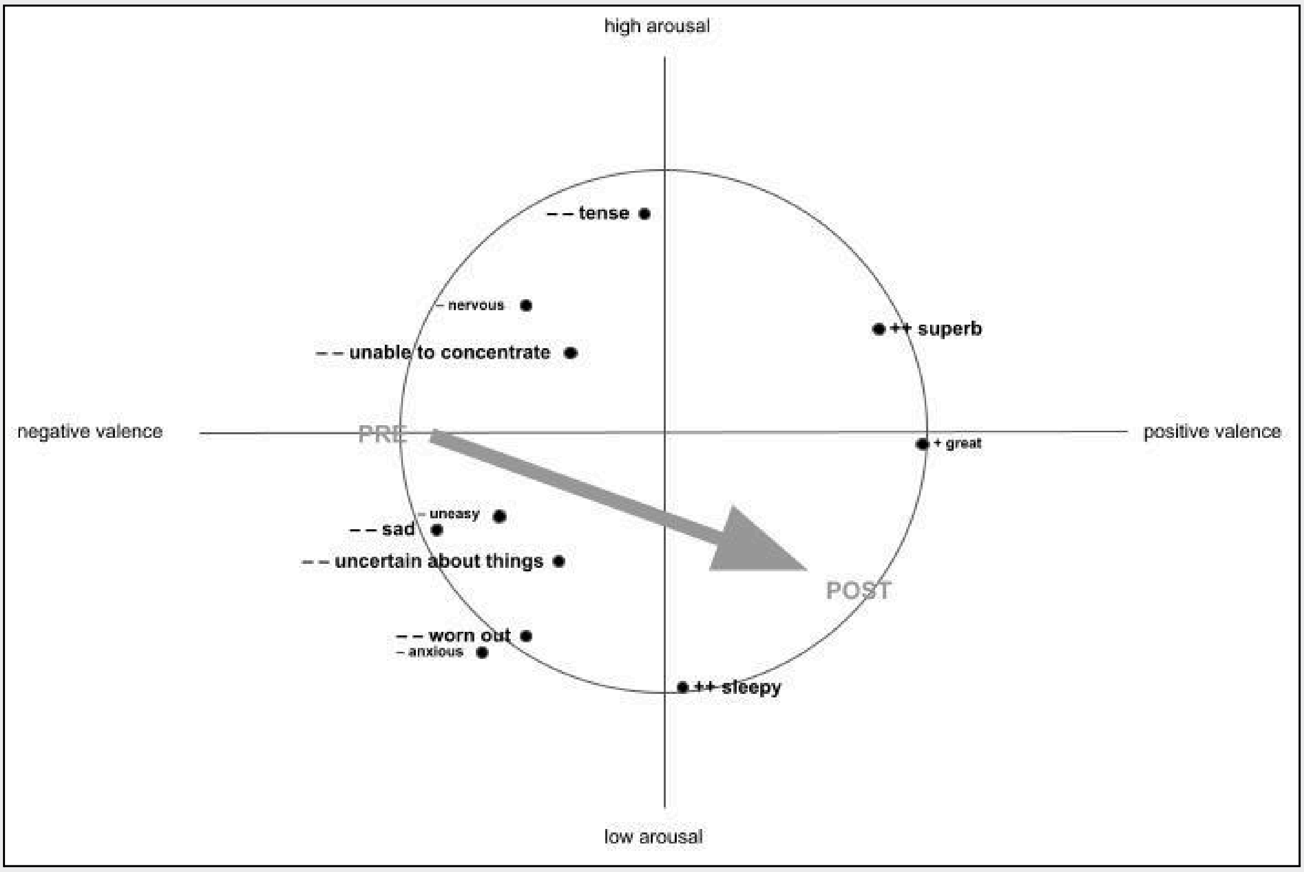


Fig 16. 2D plane showing items with significant decrease (—), highly significant decrease (——), significant increase (+) and highly significant increase (++) for the group post-exposure to 110 Hz compared to the group post-exposure to 73 Hz and both groups combined.

In general, the findings of the present study indicate that psychological wellbeing can be restored and improved through sound intervention, even only after 5 minutes of exposure [107]. These findings validate that sound intervention using singing bowls, as already observed in several other studies, is an effective and non-invasive method to relieve emotional states such as anxiety [159], tension and sadness and to restore emotional wellbeing [125–126]. This corroborates with further scientific evidence demonstrating the effectiveness of alternative, non-invasive and non-pharmacological methods to restore and maintain emotional wellbeing and improve homeostasis. Low-frequency sound treatments have been shown to induce several beneficial effects. These treatments include vibroacoustic therapy (VAT), a method that uses low-frequency sinusoidal sound vibrations between 20 and 120 Hz with the support, in some cases, of listening to music. VAT has been shown to induce several beneficial effects in individuals, including a reduction in anxiety and stress [162–163], as well as positive effects on physiological functions in both healthy and unhealthy subjects, including normalisation of blood pressure, reduction in muscle stiffness and heart rate [164–165]. Similarly, music therapy and sound therapy interventions also promote states of wellbeing and related physiological responses, especially in numerous neuro-degenerative conditions and diseases [112–119, 166–167]. The abundant evidence supporting the positive outcomes of music therapy in particular has meant that these interventions are incorporated into clinical care settings. Meditation, in all its forms, has also been shown to be an alternative effective method in inducing relaxation responses, helping to alleviate anxiety and improve wellbeing [115], triggering numerous mechanisms such as activation of the limbic system and ANS, and modulation of the secretion of neurotransmitters, hormones and cytokines in the body, as documented in the literature review paper by Jindal et al. [168].

We find that the emotional responses after sound immersion indicate an overall improvement of emotional wellbeing, predominantly expressed as an increase in positive emotions. This further demonstrates the efficacy of spatial sound technologies and singing bowl sounds as active components of sound intervention, and the need for further research on their effects on human physiology and homeostasis.

