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Pitch coding of complex tones in the normal and impaired auditory system

Federica Bianchi[1*], Sébastien Santurette[1], Torsten Dau[1]

*fbia@elektro.dtu.dk

[1] Oticon Center of Excellence for Hearing and Speech Sciences, Technical University of Denmark, Ørsteds Plads Building 352, 2800 Kongens Lyngby, Denmark

Oticon Centre of Excellence for Hearing and Speech Sciences

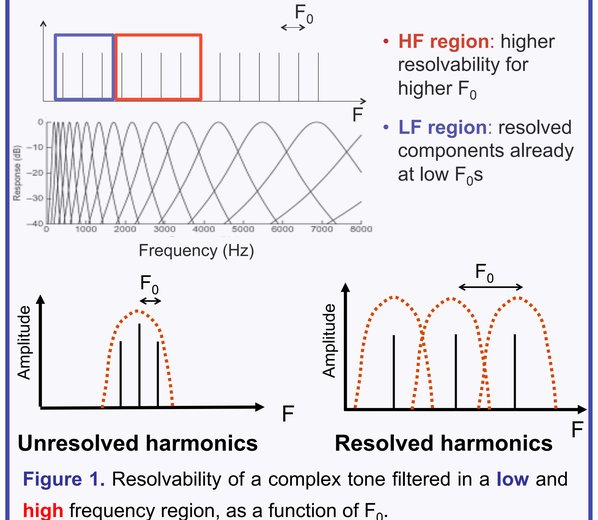
Introduction

Recent physiological studies suggested that sensorineural hearing loss (SNHL) can lead to an enhancement of temporal envelope coding which may arise from a variety of factors, e.g., broader auditory filters, a reduction of cochlear compression due to outer hair cell damage (Kale and Heinz, 2010; Henry et al., 2014) and altered auditory-nerve response temporal dynamics (Scheidt et al., 2010). The aim of the present behavioral study in humans was to clarify if an enhancement of temporal envelope coding affects the pitch perception of hearing-impaired (HI) listeners. An **amplitude-modulation detection task** and a **pitch discrimination task** were performed in normal hearing (NH) and HI listeners .

1. Pitch discrimination

Method

Pitch discrimination of complex tones was measured via difference limens for fundamental frequency (F_0DLs). Complex tones were filtered in a **low** (LF: 0.3-1.5 kHz) and **high** (HF: 1.5-3.5 kHz) frequency region, with components added either in sine or random phase.



- **HF region**: higher resolvability for higher F_0
- **LF region**: resolved components already at low F_0s

Figure 1. Resolvability of a complex tone filtered in a **low** and **high** frequency region, as a function of F_0.

Results F_0DL

14 normal-hearing listeners

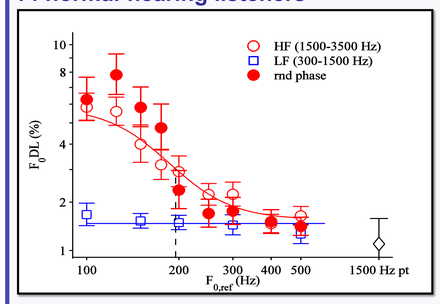


Figure 2. Mean F_0DLs for 14 NH listeners (open symbols: sine phase; closed symbols: random phase).

- HF region: performance improves with increasing F_0 (**F_0DL_{max}: 6%**)
- LF region: pitch discrimination independent of F_0 (**F_0DL_{min}: 1.7%**)
- resolvability: F_0 > 200 Hz

5 hearing-impaired listeners (30-60 dB HL between 1.5-4 kHz)

