Threshold for Pitch Discrimination of Complex Tones Explained by Harmonic Numbers

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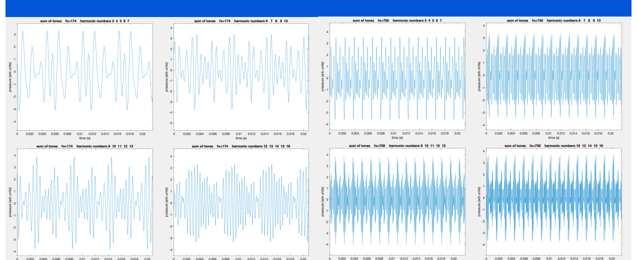
Background

The results from Bernstein and Oxenham's research on pitch perception and harmonic number indicate the dependence of pitch perception on harmonic numbers. As harmonic number increases, performance on pitch discrimination decreases (Bernstein and Oxenham, 2003). This is thought to reflect basilar membrane function, often modeled as a bank of bandpass filter with bandwidths increase with increasing frequency. Thus, low harmonics are 'resolved' because harmonics are encoded in separate filters whereas higher harmonics are not 'resolved' because they are jointly encoded in single filters, leading to temporal envelope (Plack and Oxenham, 2005).

The purpose of this project is to investigate how pitch discrimination is dependent on harmonic numbers and independent of frequency.

Method



Harmonics	174 Hz	700 Hz
3-7	522-1218 Hz	2100-4900 Hz
6-10	1044-1740 Hz	4200-7000 Hz
9-13	1566-2262 Hz	6300-9100 Hz
12-16	2088-2784 Hz	8400-11200 Hz

Table 1. Frequencies at different harmonics of fundamental frequencies 174 Hz and 700 Hz.

Subjects: one female, and one male were tested on pitch perception using 48 blocks in which each contains 50 trials. Each trial is a complex tone of 5 harmonic numbers.

Based on the results of Bernstein and Oxenham, fundamental frequencies of 174 Hz and 700 Hz were chosen.

Stimuli had durations of 300 milliseconds. Low-pass filtered white noise was added to reduce the low-frequency information potentially provided by non-linearities in the cochlea.

Results

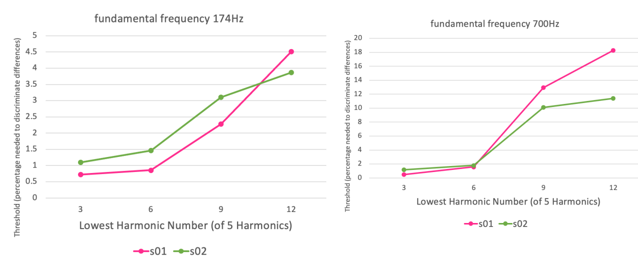


Figure 1. Results of each subject's threshold at low (174 Hz) and high (700 Hz) fundamental frequency across different harmonic numbers. The stimuli were composed on 5 sequential harmonics, the lower harmonic number being indicated on the x-axis.

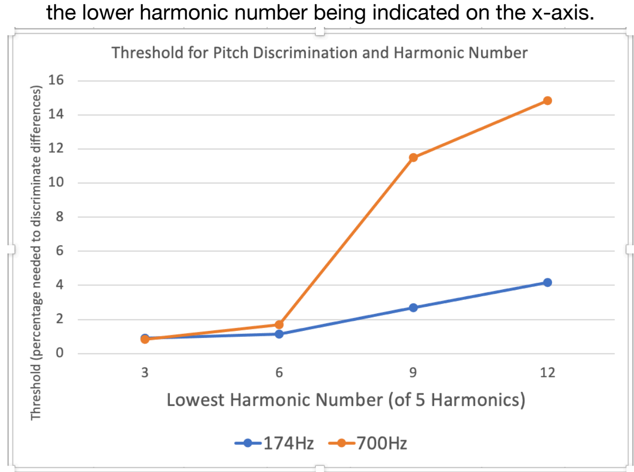


Figure 2. Average threshold of both subjects at low and high fundamental frequencies across different harmonic numbers.

Thresholds of both low and high fundamental frequencies are low for harmonic numbers starting at 3 and 6:

- For fundamental frequency 174 Hz with harmonic number 3-7, the threshold is 0.91% (as deltaFo/Fo, where Fo is the fundamental frequency), and 1.16% when lower harmonic number was 6.
- For higher harmonic numbers, thresholds increased, and the increase on thresholds is more rapid for the 700 Hz fundamental frequency than for 174 Hz fundamental frequency.

On the other hand, discrimination thresholds at both low and high fundamental frequencies drastically increases at harmonics 9 and 12:

- Threshold for fundamental frequency 174 Hz is 2.69% at harmonics 9, and 4.19% at harmonics 12.
- Threshold for fundamental frequency 700 Hz is 11.52% at harmonics 9, and 14.84% at harmonics 12.