On the other hand, a reduction in negative emotions was found to be associated with the effect of the frequencies 73 Hz and 110 Hz. In particular, it was shown that the participants felt significantly less nervous, less anxious and less uneasy, and highly significantly less worn out and less tense after exposure to both these frequencies. The present study further demonstrates that the difference in frequency impacts different psycho-physiological effects in participants. We find that 73 Hz elicits a shift of emotions towards positive valence with higher arousal, as participants felt profoundly more wide awake after exposure to this frequency. Unlike 73 Hz, exposure to 110 Hz elicits a shift of emotions towards positive valence with lower arousal. Participants reported that after exposure to this frequency, they felt profoundly more superb and more sleepy.

In conclusion, sound interventions have great potential for the restoration and maintenance of emotional wellbeing and homeostasis. Specific differences in the effects are observed with different frequencies, where 73 Hz elicits feeling more wide awake while 110 Hz elicits sleepiness, indications that may be further investigated and verified in future studies. These findings underline the need for further research into the effects of specific frequencies on human psychology and physiology to further understand their underlying mechanisms, which we assume to be suitable for treatment of associated conditions and diseases.

REFERENCES

[1] R. G. Jahn, P. Devereux, and M. Ibison, "Acoustical resonances of assorted ancient structures," The Journal of the Acoustical Society of America, vol. 99, no. 2, pp. 649-658, 1996.

[2] I. A. Cook, S. K. Pajot, and A. F. Leuchter, "Ancient Architectural Acoustic Resonance Patterns and Regional Brain Activity," Time and Mind, vol. 1, no. 1, pp. 95-104, 2013.

[3] J. M. Gaona, N. Rouleau, J. M. Caswell, L. W. E. Tessaro, R. C. Burke, and D. S. Schumacher, "Archaeoacoustic Investigation of a Prehistoric Cave Site: Frequency-Dependent Sound Amplification and Potential Relevance for Neurotheology," NeuroQuantology, vol. 12, no. 4, 2014.

[4] P. Debertolis, F. Coimbra, and L. Eneix, "Archaeoacoustic Analysis of the Hal Saflieni Hypogeum in Malta," Journal of Anthropology and Archaeology, vol. 3, no. 1, 2015.

[5] S. Gu, F. Wang, N. P. Patel, J. A. Bourgeois, and J. H. Huang, "A Model for Basic Emotions Using Observations of Behavior in Drosophila," Frontiers in Psychology, vol. 10, 2019.

[6] M. Kowalska and M. Wróbel, "Basic Emotions," in Encyclopedia of Personality and Individual Differences, V. Zeigler-Hill and T. K. Shackelford Eds., 2017, ch. Chapter 495-1, pp. 1-6.

[7] J. A. Russell, "A circumplex model of affect," Journal of Personality and Social Psychology, vol. 39, no. 6, pp. 1161-1178, 1980.

[8] D. Watson and A. Tellegen, "Toward a consensual structure of mood," Psychological Bulletin, vol. 98, no. 2, pp. 219-235, 1985.

[9] I. B. Mauss and M. D. Robinson, "Measures of emotion: A review," Cognition & Emotion, vol. 23, no. 2, pp. 209-237, 2009.

[10] W. Sato, K. Murata, Y. Uraoka, K. Shibata, S. Yoshikawa, and M. Furuta, "Emotional valence sensing using a wearable facial EMG device," Scientific Reports, vol. 11, no. 1, 2021.

[11] L. R. F. Branco, A. Ehteshami, H. F. Azgomi, and R. T. Faghih, "Closed-Loop Tracking and Regulation of Emotional Valence State From Facial Electromyogram Measurements," Frontiers in Computational Neuroscience, vol. 16, 2022.

[12] C. M. Laine, K. M. Spitler, C. P. Mosher, and K. M. Gothard, "Behavioral Triggers of Skin Conductance Responses and Their Neural Correlates in the Primate Amygdala," Journal of Neurophysiology, vol. 101, no. 4, pp. 1749-1754, 2009.

[13] P. Juslin and J. Sloboda, "Psychological perspectives on music & emotion," in Music and Emotion: Theory and Research, P. N. Juslin & J. A. Sloboda Eds., 2001. pp. 71–104. Oxford University Press.

[14] G. Šimić, M. Tkalčić, V. Vukić, D. Mulc, E. Španić, M. Šagud, FE. Olucha-Bordonau, M. Vukšić and P. R Hof, "Understanding Emotions: Origins and Roles of the Amygdala," Biomolecules, vol. 11, no. 6, 2021.

[15] R. Plutchik, The psychology and biology of emotion. HarperCollins College Publishers, 1994.

[16] I. B. Mauss, R. W. Levenson, L. McCarter, F. H. Wilhelm, and J. J. Gross, "The Tie That Binds? Coherence Among Emotion Experience, Behavior, and Physiology," Emotion, vol. 5, no. 2, pp. 175-190, 2005.

[17] L.-O. Lundqvist, F. Carlsson, P. Hilmersson, and P. N. Juslin, "Emotional responses to music: experience, expression, and physiology," Psychology of Music, vol. 37, no. 1, pp. 61-90, 2008.

[18] A. J. Blood and R. J. Zatorre, "Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion," Proceedings of the National Academy of Sciences, vol. 98, no. 20, pp. 11818-11823, 2001.

[19] W. James, "Ii.—What Is an Emotion?," Mind, vol. os-IX, no. 34, pp. 188-205, 1884.

[20] W. B. Cannon, "The James-Lange Theory of Emotions: A Critical Examination and an Alternative Theory," The American Journal of Psychology, vol. 39, no. 1/4, 1927.

[21] A. R. Damasio, "Emotions and Feelings," in Feelings and Emotions: The Amsterdam Symposium, A. S. R. Manstead, N. Frijda, and A. Fischer Eds., ch. 4, pp. 49-57, 2004.

[22] R. W. Levenson, "Blood, Sweat, and Fears," Annals of the New York Academy of Sciences, vol. 1000, no. 1, pp. 348-366, 2006.

