Although many people describe their tinnitus using complex terms (such as a tea-kettle, crickets, and roaring), past studies of tinnitus have focused using pure tones and noises as stimuli. Therefore, this study was developed to begin to address the usefulness of using complex, dynamic sounds in the assessment of tinnitus. In a previous study, a free-classification task was used to ascertain the perceptual dimensions of tinnitus-like sounds in normally hearing listeners. Sounds were representative of those commonly used to describe tinnitus (e.g., ringing, tonal, noisy, pulsing, and clicking sounds). Listeners placed icons associated with each sound on a grid and placed similar sounds in clusters. Multi-dimensional scaling conducted on the classification data revealed three different perceptual dimensions. This study evaluated the acoustics of the stimuli to determine the nature of the perceptual dimensions. These analyses estimated a variety of temporal and spectral stimulus properties (e.g., autocorrelation statistics, spectral statistics, envelope characteristics, etc.). The acoustic characteristics were then correlated with the ordering along the three perceptual dimensions. Results suggest a noisy versus tonal dimension, an envelope-based dimension stimulus (choppy versus smooth), and a dimension related to dynamic stimulus characteristics.
INTRODUCTION

One limitation to applying verbal descriptors to the perception of tinnitus (e.g., “ringing”, “tonal”, and “buzzing”) is the ambiguity of the terminology that may be related to an individual’s perceptual experience and familiarity with the descriptors. The present study was designed to take initial steps toward establishing the perceptual dimensions present in tinnitus by relating acoustic analyses to multi-dimensional scaling results from normal-hearing listeners. The purposes of this study are to understand tinnitus-like sounds from a perceptual perspective and to establish a representative sound bank to be used for matching studies and a tinnitus screener for people who have tinnitus. We expect to ultimately develop a replacement to pitch matching, which has been shown to have poor test-retest reliability and questionable validity in tinnitus patients (Henry and Meikle, 2000).

METHODS

Stimuli

60 unique sounds were chosen as being representative of the major terms used to describe tinnitus (such as buzzing, ringing, whistling, tonal, crickets, roaring etc.; see Meikle and Griest, 1989; Meikle et al., 2004). Environmental sounds were taken from The General Series 6000 Sound Library, whereas the noises and tones were digitally generated by the experimenters. All sounds were presented to subjects through one earphone of a Sennheiser HD250 II Linear headset via a 24-bit Card Deluxe sound card.

Free Classification Procedure

A free classification method similar to that used by Clapper and Pisoni (2007) was adopted. 15 normal-hearing listeners were presented with buttons corresponding to each of the 60 sounds (buttons were labeled with numbers). Clicking these buttons allowed the sounds to be played. Subjects listened to the sounds and created similarity clusters by placing the buttons corresponding to the sounds onto an empty grid. Sounds that were similar to each other would be placed in a bundle (anywhere on the grid) and dissimilar sounds should be placed in separate bundles. Subjects were allowed to replay the sounds at any time, to move the sounds around the grid, and to create as many clusters as desired. The end result was a grid consisting of sound clusters, with sounds in each cluster being perceived as having similar characteristics by a particular subject. See Figure 1 for an example of a single subject’s grid after all buttons have been placed.

![Figure 1](image.png)

FIGURE 1. Final result of Free Classification (one subject).

Analyses

Similarity matrices were generated for each subject by assigning zeros to the sounds within a cluster and ones to sounds in separate clusters. Data from the 15 subjects were then combined to generate a group similarity matrix.
This matrix was then subjected to multi-dimensional scaling (MDS) using SPSS (see also Gygi et al., 2007). In order to establish the nature of the perceptual dimensions resulting from MDS, acoustical analyses were conducted on each stimulus and correlated with the perceptual dimensions. Acoustical measures included spectral, temporal, and spectro-temporal analyses – see Table 1.

TABLE 1. List of Acoustic Analyses

<table>
<thead>
<tr>
<th>Time Domain</th>
<th>Frequency Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crest factor</td>
<td>Octave-band RMS power</td>
</tr>
<tr>
<td>Peak statistics</td>
<td>Spectral change statistics</td>
</tr>
<tr>
<td>Across-channel envelope correlation</td>
<td>Octave-band modulation statistics</td>
</tr>
<tr>
<td>Burst statistics</td>
<td>Spectral moments</td>
</tr>
<tr>
<td>Autocorrelation statistics</td>
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</tbody>
</table>

RESULTS AND DISCUSSION

Figure 2 illustrates the 3-dimensional MDS solutions for the 60 tinnitus-like sounds. The stress value was 0.25 and the R squared was 0.67. The stress and R squared values are very similar to those reported by Gygi et al. (2007) who used a traditional scaling procedure and only environmental sounds.

Sounds are ordered along Dimension 1 with narrowband noises and tones on the negative side and roars and broadband noises on the positive side. Sounds in the middle of the perceptual dimension are buzzes, rings, hums, and pulsing sounds. These sounds have complex spectra or harmonic characteristics. Consequently, we anticipate that this dimension may be related to the pitch percept, with strong-pitched sounds on the negative side (tones) and weak-pitched sounds on the positive side (noises). The acoustic analyses confirmed this interpretation. Significant correlations between dimension 1 and the number of temporal peaks, the cross-channel envelope correlation, octave band RMS power, and the size of the autocorrelation function peak were obtained.

Sounds are ordered along Dimension 2 with noises, tones, and roars being negative and buzzes, hums, pulses and rings being positive. Here, it appears that the sounds are ordered from steady (e.g., tones and noises) to pulsating (hums and buzzes). Few sounds are in the middle of this dimension. This dimension may be related to the perception of the stimulus envelope with steady sounds on the negative side and temporally varied sounds on the positive side. The acoustic analyses confirmed this interpretation. Significant correlations between dimension 2 and the crest factor, octave-band modulation statistics, and the octave band RMS power were obtained.
The interpretation of Dimension 3 is not as obvious from visual inspection as that of Dimensions 1 and 2. Noises, tones, and roars are in the center of the dimension. Buzzes and hums are on the negative side whereas rings and pulsing sounds are on the positive side. Here, the acoustic analyses are important for interpreting the nature of this perceptual dimension. Significant correlations were obtained between Dimension 3 and the crest factor, cross-channel envelope correlation, and the spectral change statistics. These correlations are related to both envelope and spectrum. Consequently, it is likely that Dimension 3 is related to the spectro-temporal properties of the sounds. In particular, spectral changes occurring over time appear to be important for these sounds. Noises, tones and roars are in the center of this dimension because these sounds have almost time-invariant spectral composition. Yet, additional analysis is needed to further elucidate the nature of this dimension.

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REFERENCES