Immersive Composition for Sensory Rehabilitation: 3D Visualisation, Surround Sound, and Synthesised Music to Provoke Catharsis and Healing

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Abstract. There is a wide range of sensory therapies using sound, music and visual stimuli. Some focus on soothing or distracting stimuli such as natural sounds or classical music as analgesic, while other approaches emphasize the active performance of producing music as therapy. This paper proposes an immersive multi-sensory Exposure Therapy for people suffering from anxiety disorders, based on a rich, detailed surround-soundscape. This soundscape is composed to include the users' own idiosyncratic anxiety triggers as a form of habituation, and to provoke psychological catharsis, as a non-verbal, visceral and enveloping exposure. To accurately pinpoint the most effective sounds and to optimally compose the soundscape we will monitor the participants' physiological responses such as electroencephalography, respiration, electromyography, and heart rate during exposure. We hypothesize that such physiologically optimized sensory landscapes will aid the development of future immersive therapies for various psychological conditions, Sound is a major trigger of anxiety, and auditory hypersensitivity is an extremely problematic symptom. Exposure to stress-inducing sounds can free anxiety sufferers from entrenched avoidance behaviors, teaching physiological coping strategies and encouraging resolution of the psychological issues agitated by the sound.

Keywords: Surround sound, Ambisonics, Anxiety, Physiological monitoring, Exposure therapy, desensitization, immersive virtual environment.

1 Introduction

Immersive Composition for Sensory Rehabilitation is an interdisciplinary research project based in the optimal audio-visual production suite of Glasgow School of Art's Digital Design Studio, in collaboration with the Centre for Cognitive Imaging, at the University of Glasgow's Institute of Neuroscience. In a collaboration between a sensory artist practicing in diverse socio-cultural contexts, a serious games specialist and a neuroscientist, high-quality, innovative sound works will be composed and psychophysically tested to quantify emotional and visceral affect. The compositions will incorporate personalized sound triggers identified through interviews with Anxiety,

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Depression and Trauma sufferers (rather than the common implementation of familiar music or natural sound). A key variable in the research is the effect of spatial immersion in a soundscape composed in 5.1 Surround Sound, along with Ambisonic and 3D Visualisation experiments, compared to existing psychophysical studies which focus on the arousal caused by specific isolated timbres or naturally occurring sounds, primarily using stereo sound through headphones.

2 Established Modes of Sensory Therapy

2.1 Music Therapy: Listening versus Active Participation

Music and Arts Therapies often prefer an active approach, encouraging clients to play instruments or sing to *express* their own emotions. Yet, the benefits of passive listening to the prescribed *mood induction* [1, 2] within existing music are widely acknowledged. An optimal compromise between passive listening exposure and expressive performance-based therapy could be giving the participant-receiver a degree of input. Previously, input could be as minimal as asking musicians performing cathartic hospital *recovery services* for diverse empathetic song requests, from the elegiac to flamboyant pop-rock [2]. True Aristotelian catharsis ("the cleansing of the soul through an emotional experience" [3]) was even provoked in terminal AIDS sufferers, by addictive listening to Arvo Part's *Tabula Rasa* [4]. Furthermore, participant input could become as incremental as a compositional decision: to include their own anxiety triggers or sounds associated with pleasant memories; to choose between rousing and soothing tempo, or major and minor chords [5].

Sound, movement or visualization provides non-verbal catalysts for catharsis: the sensation and stimulation during exposure can provoke unexpected feelings, a powerful discussion stimulus, as listeners primarily reflect on the intensely emotional session itself and then verbalise their more underlying emotions stirred. Hospital patients "sharing innermost feelings" bring myriad benefits: a patient-clinician dialogue aids a more personalised treatment; nausea can be reduced and musically triggered endorphins boost the immune system [2].

Music is known for its' powerful mood-inductive ability, capable of provoking *renewal ecstasies* [6] through peak musical experiences. Moments of viscerally felt *frisson* occur in traditional music at an instantaneous climax, or can appear in waves, with a build of texture or complexity. Gabrielson notes a biological mimicry to musical features, as an accelerando sets a pulse racing, shivers are provoked by deviation of anticipated harmony, and emotionally expressive melodies cause tears [6]. The overstated 'heart-rending and ghost-ridden' shock chord in Mahler's Tenth Symphony (where the whole orchestra suddenly roars in dissonant minor thirds) commonly triggered a *Strong Emotional Experience* among several participants. [6].