[23] R. W. Levenson, "The Autonomic Nervous System and Emotion," Emotion Review, vol. 6, no. 2, pp. 100-112, 2014.

[24] J. A. Waxenbaum, V. Reddy, and M. Varacallo, Anatomy, autonomic nervous system. Tampa, FL: StatPearls Publishing, 2022.

[25] P. Brodal, The central nervous system: Structure and function 4th ed. Oxford: Oxford University Press, 2010.

[26] C. D. Ryff and B. Singer, "The Contours of Positive Human Health," Psychological Inquiry, vol. 9, no. 1, pp. 1–28, 2009.

[27] P. Salovey, A. J. Rothman, J. B. Detweiler, and W. T. Steward, "Emotional states and physical health," American Psychologist, vol. 55, no. 1, pp. 110–121, 2000.

[28] B. Tarr, J. Launay, and R. I. M. Dunbar, "Music and social bonding: “self-other” merging and neurohormonal mechanisms," (in English), Frontiers in Psychology, Hypothesis and Theory vol. 5, 2014-September-30 2014.

[29] B. L. Fredrickson, "Cultivating positive emotions to optimize health and well-being," Prevention & Treatment, vol. 3, no. 1, 2000.

[30] B. L. Fredrickson, "What Good Are Positive Emotions?," Review of General Psychology, vol. 2, no. 3, pp. 300–319, 1998.

[31] H. J. Bowen, S. M. Kark, and E. A. Kensinger, "NEVER forget: negative emotional valence enhances recapitulation," Psychonomic Bulletin & Review, vol. 25, no. 3, pp. 870-891, 2017.

[32] B. Q. Ford, P. Lam, O. P. John, and I. B. Mauss, "The psychological health benefits of accepting negative emotions and thoughts: Laboratory, diary, and longitudinal evidence," Journal of Personality and Social Psychology, vol. 115, no. 6, pp. 1075-1092, 2018.

[33] A. J. Shallcross, A. S. Troy, M. Boland, and I. B. Mauss, "Let it be: Accepting negative emotional experiences predicts decreased negative affect and depressive symptoms," Behaviour Research and Therapy, vol. 48, no. 9, pp. 921-929, 2010.

[34] J. Patel, P. Patel, and W. Xu, "Consequences of Repression of Emotion: Physical Health, Mental Health and General Well Being," International Journal of Psychotherapy Practice and Research, vol. 1, no. 3, pp. 16-21, 2019.

[35] B. P. Chapman, K. Fiscella, I. Kawachi, P. Duberstein, and P. Muennig, "Emotion suppression and mortality risk over a 12-year follow-up," Journal of Psychosomatic Research, vol. 75, no. 4, pp. 381-385, 2013.

[36] M. Mund and K. Mitte, "The costs of repression: A meta-analysis on the relation between repressive coping and somatic diseases," Health Psychology, vol. 31, no. 5, pp. 640-649, 2012.

[37] S. Koelsch, "Towards a neural basis of music-evoked emotions," Trends in Cognitive Sciences, vol. 14, no. 3, pp. 131-137, 2010.

[38] S. Koelsch, "Brain correlates of music-evoked emotions," Nature Reviews Neuroscience, vol. 15, no. 3, pp. 170-180, 2014.

[39] S. Koelsch, "Investigating the Neural Encoding of Emotion with Music," Neuron, vol. 98, no. 6, pp. 1075-1079, 2018.

[40] V. Rajmohan and E. Mohandas, "The limbic system," Indian Journal of Psychiatry, vol. 49, no. 2, 2007.

[41] R. J. Zatorre and V. N. Salimpoor, "From perception to pleasure: Music and its neural substrates," Proceedings of the National Academy of Sciences, vol. 110, no. supplement_2, pp. 10430-10437, 2013.

[42] D. Mansens, D. J. H. Deeg, and H. C. Comijs, "The association between singing and/or playing a musical instrument and cognitive functions in older adults," Aging & Mental Health, vol. 22, no. 8, pp. 970-977, 2017.

[43] S. I. Kim, "Neuroscientific Model of Motivational Process," Frontiers in Psychology, vol. 4, 2013.

[44] A. C. Gore, "Chapter 38 - Neuroendocrine Systems," in Fundamental Neuroscience, L. R. Squire, D. Berg, F. E. Bloom, S. d. Lac, A. Ghosh, and N. C. Spitzer Eds.: Academic Press, pp. 799-817, 2013.

[45] J. E. LeDoux, "Emotion Circuits in the Brain," Annual Review of Neuroscience, vol. 23, no. 1, pp. 155-184, 2000.

[46] J. Panksepp, Affective neuroscience: The foundations of human and animal emotions, New York, NY, US: Oxford University Press, pp. xii, 466-xii, 466, 1998.

[47] L. Pessoa, "A Network Model of the Emotional Brain," (in eng), Trends in Cognitive Sciences, vol. 21, no. 5, pp. 357-371, May 2017.

[48] L. Pessoa, "Understanding emotion with brain networks," (in eng), Current Opinion in Behavioral Sciences, vol. 19, pp. 19-25, Feb 2018.

[49] L. Pessoa, L. Medina, P. R. Hof, and E. Desfilis, "Neural architecture of the vertebrate brain: implications for the interaction between emotion and cognition," Neuroscience & Biobehavioral Reviews, vol. 107, pp. 296-312, 2019/12/01/ 2019.

[50] P. Nuss, "Anxiety disorders and GABA neurotransmission: a disturbance of modulation," (in eng), Neuropsychiatric Disease and Treatment, vol. 11, pp. 165-75, 2015.

[51] J. G. Partridge et al., "Stress increases GABAergic neurotransmission in CRF neurons of the central amygdala and bed nucleus stria terminalis," (in eng), Neuropharmacology, vol. 107, pp. 239-250, Aug 2016.

[52] E. M. Prager, H. C. Bergstrom, G. H. Wynn, and M. F. Braga, "The basolateral amygdala γ-aminobutyric acidergic system in health and disease," (in eng), Journal of Neuroscience Research, vol. 94, no. 6, pp. 548-67, June 2016.

