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Limits of the Cochlear Bandpass

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ABSTRACT

This study focused on the bandpass function of the human cochlea and how the superimposition of sine waves on a musical stimulus may aid in more individualized frequency ranges when presented to subjects. Based on the Nyquist theorem, musical samples chosen were of ample sampling rate to provide an absolute base for accurate perception when paired alongside sine waves near or beyond the upper limit of discernibility. Utilizing musical samples as a setting for sine wave detection tested subjects' psychoacoustical abilities beyond the recognition of tones without partial interferences (i.e., audiogram). Frequencies that were recognizable at a significant level contributed towards the development of a more accurate frequency range of hearing near 16 kHz.

1 Introduction

Within the field of audiology, audiometric tests are the standard practice for determining high-frequency hearing loss or notched hearing loss in human subjects. These tests, however, utilize single-stimuli systems that may not stimulate the brain as effectively in determining accurate hearing thresholds. Conversely, the superimposition of sine waves within various sound beds (e.g., musical samples) should help to strengthen the ability to contextualize results more thoroughly with common hearing practices.

2 Background

Given the bandwidth of human hearing as dictated by the scientific literature (20 Hz to 20 kHz), there are inconsistencies between both the broad frequency range found in the scientific literature and the frequency range of the general population who have experienced any kind of general hearing loss or noise-induced hearing loss (NIHL) [1]. Prior research regarding sine detection of ultrasonic components (tones above 20 kHz) has shown little significance in a subject's ability to discern said tones [2]. Similarly, when discussing the interaction of sine tones with other complex sounds, intermodulation distortions are a possible influence when a headphone or speaker's transducer(s) work non-linearly [3]. These distortions, specifically during psychoacoustical tests, become detrimental if a subject could significantly detect the ultrasonic sine tones during testing, expressing that hearing distinctions should be attributed to the distortions rather than the sinusoids themselves.

Regarding the electrophysiological processes of audiology, prior research regarding selective auditory attention was considered – this phenomenon being more commonly associated with the "Cocktail Party Problem," a concept that highlights the brain's ability to isolate and decode one signal from a series of various interfering signals [4]. The testing method used in our study approached stimulus development from the perspective of a greater sonic picture; ultimately, the goal was to stimulate the auditory system more broadly over the course of a testing period. The superimposition of sine waves on a musical stimulus may aid in more individualized frequency ranges when presented to subjects.

3 Methods

The null hypothesis for this study stated that sine waves generated and superimposed above the assumed threshold of hearing will have no effect on the subjects' ability to discriminate. The independent variables were musical segments (10 total, 3 seconds in duration) derived from two stereo classical music tracks recorded by Morten Lindberg. Within those segments, seven different sine waves (0 kHz – null, 2 kHz, 4 kHz, 8 kHz, 16 kHz, 24 kHz, and 32 kHz) were superimposed onto the samples to create 70 unique stimuli. Loudness (LUFS) was accounted for between musical segment and sine wave. Based on perceived loudness, 8 kHz's loudness level was used to standardize the rest of the stimuli. The original source material was downsampled in MATLAB from DXD stereo (24-bit/352.8kHz) to 24-bit/96kHz. The sine waves were created in MATLAB at 16-bit/96kHz and then upsampled to 24-bit to ensure uniformity among stimuli. Because the maximum frequency used was 32 kHz, a Nyquist frequency of greater than 64 kHz is necessary; 96 kHz was used as one level above the closest standard sampling rate to ensure ample headroom during reproduction.

The dependent variables for this study were the measures of correct hits per trial and means by independent variable of the subjects' ability to detect the presence of the sine tone. Collected on Scantrons as either "A" ("I hear a sine wave present") or "B" ("I do not hear a sine wave present"), subject answers were scored via a binary system where correct pairings were awarded a "1" and incorrect pairings were awarded a "0". There were 10 individual samples representing all 7 test conditions (sine wave frequency or null) with 3 total rounds that utilized random orders of the same 70 stimuli. Each of the 14 subjects completed 210 trials amounting to 2,940 total trials by the end of the data collection. Each round was divided in half to avoid listening fatigue.

The total trials were divided into sections of "control," "test," and "null." Initially, a normality test was run for the "null" data to ensure it was not chance performance (e.g., score means near 50%). Normality for "null" ($W = 0.31$, $p < .001$), "control" ($W = 0.10$, $p < .001$), and "test" ($W = 0.56$, $p < .001$) was all rejected. Because the data were not normally distributed, nonparametric tests were used. A multiple related samples (ANOVA) test was run with concatenated data regarding subject and frequency data providing a scatterplot of score means per frequency (per subject). Utilizing a 90% accuracy rate for means ($p = 0.22$), half the population was able to significantly discern frequencies at (and below) 16 kHz; similarly, no one was able to significantly discern frequencies above that threshold. Two other multiple related samples tests were run on pertinent variables (e.g., per frequency in kilohertz and per musical sample). For frequency, a nonparametric ANOVA test showed considerably high means for frequencies including and below 8 kHz proving significance ($N = 420$, $p < .001$). Similarly, a nonparametric ANOVA test on musical samples was run to test for the possible presence of masking; based on the results, masking did have a potential – yet not concerning – effect ($N = 294$, $p = .001$). To find a concluding threshold level, a Wilcoxon test was run between mean scores of the "control" and "test" pools where significance was proven ($N = 1260$, $p < .001$).

4 Results

Given the presented data, we rejected the null hypothesis and determined that, contrary to previous literature about the cochlea's limits, the cochlear bandwidth for this population was 16 kHz. Additional bands of sinusoidal frequencies during stimuli reproduction would be needed to determine a more precise high-frequency threshold of detection.

5 Discussion

The use of more complex stimuli systems proved more sensitive in hearing responses among the population. The method utilized here was designed to create a more natural and applicable result when comparing the final data to a population's real-world experiences. The cochlear bandwidth of 16 kHz demonstrated here suggests that the generally understood bandwidth of 20 kHz may be an inaccurate assessment of the auditory bandwidth of the general population of this given demographic, i.e., music-oriented college students in their twenties.

References

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