So music can provoke powerful sensations on even emotionally stable listeners; however the subjective experience of sound for those with neurological disorders can be remarkably heightened. Anxiety sufferers can experience hypersensitivity to any sonic intrusion, but especially to sounds imbued with connotative reminders of a traumatizing experience. Musical frisson, a sensation commonly perceived as

pleasurable, can initially disturb a sensory therapy participant with anorexia, as it enforces a strong physiological reaction – clients are reminded they "have a body"[5]. Conversely, a symptom of repression of a traumatic experience is a defensive sensory switch-off, or emotional deadening. Detachment is problematic, rendering the traumatized sufferer's stability extremely fragile, as attempts to avoid conscious emotional realization will eventually be overwhelmed. If trauma sufferers' "spontaneous impulses become short-circuited by secondary inhibitive ones" [5], perhaps embodied music cognition may encourage a break from sensory-emotional avoidance. A pulsating rhythm that strongly invokes finger-tapping may surprise listeners into physical movement, as the non-verbal musical stimuli can bypass cognitive, linguistic modes of perception, with potential to be received kinesthetically. Even coma patients exposed to music in an Intensive Care Unit have shown a consequential reduction in blood pressure - the music can filter through their sympathetic nervous system, although they may not be cognitively interpreting it [2].

Mental disturbance caused by poorly recorded or considered audio, for use in rehabilitation, is often overlooked. Patients in physical pain and mental distress are soothed by natural organic, ordered smoothness, and can be irritated by digital distortion [7]. Soothing music and natural soundscapes reduce stress and anxiety in the post-operation patient, pregnant women, palliative care patients, and a virtual sensorial opposite (immersing a burns victim in a "snow-world scene") offers a distracting analgesic [8]. So, the sound composer must sensitively produce high quality audio and carefully consider the sonic events to feature in the soundscape. However, an analgesic stress reduction soundscape will doubtless need to be more delicate and soothing than sounds for sensory exposure therapy, which need to become more abrasive and challenging over time.

Another innovative use of auditory stimulation is found in *EASe* (Electronic Auditory Stimulation effect) Listening Therapy CDs [9], designed to habituate children with hypersensitivity disorders by means of sophisticated manipulation of sound frequencies (the Berard AIT modulation system). A low-pass filter is imposed on passages of music, with the high frequencies only emerging in 0.3-second intense volume-boosted bursts. The bursts are constructed to be too short to trigger the flight-or-flight response, so the child becomes familiar with the stimulation but is not frightened - encouraging tolerance of real-world sensory cacophony.

2.2 Exposure Therapy: Visual Virtual Reality versus Immersive Audio-Visual Composition

Using immersive soundscapes to reconstruct the frightening sensations of neurological disorder in a safe environment encourages trauma and anxiety sufferers to stop their life-restricting reliance on *safety behaviours* through training to endure, acknowledge and feel more at ease during stimulation. Current exposure therapies mostly rely on visual stimuli, such as the replication of fearful situations in virtual reality, with accompanying sound - but rarely with sound as the focus. However, using sound alone has great visceral potential, using non-verbal and non-literal imagery that could be used to enhance or complement exposure therapies. Using spatially pointed sonic cues can negate the need for a visual overload of information [10];

using sound alone can even encourage the user to close their eyes to induce immersion and block out external distractions. Visual-less games such as *Beowulf* show an innovative shift of focus onto the auditory imagination rather than dominating visual quality, arguing that prominent spatial cues in the game-soundscape can stimulate a richer, individualized internal mental imagery [11]. Roy et al. showed the amygdala's marked fear response became diminished as war veterans used visual Virtual Reality Exposure Therapy (VRET), where they re-enacted combat situations through a gaming environment [12]. However, creating soundscapes can provoke otherworldly, spiritual catharsis – through the established mood-inductive emotional triggering from musical structures, fused with real world sounds, and the unnatural timbre of digital synthesis. Perception of sound is a far more personalized, memory-triggering mode of reception than watching a visual VR: sound feels more directly applicable to our own memories and real life encounters - no matter how realistic or universal a visual image is, it is unlikely it will match our memories and experiences as precisely as replicable sound events do [11]. Moreover, using aversive sound stimuli is crucial in desensitization, since auditory hypersensitivity is the most common sensory-perceptual abnormality, more prevalent than visual and tactile hypersensitivity. Panksepp and Bernatzky [13] even deemed sound to have a more direct neurological affect (primarily in the subcortical emotional systems) than visuals. It has also been found that to enhance a subjective sense of presence within a mediated environment, spatial surround sound is not the key sonic augmentation - it is in fact the addition of Low Frequency Effects (bass) and a rise in volume that align with the vibratory tactility of everyday sound perception [14]. However 5.1 Surround Sound importantly does raise enjoyment, therefore engagement and likelihood to consistently attend a program of exposure therapy.

