The body as instrument: tissue conducted multimodal audio-tactile spatial music.

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We describe early progress in exploring the compositional potential for multimodal music of a multi-transducer audio-plus-vibrotactile apparatus, utilising ambisonics encoding; the tactile component is an incidental by-product, carried by the same transducers. An elicitation exercise with one hundred uninstructed listeners who gave responses in their own words was conducted and responses were transcribed and aggregated to identify emergent descriptive themes. The tactile components of the stimuli assume greater importance in the perceptual experience than originally considered, suggesting compositional opportunities in utilizing additive effects of audio-plus-tactile signals. This could engender assistive technologies for those with some degree of conductive hearing loss, ameliorating music-deprivation and addressing quality-of-life (QoL) issues.

INTRODUCTION

Methods for artificial reproduction of music and other audio programme material generally utilise transducers to produce a field of pressure fluctuations at the intended listeners' ears. For spatial sound, listeners' interaural differences must be coherently managed in order to produce phantom imagery (the appearance of sound sources at locations other than the transducer sites).

Loudspeakers transmit sound beyond the intended listener, potentially causing annoyance. This problem is exacerbated for those with some degree of conductive hearing loss, who may object to others' music, yet listen to their own louder than others would prefer in efforts to achieve 'clarity'.

Headphones generate pressure fluctuations proximate to the ear canals, producing local (to the individual perceiver) sound fields with many of the required spatial attributes. However, some people do not like listening via headphones, finding the experience unnatural and lacking externalisation (unless specific binaural technologies are employed). Headphone listening can also be isolating; people feel insufficiently aware of their surroundings. A common objection to headphones is that the experience lacks something visceral, that they would prefer to 'feel' the music.

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An alternative approach (which we are investigating) utilises direct-to-tissue energy transfer, which is often referred to as "bone conduction" (though other tissues are involved). As cranial tissue is most proximate to the targets (the cochleae), this involves mounting transducers in contact with the listener's head. Cranial tissue is caused to vibrate; the resulting vibrations are transferred to the basilar membrane, stimulating the hair cells in similar fashion to that evoked by air-conducted sound. This technique essentially bypasses the mechanical conduction apparatus of the outer and middle ear, and can provide individual listening experiences without risk of annoyance to others. The technique works for those with normal hearing, or those with conductive loss but not sensorineural impairment. Music listening is feasible, though quality of presentation does not currently match that for high-quality headphones/speaker listening.

We report here on the subjective impressions of the experience of spatial sound and music conveyed via this apparatus to one hundred untrained listeners. Early indications are that the experience is interesting and positive, has some degree of clarity and externalisation but is lacking in low frequencies. The vibrotactile aspect of the presentation (listeners could 'feel' as well as hear the material) was positively commented on by many listeners. We conclude that the technique is worth developing, and that refinement of the program-material-modulated vibrotactile stimuli should be explored further as an adjunct to, and possibly an intrinsic component of, musical experience.

MUSIC THROUGH TISSUE CONDUCTION

Bone conduction (which actually includes non-osseous fluid pathways, see: Sohmer *et al* 2000) is routinely used in audiometry to elicit individual contributors to hearing loss, and it is used in bone-anchored hearing assistive devices. It would not generally be a first choice of auditory display for music listening. Impedance matching problems for non-anchored transducers tend to limit dynamic range and linearity of frequency response, with harmonic distortion products becoming prominent at lower frequencies. (Jansson *et al* 2015). For spatial audio display, the complex multiple transmission paths associated with each transducer inhibit accurate control; precision of spatial imagery is an ambitious proposition.

Nevertheless, as Stenfelt & Zeitooni (2013) and Stanley & Walker (2006) have shown, lateralisation can be evinced using two transducers (one at each mastoid) and so, theoretically, stereo music could be listened to in this way. Whether other spatial parameters (such as externalisation, coherent movement of images, elevation, immersiveness, spaciousness) might be feasible is a matter for investigation.

If it were found to be so, then theoretically, it would be possible to generate a personal listening experience of spatial, or surround music comparable to loudspeaker or binaural headphone presentation methods. Of a number of possible applications, perhaps the most notable would be for individuals with hearing loss featuring some substantial component of conductive impairment. Hearing loss

entails diminished enjoyment of music and diminished auditory spatial acuity. Given the burgeoning interest in spatial music, there is a widening disparity between the musical experiences of those with, and without hearing loss.

SPATIAL MUSIC

Historically, spatial music is no novelty. Prior to the invention of mono recording techniques at the end of the 19th century, music was intrinsically spatial, interacting with the complex acoustics of performance spaces. There is a documented history of composers experimenting with spatial elements in music (see: Bates 2009, Zvonar 2015, Lennox 2017), and some in the Archaeological Acoustics community conjecture deliberate use of resonant characteristics of ceremonial spaces in Palaeolithic times (Reznikoff, 2006).

More recent technologies (including binaural, ambisonic, wave field synthesis, Dolby Atmos and others) facilitate various degrees of spatial verisimilitude, and they also provide means for composers to experiment with auditory spatial experiences. This is important because accurate reproduction of 3-dimensional space is just one avenue of exploration; more metaphorical uses of spatial impression offer interesting possibilities.

Spatial qualia in artificial sound

Spatial hearing functionally utilises binaural disparities and monaural pinnae cues, yielding a variety of qualia such as spaciousness, immersiveness, lateralisation, elevation, externalisation, range (including *relative* range where multiple sources are involved), and movement (of sources, and/or of the perceiver through an environment).