[53] A. Bartels and S. Zeki, "The neural basis of romantic love," (in eng), NeuroReport, vol. 11, no. 17, pp. 3829-34, Nov 27 2000.

[54] C. M. Schumann, M. D. Bauman, and D. G. Amaral, "Abnormal structure or function of the amygdala is a common component of neurodevelopmental disorders," (in eng), Neuropsychologia, vol. 49, no. 4, pp. 745-59, Mar 2011.

[55] V. N. Nikolenko et al., "Amygdala: Neuroanatomical and Morphophysiological Features in Terms of Neurological and Neurodegenerative Diseases," Brain Sciences, vol. 10, no. 8, 2020.

[56] B. S. Peterson et al., "Morphologic Features of the Amygdala and Hippocampus in Children and Adults With Tourette Syndrome," Archives of General Psychiatry, vol. 64, no. 11, 2007.

[57] X. N. Zuo et al., "Surface Morphology of Amygdala Is Associated with Trait Anxiety," PLoS ONE, vol. 7, no. 10, 2012.

[58] M. Beauregard et al., "The functional neuroanatomy of major depression," NeuroReport, vol. 9, no. 14, pp. 3253-3258, 1998.

[59] E. M. Reiman et al., "Neuroanatomical correlates of externally and internally generated human emotion," American Journal of Psychiatry, vol. 154, no. 7, pp. 918-925, 1997.

[60] R. J. Davidson and W. Irwin, "The functional neuroanatomy of emotion and affective style," Trends in Cognitive Sciences, vol. 3, no. 1, pp. 11-21, 1999.

[61] J. A. Sheng et al., "The Hypothalamic-Pituitary-Adrenal Axis: Development, Programming Actions of Hormones, and Maternal-Fetal Interactions," (in eng), Frontiers in behavioral neuroscience, vol. 14, p. 601939, 2020.

[62] S. M. Smith and W. W. Vale, "The role of the hypothalamic-pituitary-adrenal axis in neuroendocrine responses to stress," Dialogues in Clinical Neuroscience, vol. 8, no. 4, pp. 383-395, 2022.

[63] C. Tsigos and G. P. Chrousos, "Hypothalamic–pituitary–adrenal axis, neuroendocrine factors and stress," Journal of Psychosomatic Research, vol. 53, no. 4, pp. 865-871, 2002.

[64][1] N. Ali and U. M. Nater, "Salivary Alpha-Amylase as a Biomarker of Stress in Behavioral Medicine," International Journal of Behavioral Medicine, vol. 27, no. 3, pp. 337-342, 2020.

[65] B. L. Fredrickson, K. E. Maynard, M. J. Helms, T. L. Haney, I. C. Siegler, and J. C. Barefoot, "Hostility predicts magnitude and duration of blood pressure response to anger," Journal of Behavioral Medicine, vol. 23, no. 3, pp. 229-243, 2000.

[66] S. Koelsch, A. Boehlig, M. Hohenadel, I. Nitsche, K. Bauer, and U. Sack, "The impact of acute stress on hormones and cytokines and how their recovery is affected by music-evoked positive mood," Scientific Reports, vol. 6, no. 1, 2016.

[67] F. D'Hondt et al., "Early brain-body impact of emotional arousal," (in English), Frontiers in Human Neuroscience, Original Research vol. 4, 2010-April-19 2010.

[68] M. Y. Balban et al., "Brief structured respiration practices enhance mood and reduce physiological arousal," Cell Reports Medicine, vol. 4, no. 1, 2023.

[69] M. J. Lucht et al., "Associations between the oxytocin receptor gene (OXTR) and affect, loneliness and intelligence in normal subjects," Progress in Neuro-Psychopharmacology and Biological Psychiatry, vol. 33, no. 5, pp. 860-866, 2009.

[70] K. Uvnäs-Moberg, "Antistress Pattern Induced by Oxytocin," Physiology, vol. 13, no. 1, pp. 22-25, 1998.

[71] K. Uvnäs-Moberg and M. Petersson, "Oxytocin, ein Vermittler von Antistress, Wohlbefinden, sozialer Interaktion, Wachstum und Heilung/ Oxytocin, a mediator of anti-stress, well-being, social interaction, growth and healing," Zeitschrift für Psychosomatische Medizin und Psychotherapie, vol. 51, no. 1, pp. 57-80, 2005.

[72] V. Morhenn, L. E. Beavin, and P. J. Zak, "Massage increases oxytocin and reduces adrenocorticotropin hormone in humans," (in eng), Altern Ther Health Med, vol. 18, no. 6, pp. 11-8, Nov-Dec 2012.

[73] A. H. Veenema and I. D. Neumann, "Central vasopressin and oxytocin release: regulation of complex social behaviours," (in eng), Prog Brain Res, vol. 170, pp. 261-76, 2008.

[74] D. Viviani and R. Stoop, "Opposite effects of oxytocin and vasopressin on the emotional expression of the fear response," (in eng), Prog Brain Res, vol. 170, pp. 207-18, 2008.

[75] A. Drigas and E. Mitsea, "Metacognition, Stress – Relaxation Balance & Related Hormones," International Journal of Recent Contributions from Engineering, Science & IT (iJES), vol. 9, no. 1, pp. 4–16, 2021.

[76] L. D. Ochoa-de la Paz, R. Gulias-Cañizo, E. D´Abril Ruíz-Leyja, H. Sánchez-Castillo, and J. Parodí, "The role of GABA neurotransmitter in the human central nervous system, physiology, and pathophysiology," Revista Mexicana de Neurociencia, vol. 22, no. 2, pp. 67–76, 2021.

[77] S. Kim, K. Jo, K.-B. Hong, S. H. Han, and H. J. Suh, "GABA and l-theanine mixture decreases sleep latency and improves NREM sleep," Pharmaceutical Biology, vol. 57, no. 1, pp. 64-72, 2019.