The opiate receptors are a crucial element of the emotions and physical sensations of bliss and shock triggered by music, the most influential neurochemical secretion being the release of dopamine linked to a momentary musical climax. Altenmuller [15] notes that when participants were monitored during listening to pleasant and unpleasant music, that serotonin levels rose substantially when they found the music pleasing. Our research will investigate the neurochemical and psychosomatic effect of a more continuous catharsis and evolved anticipatory system reaction to abstracted electroacoustic and found-sounds akin to Shaefferian *Music Concrète*. We hypothesize that unpleasant music may regulate the opioid secretion: an unpleasant but complex, sculpted soundscape could be intellectually intriguing, thus have more of a long-term reward than a fleeting pleasurable sensation. A gradual fade to a pleasing sound may even generate a more stable, healthy neurochemical response than a manic low-to-high jump.

Personalising VRET to individual perspectives is expensive and time consuming, but it has been shown that even one simulated situation (e.g., the 9/11 terrorist attack) can be effective for numerous survivors, as Goncalves et al. [16] find that only some stimuli depicted in the virtual environment are required to produce enough anxiety to activate the traumatic memory. The use of a partial sensory exposure focusing on one isolation of specific stimuli can be adequate to stimulate anxiety (shown from of public speaking to a VR simulated audience of disembodied eyes [17]), and may even be helpful as the user realizes it is not necessarily a whole situation that is feared,

perhaps just one sensory hypersensitivity that can stimulate a panic attack. Whilst it is ideal to tailor soundscapes to include personalized sonic triggers, the commonality of psychophysical affect provoked by abrasive sounds and unfamiliar synthesized timbres mean that one soundscape may provide a rich, diverse array of sounds applicable to many unique sufferers. Indeed the ambiguity of reduced listening to sonic stimuli may even lend itself more readily to a wider range of disorders and circumstances than a specific situational narrative exposure. Additionally, humans' inherently selective perceptual processes (such as the *Cocktail Party Effect* which enables focus on one voice in a chatter-saturated environment) mean that each participant will internally amplify those sounds with most relevant resonance in their own memories.

Post Traumatic Stress Disorder (PTSD) sufferers are not merely sad, but have fragmented memory of the event and even struggle to process new memories. They are hypersensitive to stimuli, can be unable to focus, and can have indescribable feelings, particularly unable to find an outlet for their anger or open up to feel pleasure [18]. Primarily, these are symptoms of a larger dislocation of the past-traumatized body from the present-self, as hallucinatory horror-memories intrude upon their daily life. Hence, engaging trauma sufferers in a composition that seizes their attention, and lets them over-react, could be a useful outlet and exaggeration for their struggles to fully experience emotion in everyday life. Karen Callaghan, a movement therapist experienced with torture survivors, notes a frustration of conflicting emotions, as victims stifle their anger by deliberate seclusion or self-harm "for fear of being overwhelmed or destroying others with their rage" [19]. Stimulating, aversive compositions could trigger this overwhelmed sensation within a safe environment, increasing confidence that sufferers can survive it and experience can make them more resilient. The over-stimulation is only temporary, and real life is rarely going to be as phenomenologically assaulting as the sensorial exposure therapy. Moreover, music has the capacity to integrate two or more conflicting emotions or messages through melodic layering, directly emulating psychological confusion: for example, the left hand on a piano can play slow peaceful melancholy notes, while the right hand plays sharp, staccato spiky fractured movements.

3 Sound Production Techniques to Physiologically Optimize Exposure

3.1 Compositional Technique: Idiosyncratic Triggers, Digital Manipulation of Sounds, and Inaudible Frequencies

Idiosyncratic Sonic Triggers. An illustrative example of a particularly problematic anxiety trigger sound is found in a torture survivor's report:

"Reemtsma… became the victim of a hostage situation and realized afterward that his intrusive memories were triggered by hearing footsteps or a knocking sound... he had heard footsteps approaching the cellar before the kidnappers knocked at the door during his captivity." [20]