Discussion

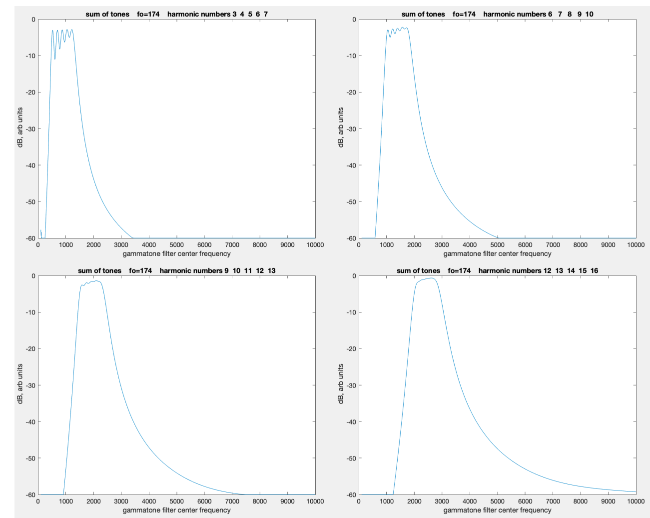


Figure 3. Estimated excitation patterns of basilar membrane at low fundamental frequency across various harmonic numbers.

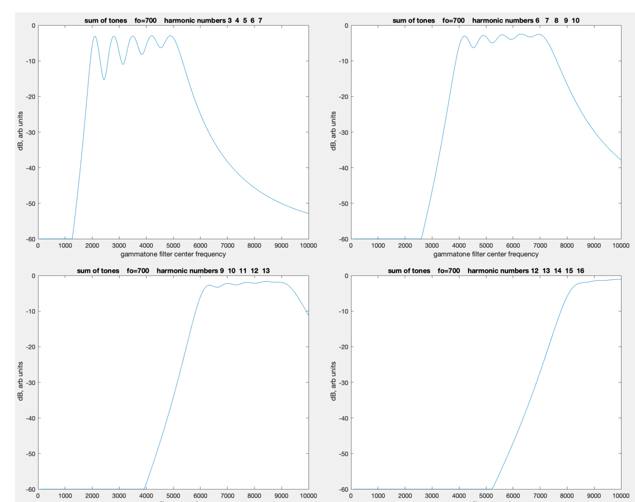


Figure 4. Estimated excitation patterns of basilar membrane at high fundamental frequency across various harmonic numbers.

Low pitch discrimination threshold at low harmonic numbers and high pitch discrimination threshold at high harmonic numbers suggests its consistent with the basis of pitch perception being based on the "excitation pattern" where the level of the individual components are well resolved. On the other hand, high harmonic numbers are encoded jointly within one 'filter' and this realm pitch discrimination threshold depend on the periodicity of the neural response encoded at the periphery.

Nonetheless, pitch discrimination at high harmonic numbers are not equal between low and high fundamental frequency. This suggests Moore's research on difference limen as a function of frequency where best pitch discrimination falls below 2000 Hz. At high harmonics, low fundamental frequency still has frequency around 2000 Hz but high fundamental frequency jumps above 4000 Hz at harmonics 6 (*Table 1*).

Figure 5 shows that there is a loss in sensitivity to tones for higher frequencies because high-frequency tones are not as well encoded as low-frequency, the tones comprising the stimuli with higher fundamental frequencies are more poorly encoded, and thus thresholds are diminished.

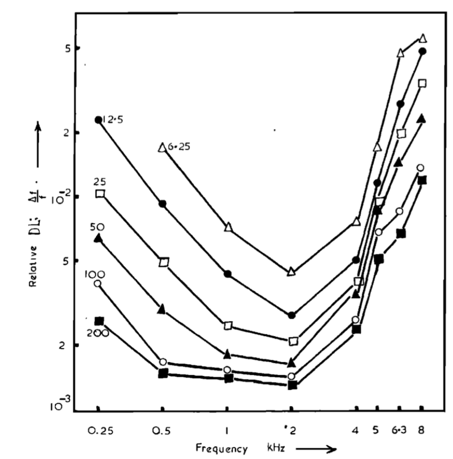


Figure 5. Moore's study of frequency difference limens as a function of frequency.

References

Bernstein, J. G., & Oxenham, A. J. (2003). Pitch discrimination of diotic and dichotic tone complexes: Harmonic resolvability or harmonic number?. *The Journal of the Acoustical Society of America*, 113(6), 3323-3334.

Moore, B. C. (1973). Frequency difference limens for short-duration tones. *The Journal of the Acoustical Society of America*, 54(3), 610-619.

Plack, C. J., & Oxenham, A. J. (2005). The psychophysics of pitch. In *Pitch* (pp. 7-55). Springer, New York, NY.

Acknowledgements

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