[78] O. Stiedl, E. Pappa, Å. Konradsson-Geuken, and S. O. Ögren, "The role of the serotonin receptor subtypes 5-HT1A and 5-HT7 and its interaction in emotional learning and memory," (in eng), Front Pharmacol, vol. 6, pp. 1–17, 2015.

[79] M. Berger, J. A. Gray, and B. L. Roth, "The Expanded Biology of Serotonin," Annual Review of Medicine, vol. 60, no. 1, pp. 355-366, 2009.

[80] K. Dzirasa et al., "Dopaminergic Control of Sleep–Wake States," The Journal of Neuroscience, vol. 26, no. 41, pp. 10577-10589, 2006.

[81] G. Ayano, "Dopamine: Receptors, Functions, Synthesis, Pathways, Locations and Mental Disorders: Review of Literatures," Journal of Mental Disorders and Treatment, vol. 2, no. 2, 2016.

[82] A. C. Hartwig, "Peripheral beta-endorphin and pain modulation," (in eng), Anesthesia Progress, vol. 38, no. 3, pp. 75-78, May-June 1991.

[83] A. Pilozzi, C. Carro, and X. Huang, "Roles of β-Endorphin in Stress, Behavior, Neuroinflammation, and Brain Energy Metabolism," International Journal of Molecular Sciences, vol. 22, no. 1, 2020.

[84] S. C. Segerstrom, "Personality and the immune system: Models, methods, and mechanisms," Annals of Behavioral Medicine, vol. 22, no. 3, pp. 180-190, 2000.

[85] M. G. Gurok, S. Yılmaz, A. Temizkan, B. Ustundag, and M. Atmaca, "Levels of basophils and eosinophils are elevated while lymphocytes are reduced in patients with panic disorder compared to controls: a preliminary study," Psychiatry and Clinical Psychopharmacology, vol. 29, no. 3, pp. 315-319, 2018.

[86] R. Gaspersz et al., "The role of anxious distress in immune dysregulation in patients with major depressive disorder," Translational Psychiatry, vol. 7, no. 12, 2017.

[87] F. D'Acquisto, J. Masih, F. Belschak, and J. M. I. W. Verbeke, "Mood configurations and their relationship to immune system responses: Exploring the relationship between moods, immune system responses, thyroid hormones, and social support," Plos One, vol. 14, no. 5, pp. 1–15, 2019.

[88] M. Reybrouck, P. Podlipniak, and D. Welch, "Music Listening and Homeostatic Regulation: Surviving and Flourishing in a Sonic World," International Journal of Environmental Research and Public Health, vol. 19, no. 1, 2021.

[89] P. J. Rentfrow and S. D. Gosling, "The do re mi's of everyday life: The structure and personality correlates of music preferences," Journal of Personality and Social Psychology, vol. 84, no. 6, pp. 1236-1256, 2003.

[90] H.-A. Arjmand, J. Hohagen, B. Paton, and N. S. Rickard, "Emotional Responses to Music: Shifts in Frontal Brain Asymmetry Mark Periods of Musical Change," Frontiers in Psychology, vol. 8, pp. 1–13, 2017.

[91] A. Fernández-Sotos, A. Fernández-Caballero, and J. M. Latorre, "Influence of Tempo and Rhythmic Unit in Musical Emotion Regulation," Frontiers in Computational Neuroscience, vol. 10, pp. 1–13, 2016.

[92] M. D. van der Zwaag, J. H. D. M. Westerink, and E. L. van den Broek, "Emotional and psychophysiological responses to tempo, mode, and percussiveness," Musicae Scientiae, vol. 15, no. 2, pp. 250-269, 2011.

[93] P. N. Juslin and D. Västfjäll, "Emotional responses to music: The need to consider underlying mechanisms," Behavioral and Brain Sciences, vol. 31, no. 5, pp. 559-575, 2008.

[94] E. Asutay, D. Västfjäll, A. Tajadura-Jiménez, A. Genell, P. Bergman, and M. Kleiner, "Emoacoustics: A Study of the Psychoacoustical and Psychological Dimensions of Emotional Sound Design," Journal of the Audio Engineering Society, vol. 60, 21–28, 2012.

[95] N. S. Rickard, "Intense emotional responses to music: a test of the physiological arousal hypothesis," Psychology of Music, vol. 32, no. 4, pp. 371-388, 2016.

[96] O. Grewe, "How Does Music Arouse "Chills"? Investigating Strong Emotions, Combining Psychological, Physiological, and Psychoacoustical Methods," Annals of the New York Academy of Sciences, vol. 1060, no. 1, pp. 446-449, 2005.

[97] O. Grewe, R. Kopiez, and E. Altenmüller, "Chills As an Indicator of Individual Emotional Peaks," Annals of the New York Academy of Sciences, vol. 1169, no. 1, pp. 351-354, 2009.

[98] J. A. Etzel, E. L. Johnsen, J. Dickerson, D. Tranel, and R. Adolphs, "Cardiovascular and respiratory responses during musical mood induction," International Journal of Psychophysiology, vol. 61, no. 1, pp. 57-69, 2006.

[99] S. Khalfa, M. Roy, P. Rainville, S. Dalla Bella, and I. Peretz, "Role of tempo entrainment in psychophysiological differentiation of happy and sad music?," International Journal of Psychophysiology, vol. 68, no. 1, pp. 17-26, 2008.

[100] J. Lauwereyns, V. N. Salimpoor, M. Benovoy, G. Longo, J. R. Cooperstock, and R. J. Zatorre, "The Rewarding Aspects of Music Listening Are Related to Degree of Emotional Arousal," PLoS ONE, vol. 4, no. 10, 2009.

[101] J. Burns, E. Labbe, K. Williams, and J. McCall, "Perceived and Physiological Indicators of Relaxation: As Different as Mozart and Alice in Chains," Applied Psychophysiology and Biofeedback, vol. 24, no. 3, pp. 197-202, 1999.