So Reemtsma has a strong, visceral aversion to the sound of footsteps, due to the fear-conditioned response learned throughout his captivity. This account exemplifies

the necessity for catharsis and desensitization to the sonic trigger: it is an extremely problematic aversion, as Reemtsma would frequently encounter footsteps in everyday situations - to stick to a strategy of avoidance, he would have to live alone locked in a soundproof domicile, socially paralyzed. A soundscape designed for Reemtsma's exposure therapy could include footsteps which fade in and out of focus, gradually foregrounding the composition, and transform through a variety of filters and reverberation to fully explore the acoustic qualities of the sound, dislocating it from its' learned causal association. Footsteps could also work as a universal anxiety trigger, due to the ominous threat associated with an angry gait rushing towards the listener, in a directionally pointed sound array. Indeed, there is a multitude of clichéd shorthand to provoke fear in the listener, universally used in film (especially *stingers*, short stabbing anthropomorphized instrumentation most recognized in the shrieking violins of Hitchcock's *Psycho* (1960)) and video games (like gunfire and explosions in first-person shooter games such *Call of Duty*)[21]. These shorthands are sometimes created through inventive instrumentation, but are also sound effects including barking dogs, squeaking doors, cats screaming, ravens caw-ing, and lightning strikes. Whilst these sounds are acoustic symbols widely known to induce fear, the hypersensitivity of anxiety actually renders a wide array of causally inoffensive sounds frequenting everyday environments just as traumatic, if not more due to their chronic, ongoing nature. Initial searching for "sound triggers for anxiety" in online forums such as psychcentral.com, [22] revealed a plethora of individual sensitivities, which can then be categorized into several common sources: domestic, environmental, social and visceral. The domestic triggers seem to recur frequently, perhaps due to the invasive nature of the unwanted sound - the sounds of inconsiderate neighbors pervade what should be the anxiety sufferer's safe zone.

Table 1. Sonic triggers for anxiety shared by users on psychcentral.com

Domestic	**Environment**	**Social**	**Visceral**
vacuum cleaners	cars splashing water,	toddlers running &	cracking bones
"loud bass drum noise	coming & going, idling	screaming	(fingers, ankles,
when a neighbor has a	dogs barking	people talking	knees)
party"	lawnmowers	"people that talk loud	nail-picking "it
"floor shaking when air	leaf blowers	by nature"	makes me feel
conditioner is running"	power tools	people hollering	utterly sick to my
"the shower & toilet	high-pitched drill	whistling	stomach"
above me"	hammering	footsteps "especially	tinnitus
abruptly opening doors	revving motorbikes	women in high heels"	loud clapping
squeaky hinges on a	airplanes	crackling sounds of	snoring
door	siren	wrappers or chip bags	eating sounds "like
doors slamming	birds singing	tapping	Chomp, chomp,
"too much sensory input	"constant mechanical	"low repetitive beat of	slurp, sip, squish"
going on (TV, chat,	noise of printer wheels"	the big drum in a live	
radio, computer)"	hand-dryer	band"	
loud TV commercials			

Categorizing by Shaefferian *reduced listening,* that is distinguishing the acoustic property of the sound, provides further creative potential as we can use the acoustic property as a template to record or create different nuanced sound messages based on the aversive properties.

Table 2. Categorization of sonic triggers by quality using Shaefferian reduced listening

Mechanical	**Loud, abrasive frequency**	**Vocal**	**Repulsive Visceral**	**Rhythmic irritation: Irregular - Repetitive**
vacuum cleaners	cars splashing water	toddlers running & screaming	cracking bones (fingers, ankles, knees)	cars idling outside
"floor shaking when air conditioner or washing machine is running"	"the shower & toilet above me"	people talking	nail-picking,	doors slamming abruptly opening doors
lawnmowers	crackling sounds of wrappers or chip bags	"people that talk loud by nature"	"it makes me feel utterly sick to my stomach"	loud TV ads
leaf blowers	cars coming & going	people hollering	tinnitus	"loud bass drum when neighbor has party"
power tools	revving motorbikes	whistling	loud clapping	birds singing
high-pitched drill	squeaky hinges on a door	too much sensory input going on (TV, talking, radio, computer)	snoring	dogs barking
airplanes			eating sounds	"low repetitive beat of big drum in live band"
siren		football crowds	"like Chomp, chomp, slurp, sip, squish"	hammering
mechanical noise of printer wheels				footsteps "especially women in high heels"
hand-dryer				tapping

Digital Sound Manipulation. Recording in real world sites known for their striking acoustic properties, predicting the type of sound that would be made in the space makes for a solid base to start a soundscape composition. Using a *reduced listening* technique to select intriguing, sudden, or tonal sounds provides hundreds of short clips, which can be stitched together in looping musical sequences. These sounds can then be creatively skewed to reproduce the unsettling phenomenological distortion perceived during moments of panic, anxiety or depression, using digital filters, time stretching, delays or even altered equalization to sweep up from a natural sound to a distorted high frequency, or to strip a voice of its clarifying harmonics to abstract words or make it sound monstrous. These initial composition techniques are further enhanced by the mind-bending capabilities of surround-sound panning, used frequently in mass entertainment (mainly to aid suspension of disbelief and heighten immersion in cinema or to provoke fear in theme parks).