In various forms of hearing deficit, spatial perceptual performance may be degraded. Neher *et al* (2012) refer to “spatial hearing loss” and how bilateral hearing aids can actually exacerbate this (see also: Van den Bogaert *et al* 2006). Much research focuses on speech intelligibility problems in noisy environments; less focuses on the diminishment of enjoyable qualities of sound fields, and the degree to which they might be restored.

TRANSDUCER ARRAY FOR SPATIAL MUSIC

Audition elicited during the experiment was through a multi-channel vibro-tactile transducer array; five BCT-1 8Ω 90dB 1W/1 m tactile transducers held in contact with cranium were used to elicit auditory spatial impressions through tissue conduction. Signals included soundscapes and music, ambisonically encoded either by use of native recordings via a Soundfield microphone, or by encoding via WigWare VST plugins. One hundred volunteers (24 female 16 -60 yrs. 76 male 16 - 62 yrs.) took part in a listening experiment, receiving no prior instruction on target attributes. Participants were invited to comment in writing on the experience.

Comments

Female, 36, Stage Manager
"Although the sound was still 'one sided ' to a certain degree I felt for the first time that I was immersed in a soundscape and that my hearing loss was not making me lose out on part of the effect. The train in particular really felt 360"
(positive, immersed, hearing loss, soundscape, 360)

Male, 40, Music Manager, Musician
"Really amazing to feel and sense the music and sounds around you without actual sound 'in ears'. The spikes, high levels vibrate against your skull and this gives sense, interesting to hear without your ears!!"
(positive, feel, external, vibration)

Fig 1: Transducer Headset array

Emergent themes

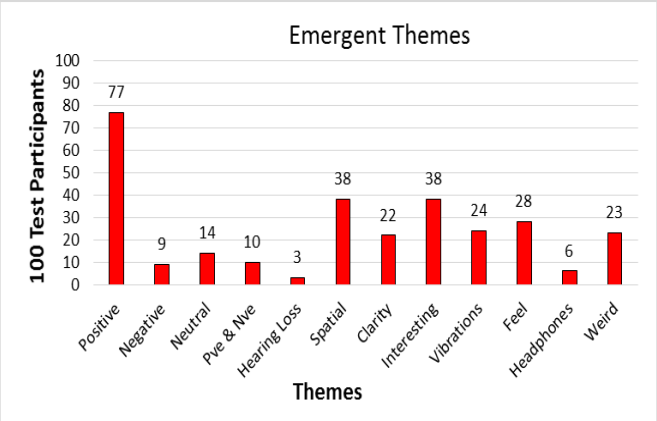

Fig 2: Themes aggregated from comments

Vibrations

Male, 23, DJ, Musician
"Very interesting, new experience of sound. Vibrations feel slightly unusual but also add a new dimension to the sound experience. Very cool."
(positive, interesting, vibrations, weird)

An unexpected result emerged from the aggregated comments, 24% referred to vibration in a neutral or positive context; 12% of these where positively associated with comments on spatial impression. The result was unexpected as we had assumed that any vibration from the array would generate negative terms, this was only the case in 3% of the responses.

Vibrotactile augmentation: multimodal music?

Although direct-to-tissue conduction has been thought of as a convenient alternative method for evoking auditory perception, it is not certain that auditory-*only* perception is occurring. The technique utilises vibrating transducers in contact with tissue, and pallesthesia cannot be excluded from consideration. The contribution (of tactile stimuli) to overall spatial perceptions is currently unclear. Several listeners commented on their sensing vibrations in a positive vein (reported above) and two specifically described the experience as *feeling* a source approach and pass overhead. Notable is the contrast between descriptions of spacious, externalised sound and reports of vibrations; one might have supposed that tactile stimuli might have increased the 'in-the-head' qualia. But reports of perceptions of movement, direction and especially elevation (given that no physical equivalents of pinnae effects were deliberately generated) may depend in some part on pallesthetic components, and hence the experience is multimodal rather than unimodal. In such a case, the two stimulus domains (tactician and audition) would exhibit additive effects.

From a music compositional perspective, vibration might become an intrinsic musical parameter, with associated experiential dimensionality. A perceiver could quite literally 'feel the bass'. Movement cues might be augmented with congruent tactile stimuli. Externalisation might be a dimension of interest; a sound source could be perceived as occurring within the head/body and travelling *through* or *around* the body, to exit from a particular location and thence through the surrounding environment. "Call and response", a spatial technique used by some composers could actually utilise this 'internal-external' axis for novel effect.

If the speculations on additive effects and augmented experiential properties have substance, then one implication is that audio-only music is just one kind of experience, and multimodal music is another. This has important consequences for understanding how hearing-impaired listeners might be able to enjoy musical experiences that, though non-identical to the experiences of normal-hearing listeners, are nevertheless rewarding. There is precedent for this; Nanayakkara *et al* (2013), reported on the experience of partially and profoundly deaf participants in a study on the use of a 'vibrochair' to convey music, concluding that hearing-impaired listeners can identify and enjoy music when it its transduced to tactile signals.

CONCLUSIONS

Spatial music can be conveyed via multi-transducers tissue conduction apparatus; some spatial impressions are feasible, even though no direct equivalents to pinnae effects. The importance of the multimodal perception of audio-plus-tactile requires elucidation. Music could be designed specifically for the medium, as the qualia here might differ substantively from those for air-conducted listening of audio-only signals. Early indications support the notion that listeners with conductive hearing loss could regain some quality of life in respect of music listening.

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