[102] U. M. Nater, E. Abbruzzese, M. Krebs, and U. Ehlert, "Sex differences in emotional and psychophysiological responses to musical stimuli," International Journal of Psychophysiology, vol. 62, no. 2, pp. 300-308, 2006.

[103] S. Khalfa, S. D. Bella, M. Roy, I. Peretz, and S. J. Lupien, "Effects of Relaxing Music on Salivary Cortisol Level after Psychological Stress," Annals of the New York Academy of Sciences, vol. 999, no. 1, pp. 374-376, 2003.

[104] S. Koelsch, T. Fritz, D. Y. v. Cramon, K. Müller, and A. D. Friederici, "Investigating emotion with music: An fMRI study," Human Brain Mapping, vol. 27, no. 3, pp. 239-250, 2006.

[105] M. Boso, P. Politi, F. Barale, and E. Enzo, "Neurophysiology and neurobiology of the musical experience," (in eng), Functional Neurology, vol. 21, no. 4, pp. 187-91, Oct-Dec 2006.

[106] J. Hou et al., "Review on Neural Correlates of Emotion Regulation and Music: Implications for Emotion Dysregulation," Frontiers in Psychology, vol. 8, pp. 1–8, 2017.

[107] K. Akimoto, A. Hu, T. Yamaguchi, and H. Kobayashi, "Effect of 528 Hz Music on the Endocrine System and Autonomic Nervous System," Health, vol. 10, no. 09, pp. 1159-1170, 2018.

[108] U. M. Nater, Y. Ooishi, H. Mukai, K. Watanabe, S. Kawato, and M. Kashino, "Increase in salivary oxytocin and decrease in salivary cortisol after listening to relaxing slow-tempo and exciting fast-tempo music," Plos One, vol. 12, no. 12, pp. 1–16, 2017.

[109] W. Heinke et al., "Effects of Music Listening on Cortisol Levels and Propofol Consumption during Spinal Anesthesia," Frontiers in Psychology, vol. 2, pp. 1–9, 2011.

[110] M. Herdener et al., "Musical Training Induces Functional Plasticity in Human Hippocampus," The Journal of Neuroscience, vol. 30, no. 4, pp. 1377-1384, 2010.

[111] S. Hayasaka, S. Koelsch, S. Skouras, and G. Lohmann, "The auditory cortex hosts network nodes influential for emotion processing: An fMRI study on music-evoked fear and joy," Plos One, vol. 13, no. 1, pp. 1–22, 2018.

[112] A. M. Matziorinis and S. Koelsch, "The promise of music therapy for Alzheimer's disease: A review," Annals of the New York Academy of Sciences, vol. 1516, no. 1, pp. 11-17, 2022.

[113] M. Bleibel, A. El Cheikh, N. S. Sadier, and L. Abou-Abbas, "The effect of music therapy on cognitive functions in patients with Alzheimer's disease: a systematic review of randomized controlled trials," Alzheimer's Research & Therapy, vol. 15, no. 1, 2023.

[114] M. J. Machado Sotomayor, V. Arufe-Giráldez, G. Ruíz-Rico, and R. Navarro-Patón, "Music Therapy and Parkinson's Disease: A Systematic Review from 2015–2020," International Journal of Environmental Research and Public Health, vol. 18, no. 21, 2021.

[115] S. Torun, Q. Tang, Z. Huang, H. Zhou, and P. Ye, "Effects of music therapy on depression: A meta-analysis of randomized controlled trials," Plos One, vol. 15, no. 11, 2020.

[116] J. Fachner, C. Gold, and J. Erkkilä, "Music Therapy Modulates Fronto-Temporal Activity in Rest-EEG in Depressed Clients," Brain Topography, vol. 26, no. 2, pp. 338-354, 2012.

[117] J. Erkkilä, C. Gold, J. Fachner, E. Ala-Ruona, M. Punkanen, and M. Vanhala, "The effect of improvisational music therapy on the treatment of depression: protocol for a randomised controlled trial," BMC Psychiatry, vol. 8, no. 1, pp. 1–9, 2008.

[118] N. Landis-Shack, A. J. Heinz, and M. O. Bonn-Miller, "Music therapy for posttraumatic stress in adults: A theoretical review," Psychomusicology: Music, Mind, and Brain, vol. 27, no. 4, pp. 334-342, 2017.

[119] R. Haslam, A. Heiderscheit, and H. Himmerich, "A Systematic Review of Scientific Studies on the Effects of Music in People with Personality Disorders," International Journal of Environmental Research and Public Health, vol. 19, no. 23, 2022.

[120] D. Västfjäll, "Emotional Reactions to Sounds without Meaning," Psychology, vol. 03, no. 08, pp. 606-609, 2012.

[121] B. Berglund and T. Lindvall, Community noise. Archives of the Center for Sensory Research, 2. Stockholm: Stockholm University, 1995.

[122] M. Kumar, T. D. Abhayapala, and P. Samarasinghe, "A Preliminary Investigation on Frequency Dependent Cues for Human Emotions," Acoustics, vol. 4, no. 2, pp. 460-468, 2022.

[123] T. L. Goldsby, M. E. Goldsby, M. McWalters, and P. J. Mills, "Effects of Singing Bowl Sound Meditation on Mood, Tension, and Well-being: An Observational Study," Journal of Evidence-Based Complementary & Alternative Medicine, vol. 22, no. 3, pp. 401-406, 2016.

[124] C. Imbriani, "Le Tibetan Singing Bowls e l'intervento musicoterapeutico.", (in ita), Giornale Italiano di Medicina del Lavoro ed Ergonomia, vol. 39, no. 4, pp. 273-277, Dec 2017.

[125] L. Cooper, "Sound Affects Sound Therapy, Altered States of Consciousness and Improved Health and Wellbeing", https://www.soundtravels.co.uk . Accessed: Sep 05, 2023.

[126] S.-C. Kim and M.-J. Choi, "Does the Sound of a Singing Bowl Synchronize Meditational Brainwaves in the Listeners?," International Journal of Environmental Research and Public Health, vol. 20, no. 12, 2023.