Researching the psychological aims of Fear Extinction and Exposure Therapy also provides a creative stimulus, as the techniques can be translated into concrete sonic ideas. Fear Extinction aims to desensitize (reduce the activation of the amygdala) through repetition of aversive stimuli, or through counterconditioning, to "establish a new stimulus–outcome association where the trauma reminder no longer signals danger" [20]. So a form of counterconditioning could be pairing an aversive auditory

Table 3. Recording sites chosen by Jessica Argo, their acoustic properties and sounds found

Recording Site	**Acoustic Property**	**Sounds Found**
Grand Central Terminal, New York	Ambience transitions from noisy to serene echo chambers transport of sounds in arches	Impromptu singing in *Whispering Gallery* Children singing, screaming, coughs High heels clacking on marble Buzzing of cleaning machines Coins rattling and dropping Trains screeching resembling bowed strings
Times Square, New York	chaotic cacophony of traffic road works bursts of music from shops, phones and cars	Tourists shouting, manic laughing "Grrrr!" Frustration at congestion Unfamiliar languages and dialects spoken Drills, buzzing, and hissing dissonant tone, ambiguous subway rumbling Grinding, squeaking, beeping, revving Tinny drumbeats as phone ringtone Cheesy pop music blaring from shops
Opera de Paris, Paris	hauntingly quiet empty auditorium balcony with heavy traffic packed with tourists marble floors in large atrium long reverberance	baby crying in auditorium, child singing stilettos clacking, floorboards creaking dragging footsteps French speech, gaspy breaths, coughs faint piano playing wavering alarms, camera shutters clicking
Search and Rescue Helicopter, Glasgow	Huge helicopter circling back and forth outside silent room	flitting between high frequency whipping blades and low frequencies of engine's roar

stimulus with a pleasant visual stimulus (e.g. the sound of a pneumatic drill played alongside a soothing visual animation). It can even emerge from a singular stimulus, a grating timbre that gradually transforms to pleasant, through semantic means (a baby crying gradually transforming to laughing) or purely through sonic structure (a high frequency gradually stepping down to more comforting lower frequency, or a baby crying at close range moving further away, drifting into a indistinct echo). Even classical music uses transformation to express and provoke psychological resolution, when distressed jerky bows of a violin in a Minor mode modulate to gentle calm strokes in a Major mode.

Reverberation is the naturally occurring reflection of sound waves after an initial source, idiosyncratic to each architectural space - a longer decay time indicates a larger room, and a glass-walled room produces a longer decay time than a foam-walled studio. Reverberation provides a sense of depth, enhances a mood, or reconstructs a natural or overemphasized decay time, with ability to sample real-world acoustics using an impulse response recorded on location. It can be used either to realistically match sounds to a visually depicted environment, or to create a hallucinatory inner-subjective viewpoint if there is no reverberation, to show the sound is not occurring in a real space but is merely imagined.

Equalization is either boosting or removing the low, middle or high frequencies from a natural sound (often a complex blend of several harmonics) or music, either to

emphasize verbal clarity or to distort the voice beyond the point of recognition. Each sound quality has distinct connotations [23], often unconsciously associated, as shown across the frequency spectrum in Table 5.

Table 4. Psychoacoustic connotations of various frequencies boosted using equalization.

Frequency (Hz)	**Low 20 Hz** → **High 20kHz**		
Excess	boomy muddy	honky nasal	harsh sibilant
Connotative Association	power rumble ominous dizzied perception	natural unthreatening	definition loud edgy bright sparkly presence
Deficiency	Thin anaemic wimpy	dull too realistic	distant

Mood-induction sampling. Samples from film scores, created with a specific manipulation of mood, can attach false emotions to an abstract image or film. In *Ghosts* (Argo, 2013) the most prominent example is *Virtua Mima (Voice Version)* from Satoshi Kon's *Perfect Blue* (1997). This haunting, a-cappella theme has layered chromatic chanting, with stop-starts and demonic throaty sounds. The "mm-mm" taunts run in two tracks each floating past in opposite directions; a solitary choral voice is centered; one of the last "aaaas" floats from front to back. The voices are panned to burst through from the front and float away to the back as they end. The disembodied voices are activated to frighten the viewer and test the limits of the exit sign effect, making the viewer question their listening space, and waking them from the lull of the pleasant. As the listener is forced to listen to bombing sound effects with a visual absence of the cause, or haunting disembodied chanting vocals, their listening mode is changed, converting causal or semantic listening into a pure reduced appreciation of noise. If anything, the out-of-focus visual of people moving through galleries (being completely void of narrative and at times even of recognizable features) is anempathetic to emotionally charged music. They are merely spaces suggesting reverberation or ambience. Perhaps pairing these sounds with meaningless visuals creates a paradoxical middle ground of *unemotional physiological stirring*.

