DEVELOPMENT AND VALIDATION OF A SENSORY-SUBSTITUTION TECHNOLOGY FOR MUSIC

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1. Introduction

The Emoti-Chair is a sensory-substitution technology designed to provide greater access to music for individuals who are deaf or hard of hearing. This is accomplished by converting sound into vibrotactile information that is displayed along the back and legs. The basic conceptual design, referred to as the model human cochlea (MHC), presents discrete bands of frequency as independent points of vibration, allowing for spatiotemporal encoding of the incoming auditory signal. The back is thus treated as a basilar membrane, complete with its own tonotopic map, oriented vertically so as to align with common conceptions of pitch height. Preliminary research with artificially deafened participants has revealed that emotion judgments concerning vibrotactile music presented via the model human cochlea align closely with those of hearing participants, and the judgments are distinct from those made with vibrotactile music that is not frequency-band separated (Karam, Branje, Price, Russo, & Fels, 2007; Karam, Russo, Fels, in press).

The current paper presents progress on a series of psychophysical studies that were designed to ascertain what aspects of music can be perceived through vibration alone.

2. Frequency Difference Limen (FDL)

The first experiment used the method of limits in order to measure ability to discriminate the frequency of vibrotactile stimuli across a wide range of frequencies common to (western) music. In order for vibrotactile music to be a viable undertaking, the skin must possess some degree of frequency discrimination ability. Results from previous research vary, with Pongrac (Pongrac, 2008) reporting the smallest FDL of 18% between 100 and 700 Hz when vibration was applied to the fingertip and forearm. Much of the other work (Goff, 1967; Mahns, Perkins, Sahai, Robinson, & Rowe, 2006) regarding this topic report curves steeper than that found by Pongrac. No work to date has looked at a large contactor applied to the non-glabrous skin on the back.

2.1 Method

A single large contactor (102mm diameter) was placed on the lower back of each of 4 participants. The contactor was secured using a 5.08 cm wide nylon strap tied around the waist. Participants wore headphones with loud white noise playing in order to artificially deafen them. All anchor and comparison stimuli were equated for subjective intensity in a preliminary experiment. Anchor stimuli spanned a range of fundamental frequencies corresponding to the pitch range from C2 to C6 (with anchors on C's and F#'s). Participants were exposed to 3000 ms of the anchor stimulus, then 500 ms of no vibration and then 3000 ms of the comparison stimulus and were then asked if the two stimuli were the same or different. Initial comparison stimuli started 5 semitones above or below the anchor frequency and moved 1 semitone closer with each successive judgment, until the frequency matched and then proceeded beyond the anchor frequency. Three correct responses resulted in the run ending. Each anchor was presented twice, once in an ascending trial and once in a descending trial.

2.2 Results

Results indicate that frequency difference limens for stimuli presented as a single point of vibration on the back fall between 2 and 3 semitones across the range of vibrotactile sensitivity (5 to 1000 Hz). As seen in figure 1, the FDL curve was shallower than those found by other studies in which vibrotactile information was applied to the fingertip or forearm.

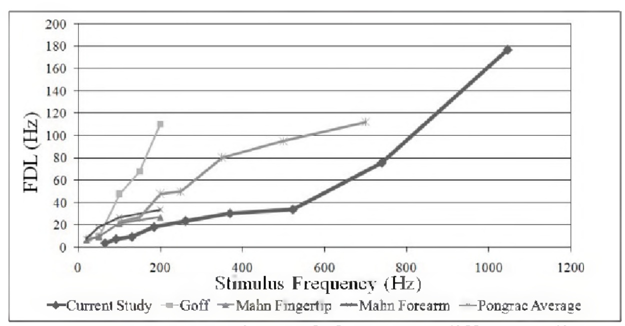

Figure 1 - A comparison of frequency difference limens reported with vibrotactile stimuli.

2.3 Discussion

Since the non-glabrous skin of back has a relatively low density of mechanorecptors and is not generally considered to be highly sensitive (Mahns et al., 2006), it appears likely that the large contactor size played a critical role in the relatively shallow FDL curve obtained in this experiment.

3. Timbre

The second experiment examines ability to discriminate between complex vibrotactile waveforms. Because timbre is an important aspect of musical structure (Seashore, 1936), ability to distinguish between different timbres is seen as crucial for perceiving music through vibrotactile channels.

3.1 Method

Complex vibrotactile waveforms generated from an acoustic signal were presented to the back via voice coils embedded in a conforming chair. Participants made same-different judgments based on timbre (piano, cello, trombone). A total of 5 undergraduate students participated in the study, 3 male and 2 females. All participants were deafened using white noise presented through headphones and by wearing *Tactaid* skin transducers taped over their cheek bones to help mask sound transmitted via bone conduction. Each trial consisted of two timbres presented for 1-s each and separated by a 1-s inter-stimulus interval. Stimuli were presented at each of 3 levels of fundamental frequency, 110, 220, and 440Hz, which correspond to pitches A2, A3, and A4, respectively.

3.2. Results

Initial results are promising as a large majority of participant responses across all instrument combinations were correct. All of the instrument combinations showed a significant chi-square result (with alpha set at .05): $\chi2(4) = 50.438$ for Cello-Cello; $\chi2(4) = 44.263$ for Cello-Piano; $\chi2(4) = 14.143$ for Cello-Trombone; $\chi2(4) = 44.263$ for Piano-Cello; $\chi2(4) = 40.909$ for Piano-Piano; $\chi2(4) = 60.842$ for Piano-Trombone; $\chi2(4) = 17.610$ for Trombone-Cello; $\chi2(4) = 49.951$ for Trombone-Piano; $\chi2(4) = 56.977$ for Trombone-Trombone). Participants achieved at least 70% accuracy for all instrument combinations, with most combinations above 80%.

3.3 Discussion

These initial results suggest that humans are able to discriminate complex vibrotactile waveforms perceived through the skin. Moreover, preliminary results from a follow-up experiment that controls for amplitude-envelope variation across timbres is yielding similar results, suggesting that ability to discriminate timbre through vibrotactile channels is based at least in part on spectral attributes.

4. Conclusions

Given the findings of these two preliminary studies, we have a more complete understanding of the specific attributes of vibrotactile music that can be perceived. The ability to discriminate frequencies between 2 and 3 semitones and discriminate complex vibrotactile waveforms may support the experience of structure and emotion in music by the Deaf. Given recent evidence, indicating that judgments of interval size can be made more accurate by providing congruent vibrotactile input (Maksimowski & Russo, 2008), the most promising application of this technology may be in supporting music listening in the hard of hearing.

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