[127] B. Sundharakumar, N. Bhalaji, K. Rema, R. Srinivasan, "Impact of Singing Bowl Playing on the Brain Using EEG," International Journal of Electrical Engineering and Technology, vol. 12, no. 9, pp. 55-66, 2021.

[128] G. Y. Trivedi, B. Saboo, and E. zico, "A Comparative Study of the Impact of Himalayan Singing Bowls and Supine Silence on Stress Index and Heart Rate Variability," Journal of Behavior Therapy and Mental Health, vol. 2, no. 1, pp. 40-50, 2019.

[129] L. Bidin, L. Pigaiani, M. Casini, P. Seghini, and L. Cavanna, "Feasibility of a trial with Tibetan Singing Bowls, and suggested benefits in metastatic cancer patients. A pilot study in an Italian Oncology Unit," European Journal of Integrative Medicine, vol. 8, no. 5, pp. 747-755, 2016.

[130] R. Nogier, "History of Auriculotherapy: Additional Information and New Developments," Medical Acupuncture, vol. 33, no. 6, pp. 410-419, 2021.

[131] R. Nogier, "How Did Paul Nogier Establish the Map of the Ear?," Medical Acupuncture, vol. 26, no. 2, pp. 76-83, 2014.

[132] T. Oleson, "Auriculotherapy stimulation for neuro-rehabilitation," NeuroRehabilitation, vol. 17, no. 1, pp. 49-62, 2002.

[133] A. Vieira, A. M. Reis, L. C. Matos, J. Machado, and A. Moreira, "Does auriculotherapy have therapeutic effectiveness? An overview of systematic reviews," Complementary Therapies in Clinical Practice, vol. 33, pp. 61-70, 2018.

[134] M. Valiani, F. Ashtari, and M. Mansourian, "The effect of auriculotherapy on stress, anxiety, and depression in ms patients: a double blind randomized clinical control trial (Parallel Design)," Acta Med Mediterran, vol. 34, pp. 561-567, 2018.

[135] H. P. Corrêa, C. d. C. Moura, C. Azevedo, M. F. V. G. Bernardes, L. R. F. P. d. Mata, and T. C. M. Chianca, "Efeitos da auriculoterapia sobre o estresse, ansiedade e depressão em adultos e idosos: revisão sistemática," Revista da Escola de Enfermagem da USP, vol. 54, pp. 1–11, 2020.

[136] O. L. Munhoz, B. X. Morais, W. M. D. Santos, C. C. Paula, and T. Magnago, "Effectiveness of auriculotherapy for anxiety, stress or burnout in health professionals: a network meta-analysis," (in eng, por, spa), Revista Latino-Americana de Enfermagem, vol. 30, p. e3708, 2022.

[137] A. Vieira et al., "The Effect of Auriculotherapy on Situational Anxiety Triggered by Examinations: A Randomized Pilot Trial," (in eng), Healthcare (Basel), vol. 10, no. 10, Sep 21 2022.

[138] P. Devereux, S. Krippner, R. Tartz, and A. Fish, "A Preliminary Study on English and Welsh Sacred Sites and Home Dream Reports", Anthropology of Consciousness, vol. 18, no. 2, pp. 2-28, 2007.

[139] D. R. Hill and K. S. Saroka, "Sonic Patterns, Spirituality and Brain Function: The Sound Component of Neurotheology", NeuroQuantology, vol. 8, no. 4, pp. 509–516, 2010.

[140] Y. Wang, M. Kumeta, D. Takahashi, K. Takeyasu, and S. H. Yoshimura, "Cell type-specific suppression of mechanosensitive genes by audible sound stimulation," Plos One, vol. 13, no. 1, 2018.

[141] K. Katoh, "Effects of Electrical Stimulation of the Cell: Wound Healing, Cell Proliferation, Apoptosis, and Signal Transduction," Medical Sciences, vol. 11, no. 1, pp. 1–13, 2023.

[142] C. F. Blackman, S. G. Benane, D. E. House, and W. T. Joines, "Effects of ELF (1–120 Hz) and modulated (50 Hz) RF fields on the efflux of calcium ions from brain tissue in vitro," Bioelectromagnetics, vol. 6, no. 1, pp. 1-11, 1985.

[143] J. Csicsvari, H. Hirase, A. Czurkó, A. Mamiya, and G. Buzsáki, "Fast Network Oscillations in the Hippocampal CA1 Region of the Behaving Rat," The Journal of Neuroscience, vol. 19, no. 16, pp. RC20-RC20, 1999.

[144] A. M. M. Oliveira and H. Bading, "Calcium signalling in cognition and ageing-dependent cognitive decline," BioFactors, vol. 37, no. 3, pp. 168-174, 2011.

[145] M. A. Persinger, "Religious and Mystical Experiences as Artefacts of Temporal Lobe Function: A General Hypothesis," Perceptual and Motor Skills, vol. 57, no. 3_suppl, pp. 1255-1262, 2016.

[146] M. A. Persinger, "Striking EEG Profiles from Single Episodes of Glossolalia and Transcendental Meditation," Perceptual and Motor Skills, vol. 58, no. 1, pp. 127-133, 2016.

[147] L. S. S. Pierre and M. A. Persinger, "Experimental Facilitation of the Sensed Presence Is Predicted by the Specific Patterns of the Applied Magnetic Fields, Not by Suggestibility: Re-Analyses of 19 Experiments," International Journal of Neuroscience, vol. 116, no. 19, pp. 1079-1096, 2009.

[148] K. Hori, M. Yamakawa, N. Tanaka, H. Murakami, M. Kaya, and S. Hori, "Influence of sound and light on heart rate variability," (in eng), Journal of Human Ergology (Tokyo), vol. 34, no. 1-2, pp. 25-34, Dec 2005.