Spatial Panning. Jessica Argo's portfolio of surround-soundscapes, produced in the Digital Design Studio, provides diverse examples of mind-altering affects induced by spatially directed sounds. *The Anti-Cocktail-Party-Effect* (2013) [24] replicates the sudden manifestation of irrational panic attacks in social situations. When an anxiety sufferer sits in a crowded restaurant, they can become hyper-attentive and paranoid of passers-by or fellow diners' scrutiny - this perception is conveyed by the dizzying swirling panning, as the chatter originates in a normal static surround (in all channels), then slowly jumps from one isolated point to the next, then runs around the room, the crowd transforming into a terrorizing poltergeist. The chatter is manipulated using interactive wavering tremolo on MAX MSP - the chatter fractures, becomes compressed and overloaded, speeds up, evolving to monstrous pure digital warping,

sweeping to a totally incomprehensible high pitch. This is the antithesis of our inherent perceptual ability to decipher language in a crowded room: the opposite of the psychoacoustic *Cocktail-Party-Effect*. Wine glasses clink with unnerving regularity blasting from various points in the room, in a lack of synchresis with the images of static glasses. The chatter and background music is at first familiar and amiable and then gradually the noise becomes overwhelming and the low-frequency effects channel is used liberally to physically shake the listener.

Encoding a sound composition into a phenomenologically engaging spatial array can be implemented through various panning styles. For example, *Blood Set in Motion* (2013) [25] is a simple hymnal synth harmonic progression with a simulation of mirror neural and circulatory responses, and corporeal imitation (imagined singing). Breathing, spatially pulsing movement of music replicates the idea of rhythm catalyzing the acceleration of heart rate. Sonic events include swooshes of a whipping stick, set in a rhythmic pulse, and the bubbling of a fountain to hyperbolize a rush of blood. *Trauma* (2013) [26] has an ominously quiet organ prelude, with an unsettling percussive arrhythm, suddenly launching into a cacophony of messy oscillating, searing chaos. Like a brain swarming with traumatic assaulting memories, random strikes burst through from all directions, and the piece ends in a blare of tinnitus. A listener, Marco Biagini, gave feedback that the timbres evoked "a digital machine gun"[27]. *Harmonising the Musical Present with the Musical Past* [28] emulates the notion of perceptual fusion of temporal events within a musical structure, as a familiar harmonic progression through G Major/E Minor, gradually morphs to a wide overlap of notes through the delayed piano and layering of timbre. The tension between F-sharp and G recurs again and again, but always harmonized slightly differently. Tape ghosts from re-recording are simulated, using occasional bursts of discordant synths, panned to emerge from the rear speakers. In 5.1 surround-sound, the illusion of appearing and disappearing ghosts is created by short bursts drifting past the listener from front to back.

Inaudible Frequencies. Steve Goodman's accounts of *Sonic Warfare* (e.g. the *Wandering Ghost* wailing voice blared to scare the Buddhist sensibilities of Vietnamese soldiers, and the nausea-inducing beating of ultrasonic frequencies from the *Squawk Box* used in Ireland [29]) exemplify the extremes of psychoacoustic manipulation, using sound as a weapon to mentally disturb or cause permanent physiological harm. However there is a therapeutic potential to use the *imperception* of *unsound,* the tactile and neurological sensations provoked by inaudible frequencies out-with the range of human hearing. *Infrasound* comprises of sound waves with low frequencies below 20 Hz and *Ultrasound* describes high frequencies above 20 kHz. The sub-bass felt resonating throughout the whole body (especially in the chest) with infrasound could have therapeutic benefits – the physiological stirring caused by the physical vibration and buzzing could be a more passive encouragement of mindfulness than physical exercise like yoga or dance. The depression or anxiety suffer may be unwilling to engage in a public movement class, known to promote ideals of awareness and enjoyment of bodily sensations and physical exertion, so offering a bodily stimulant through mere immersion in a sonic vibration can provide a passive somatic awakening. This would also be applicable

