Training-induced improvements in the ability to detect spectral modulation

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Introduction

The pattern of peaks and valleys of sound level spread across audio frequency (the spectral envelope) is one of the primary acoustical cues used to distinguish speech sounds, musical timbres, and sound locations in the vertical plane. There is both psychophysical [1] and physiological [2] evidence that spectral envelopes are analyzed by neural circuitry tuned to specific spectral modulation frequencies (cyc/oct).

Here we examined whether the improvements induced by training spectral modulation detection are selective for spectral modulation frequency. To do so we trained normal-hearing adults to detect spectral modulation at a single spectral modulation frequency and determined the extent to which the learning resulting from this training generalized to two untrained spectral modulation frequencies. We reasoned that if the neural circuitry modified by training is selective for the trained spectral modulation frequency, improvements would not generalize to untrained frequencies. We also examined selectivity for audio frequency by testing at an untrained range of audio frequencies, with the trained spectral modulation frequency.

Method

Spectral Modulation Detection:

<table>
<thead>
<tr>
<th>Amp (dB)</th>
<th>Freq (log Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>signal</td>
<td>signal</td>
</tr>
</tbody>
</table>

Procedure:
- Three-Interval Forced-Choice w/ feedback
- 3-down, 1-up: estimates 79% correct
- Adaptively varied modulation depth

Stimuli:
- Random phase gaussian noise carrier
- 100-ms duration w/ 10-ms on/off ramps
- 35 dB Spectrum Level +/- 8 dB level rove
- Random spectral modulation phase
- Presented monaurally to the left ear

Experiment Design

<table>
<thead>
<tr>
<th>Day</th>
<th>Days 2-8</th>
<th>Day 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Test</td>
<td>training (n = 11)</td>
<td>Post-Test</td>
</tr>
<tr>
<td>(n = 21)</td>
<td>controls</td>
<td>(n = 21)</td>
</tr>
</tbody>
</table>

Pre and Post Tests: 4 threshold estimates (240 trials) on each of 4 spectral modulation detection conditions

Training: 12 threshold estimates (720 trials) per day for 7 days on a single spectral modulation detection condition (1 cyc/oct; 200-1600 Hz)

Results: Pre- and Post-Test

Most trained listeners did not generalize their learning to untrained spectral modulation frequencies or an untrained range of audio frequencies.

A cluster analysis [3] revealed that 3 of 11 trained listeners showed a distinct pattern of generalization. Their performance worsened at the high spectral modulation and audio frequencies.

Untrained Spectral Modulation Frequencies

<table>
<thead>
<tr>
<th>Trained Condition</th>
<th>Untrained Spectral Modulation Frequencies</th>
<th>Untrained Audio Frequency Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM 1 cyc/oct 200-1600 Hz</td>
<td>0.5 cyc/oct 200-1600 Hz</td>
<td>1 cyc/oct 1600-12800 Hz</td>
</tr>
<tr>
<td>0.25</td>
<td>0.34</td>
<td>0.17</td>
</tr>
<tr>
<td>p = 0.03</td>
<td>p = 0.01</td>
<td>p = 0.50</td>
</tr>
</tbody>
</table>

*p-values: interaction term of a time x group ANOVA using time as a repeated measure

Results: Trained Condition

The trained listeners (p < 0.01) but not controls (p = 0.77) improved significantly between the pre- and post-test.

The trained listeners did not improve between T1 and the post-test, suggesting that training served to maintain pre-test induced learning.

Toward a Model

Representation: audio frequency and spectral modulation filterbank [4].

Naive: Average of 100 signal-standard subtractions

Simulation of Learning: Multiplication of each naive representation by naive representation of 1 cyc/oct; 200-1600 Hz

Improvement: [5]

- 259% 122% 72.7% -18.1%

Conclusions + Implications

Trained listeners improved on spectral modulation detection.

The neural circuitry underlying spectral modulation detection can be modified through experience.

For most listeners, training-induced improvements in spectral modulation detection were specific to the trained spectral modulation frequency, and range of audio frequencies.

The neural circuitry modified by the current training appears to be selective for a narrow range of spectral modulation and audio frequencies.

A small subset of trained listeners got worse at both the higher spectral modulation frequency and the higher audio frequency.

This subset of listeners might have chosen a strategy that engaged a neural circuit that is most sensitive to low spectral modulation and audio frequencies.

Footnotes

[4]Hierachical cluster analysis computed on the euclidean distance between the raw post-training values of all listeners on all conditions.

Acknowledgments

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