[149] R. Geffen and C. Braun, "Effects of Geometric Sound on Brainwave Activity Patterns, Autonomic Nervous System Markers, Emotional Response, and Faraday Wave Pattern Morphology," Evidence-Based Complementary and Alternative Medicine, vol. 2024, pp. 1–20, Mar. 2024.

[150] P. Oomen, R. Geffen, "METHOD AND SYÍSTEM FOR IMPROVING A PHYSIOLOGICAL CONDITION OF A SUBJECT", WO/2022/039598, 2022.

[151] P. Oomen, R. Geffen and D. Gentile, "The Effects of Spatial Sound on Human Wellbeing", July 26, 2021.

[152] P. Oomen, R. Geffen, D. Gentile, N. Atassi, B. Farran, N. Fellas, C. Braun, V. Cuevas, L. Nadiradze, I Mgvdliashvili, M. Csanad and A. K. F. Val Baker. "Resonant Phenomena of Sound Waves and their Expression in Physiology", May 22, 2024.

[153] P. Oomen, "METHOD FOR GENERATING A REVERBERATION AUDIO SIGNAL," Patent WO/2022/045888, 2022.

[154] British Standard Institute, "ISO 354:2003(05-15), Acoustics– Measurement of Sound Absorption in a Reverberation Room," 2003.

[155] J. P. Heuchert and D. M. McNair, "Profile of Mood States 2nd Edition™ (POMS) [Database record]," APA PsycTests.

[156] R. Steyer, P. Schwenkmezger, P. Notz, and M. Eid, Testtheoretische Analysen des Mehrdimensionalen Befindlichkeitsfragebogen (MDBF). Göttingen: Hogrefe, 1994.

[157] P. Oomen, R. Geffen, D. Gentile, B. Farran, N. Atassi, N. Fellas, C. Braun, V. Cueves, M. Csanad and A. K. F. Val Baker, "Deviations in Sound Waves Associated with Physiological and Psychological states", 4 October 2023.

[158] N. Walter and T. Hinterberger, "Neurophysiological Effects of a Singing Bowl Massage," Medicina, vol. 58, no. 5, 2022.

[159] C. Rio-Alamos, R. Montefusco-Siegmund, T. Cañete, J. Sotomayor, and A. Fernandez-Teruel, "Acute Relaxation Response Induced by Tibetan Singing Bowl Sounds: A Randomized Controlled Trial," European Journal of Investigation in Health, Psychology and Education, vol. 13, no. 2, pp. 317-330, 2023.

[160] R. Karbauskaitė, L. Sakalauskas, and G. Dzemyda, "Kriging Predictor for Facial Emotion Recognition Using Numerical Proximities of Human Emotions," Informatica, pp. 249-275, 2020.

[161] C. Liguori et al., "Effects of singing bowl exposure on Karolinska sleepiness scale and pupillographic sleepiness test: A randomised crossover study," Plos One, vol. 15, no. 6, 2020.

[162] J. Kantor et al., "Effect of low frequency sound vibration on acute stress response in university students - Pilot randomized controlled trial," Frontiers in Psychology, vol. 13, 2022.

[163] Z. Vilímek et al., "The Effect of Low Frequency Sound on Heart Rate Variability and Subjective Perception: A Randomized Crossover Study," Healthcare, vol. 10, no. 6, 2022.

[164] D. M. Mariani, M. Supplizi, G. Irace, and G. Barassi, "Role of vibration and sound in Physiotherapy," Journal of Advanced Health Care, vol. 2, 2020.

[165] E. Rüütel, "The Psychophysiological Effects of Music and Vibroacoustic Stimulation," Nordic Journal of Music Therapy, vol. 11, no. 1, pp. 16-26, 2002.

[166] S. E. Hosseini and S. A. Hosseini, "Therapeutic effects of music: Areview," Report of Health Care, vol. 4, no. 4, pp. 1–13, 2018.

[167] H. Kamioka et al., "Effectiveness of music therapy: a summary of systematic reviews based on randomized controlled trials of music interventions," Patient Preference and Adherence, pp. 727–754, 2014.

[168] V. Jindal, S. Gupta, and R. Das, "Molecular Mechanisms of Meditation," Molecular Neurobiology, vol. 48, no. 3, pp. 808-811, 2013.

APPENDIX 1.

73 Hz	Shape Projection	dBA (measured)	Source Points	Source Orientation (x, y, z)	Space Points	Space Orientation (x, y, z)
C1	Pyramid	-23.95	5	0, 0, 0	509	0, 0, 0
C2	Tetrahedron	-23.27	4	0, 180, 0	514	0, 180, 0
C3	Cube	-23.6	8	0, 0, 0	488	0, 0, 0
C4	Octahedron	-23.37	6	0, 0, 0	486	0, 0, 0
C5	Icosahedron	-24.88	12	0, 0, 0	542	0, 0, 0
C6	Dodecahedron	-25.58	20	0, 0, 0	512	0, 0, 0
C7	Cuboctahedron	-25.35	18	0, 0, 0	578	0, 0, 0
C8	Sphere	-25.57	20	0, 0, 0	500	0, 0, 0
C9	Stereo	-24.35	2	0, 0, 0	–	–

110 Hz	Shape Projection	dBA (measured)	Source Points	Source Orientation (x, y, z)	Space Points	Space Orientation (x, y, z)
C1	Pyramid	-29.45	5	0, 0, 0	509	0, 0, 0
C2	Tetrahedron	-29.62	4	0, 180, 0	514	0, 180, 0
C3	Cube	-28.47	8	0, 0, 0	488	0, 0, 0
C4	Octahedron	-29.07	6	0, 0, 0	486	0, 0, 0
C5	Icosahedron	-27.6	12	0, 0, 0	542	0, 0, 0
C6	Dodecahedron	-29.53	20	0, 0, 0	512	0, 0, 0
C7	Cuboctahedron	-27	18	0, 0, 0	578	0, 0, 0
C8	Sphere	-29.78	20	0, 0, 0	500	0, 0, 0
C9	Stereo	-29	2	0, 0, 0	–	–