to anxiety sufferers' *depersonalization* when they feel disconnected from their body [30], or a sensory numbness or fatigue felt by depression sufferers. Goodman also highlights "certain infrasonic frequencies plug straight into the algorithms of the brain and nervous system… frequencies of 7 hertz coincide with theta rhythms, thought to induce moods of fear and anger" [29]. So through carefully selecting specific frequencies we can actually alter a brainwave pattern, bypassing a cognitive or semantic reading of the sound - a synthetically generated 7 Hz tone will not even be heard by the participant, only felt directly. Oohashi et al. [31] also discovered a "hypersonic effect", as listeners showed a markedly increased alpha brainwave activity upon exposure to inaudible high frequencies over 22kHz placed in an auditory stimulus (compared to the EEG data recorded when the subject hears the stimulus missing the High Frequency Component). Alpha activity is linked to relaxation, found to emerge upon the closing of the eyes, attenuating when the eyes open or during mental exertion – so the marked change in brain state shows the affective role of the HFC as it bypasses the cognitive circuits of hearing but nevertheless elicits relaxation. The power of the alpha reading was lowered significantly when the HFC was removed with only Low Frequency Component remaining in the audio stimuli. However, the alpha-EEG reading would not increase when the HFC or LFC was played in isolation, so it appears the inaudible sounds are only effective when integrated into a larger sonic composition. Using Positron Emission Topography, Cerebral Blood Flow in the brain stem and left thalamus increased (along with the alpha-EEG reading in the occipital region) when the HFC and LFC were played together, compared to reception of the sound without the HFC. Qualitative feedback showed that the subjects "felt the sound containing an HFC to be more pleasant than the same sound lacking an HFC" [31]. So the affect triggered by inaudible high frequencies was notable, and we also learn that the subjects would find a sound lacking a complete frequency spectrum unpleasant, in addition to diminishing of the relaxed alpha state.

3.2 Physiological Monitoring to Inform Compositional Decision

We will collect audience-response data, ranging from quantitative physiological data (unconscious response) to qualitative verbal feedback (subjective response). The benefit of employing encephalography and portable physiological monitoring is that it enables regular testing in the optimal sensory environment of 5.1 and Ambisonics arrays at the Digital Design Studio. The physiological monitoring system will be fourfold, as signatures of acoustic processing are actually sometimes easier to see on the skin, than from measuring brain activity alone. Electromyography (EMG) will measure muscle contraction and tension induced by abrasive sounds, or sonic shocks activating the startle mechanism; electrical skin conductance will measure instantaneous sweat secretion and piloerection from fear or musical frisson; respiration and heart-rate will identify moments of shock or waves of relaxation; electroencephalography (EEG) will measure accurate real-time brainwave patterns to locate brain stimulation and identify if memories are being triggered or there is a purely sensory engagement. The EEG device measures raw brainwaves, distinguishing mental states across a broad spectrum, meaning that a listener's instantaneous moments of musical pleasure can be identified: from when the listener's state of engagement with the sensory envi-

ronment (alpha brainwaves at 8-12 Hz), his/her expectation of changes in the sensory environment, e.g. due to stressed, anxious states (Beta brainwaves at 12-38 Hz), to the active processing of acoustic sensations (Gamma brainwaves 30-70 Hz). Thus, the sensory stimulation composition should be provoking the stressed Beta waves, which can then lead to a sensory-euphoric Gamma state, encouraging a leap through and out of a depressive state.

Serious Games are employed as enjoyable, interactive learning strategies. Exposure therapy serves as a catalyst for a dual learning: as psychoeducation about the physiology of anxiety; but also a deeper learning, as the user uncovers repressed events buried within their psyche. There is future potential to use real-time EEG and psychophysiological data as biofeedback game input during exposure to manipulate the playback of sound events to challenge the player. For example, the more relaxed the user becomes, the louder or faster the composition could sound, integrating more abrasive timbres or triggering a higher pitched distortion so the user will always be optimally challenged to their maximum coping capacity. As the soundscape becomes louder or higher pitched, the user will know that it is a direct cause of their physiological vital signs adapting to the exposure, thus their confidence can be boosted.

Biofeedback is often used to visualize or notify a tangible reward for a user's strengthened endurance of exposure, or an excited bio-signal can even transform the music featured in a game, to empathetically match the player's nervous state [32]. Ubisoft's O.zen uses a fingertip heart rate monitor (a photoplethysmograph) as an interface to play lighthearted racing or shooter games as part of a holistic bio-monitoring package recommending personalized breathing and cardiovascular exercise programs, as well as providing psychoeducation to understand the detriment to health of stress-inducing breathing [33]. A Serious Game to aid pediatric treatment for anxiety and depression, *The Journey to the Wild Divine* [34], implements biofeedback-controlled guided-imagery situations such as a bridge construction exercise, where any progress on the structure literally crumbles as the user becomes frustrated, only allowing completion upon sustained relaxation. So instead of merely accomplishing the fleeting feeling of being relaxed, the user achieves tangible outcomes. The game trains recognition of the physiological symptoms of anxiety and bolsters the user's faith in being able to control their own predicament through disciplined regulation of breathing states for concrete short-term rewards. Indeed, it is also beneficial for the therapist to log all recorded bio-data during exposures, to build concrete psychophysical results with which to review the user's habituation progress over several sessions.

In addition to the less invasive physiological monitoring, it may prove insightful to install a speaker array in a functional Magnetic-Resonance Imagery Scanner. Issues of sonic contamination from the excessively loud scanner will need to be addressed, by means of tailoring the soundscape to account for specific loud moments, or indeed incorporating the scanner's mechanistic timbre. Participants can also feel claustrophobic in the confined space, interfering with the emotional response.

The qualitative verbal feedback will primarily include pre- and post-exposure interview and questionnaires and at times choreographic feedback (gestural response in informal exposure environments). Real time objective physiological data is absolutely necessary: if questioned after exposure, test subjects forget certain nuances - we can notice when we feel chills, (Loui et al.'s study, *Effects of Voice on Emotional Arousal* allowed the participant to document their frisson using a joystick interface, which is

problematic due to delay to allow for conscious realization [35]) but we need accurate pin-pointing of unconscious response to reveal which isolated sounds and images cause each emotion or physiological stirring. In addition to memory loss from delayed questioning, the subjective verbal response will also be subject to *social masking* [36], varying introspective ability, questionable validity of the questionnaire, and uncontrolled participant honesty; hence the necessity of real-time measure of unconscious, nervous response.

The effects of mere stereo listening will be compared to effects from immersion in spatial arrays of 5.1 surround sound and Ambisonics. The effects of sound alone, versus synchronized audio-vision, versus audio with asynchronous visual accompaniment will be compared, to quantify a higher level of engagement when the two modalities are merged, or discern if the visual is a cognitive distraction from the visceral audio, or if mismatching audio-visual causes discomfort. The difference in response to a more tangible musical melody will be compared with the response to more abstract, temporally extended use of sound in a non-musical manner. Importantly, difference in listener response between personalized soundscapes and non-relevant soundscapes will also be measured.

Table 5. Distinctions between physiological effects provoked by contrasting media outputs

Compare effects of…	stereo listening	→	surround-sound immersion
	sound alone	→	synchronized audio-visual
	synchronized audio-visual	→	asynchronous audio-visual
	tangible musical melody	…to effects of…	non-musical use of sound
	personalized soundscapes	→	non-relevant soundscapes
	real world natural sounds	→	digitally synthesized sounds
	real world video	→	abstract animation

Considerations for Response Monitoring. For EEG monitoring, an average response will need to be discerned, across repeated listens (to cancel out noise artifacts) as well as an average across subjects, to find correlations and distinct uniform responses, dispelling the subjective differences. However, repeated listens will be problematic as it may cancel the effects of musical novelty, diluting the initial shock factor of certain sounds, so these measures of repetition should be thoughtfully integrated into the composition as a whole. In fact, the method of *looping*, through isolating a sound event in a field recording and using it as a rhythmic musical structure, or continuous timbre enables this discern of an average response through repetition, or extension of sound.

3.3 Participants: Healthy Subjects or Neurological Disorder Patients

We acknowledge it will be a lengthy legislative process to invite participants diagnosed with a severe mental illness, possibly out-with the scope of a three-year project. The NHS stipulates that we need to test the compositions on healthy participants without adverse affect, before access to anxiety and depression sufferers is granted (to test the stimuli as an Exposure Therapy). Instead, we propose first to test on healthy

people first with a view to testing on anxiety and depression sufferers after, with a preference for medically healthy people who feel stressed from time to time.

4 Conclusions

An ideal amalgamation of sensitive compositional aids from Music Therapy, with the theories behind psychiatric treatments such as Fear Extinction and Exposure Therapy along with painstakingly considered high-quality audio production would provide optimized sensory rehabilitation for hypersensitive anxiety sufferers. We aim to quantify the increase in affect provided by optimized presentation modes, such as surround sound and Ambisonics and abstract synthesized soundscapes, through rigorous psychophysical testing, corroborated by qualitative questioning of participants. Upon collation of the quantitative bio-data, we may uncover applications for the fluctuating electrophysiological signals (the notable affect) to be used as a Serious Game interface; indeed an integrated reactive playback system may be the optimal mode of engagement to soundscape exposures, to maximally challenge the user.

The resulting compositions compiled from real anxiety triggers could also spread the awareness of the physicality of mental illness by replicating sufferers' altered sense-perception (rather than attempts at verbal explanation) facilitating empathy from non-sufferers. This could reduce stigma of the less visibly understood mental disorders, and provide a sensorial avenue for psychological connection, between healthy audience members and the oft-alienated anxiety sufferer - to communicate a sensation that cannot be expressed in words.

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