HI group 1

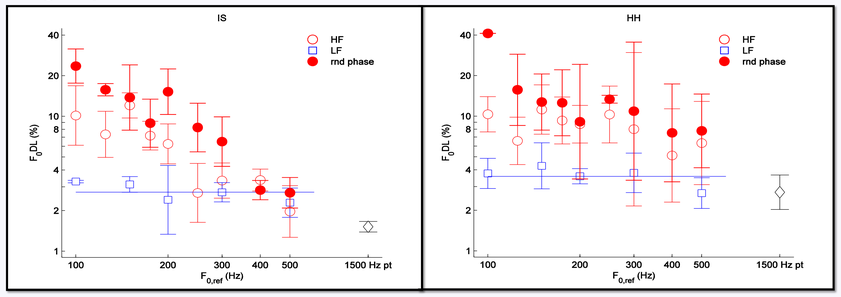


Figure 3. Individual F_0DLs for 2 HI listeners (open symbols: sine phase; closed symbols: random phase).

- similar trend as NH, but resolvability for F_0 >= 400 Hz
- higher **F_0DL_{min} (3-4%)** and **F_0DL_{max} (10% for sine phase)**

HI group 2

- low F_0s: better than NH for sine phase **(2-5%)**
- med F_0s: worsening in performance
- at 500 Hz: components begin to get resolved

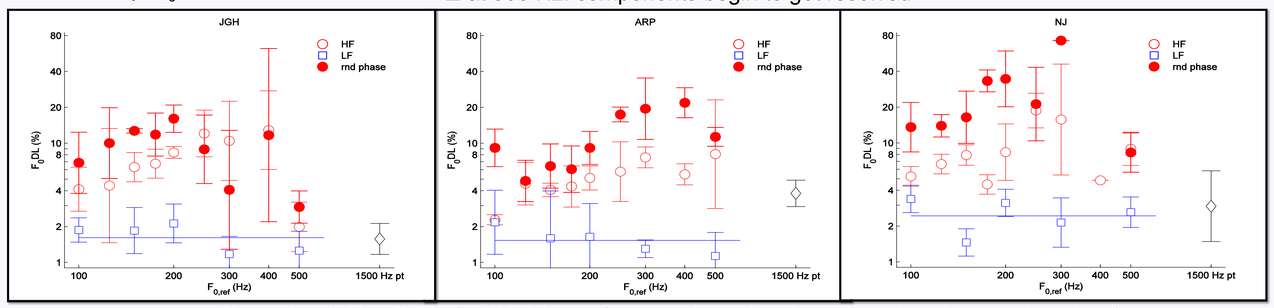


Figure 4. Individual F_0DLs for 3 HI listeners (open symbols: sine phase; closed symbols: random phase).

2. Amplitude modulation detection

- measure of the ability to detect amplitude modulations for sinusoidal carriers (f_c = 2 kHz, f_m= 25-1500 Hz) via temporal modulation transfer function (TMTF).

Results TMTF

HI group 1 vs NH

- similar (IS) or worse (HH) performance than NH
- threshold independent of f_m up to 400-500 Hz (IS), then it decreases with f_m

HI group 2 vs NH

- low F_0s: lower threshold than NH (JGH and ARP) -> not more components
- medium F_0s: worsening in performance ("sluggishness")

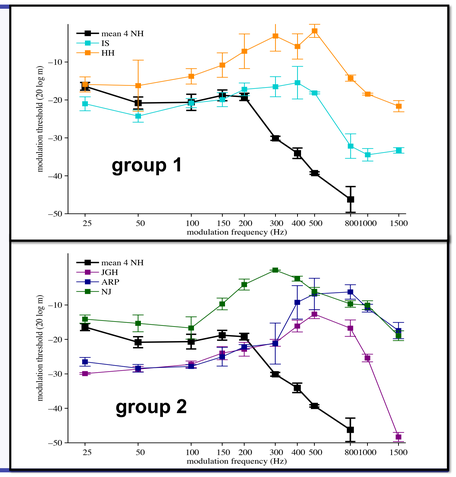


Figure 5. Mean TMTF for 4 NH (black squares) and individual TMTF for 5 HI listeners (colored symbols).

Comparison F_0DL and TMTF

- enhancement at low F_0s and "sluggishness" in both F_0DL and TMTF (enhancement occurred for 2 HI listeners).

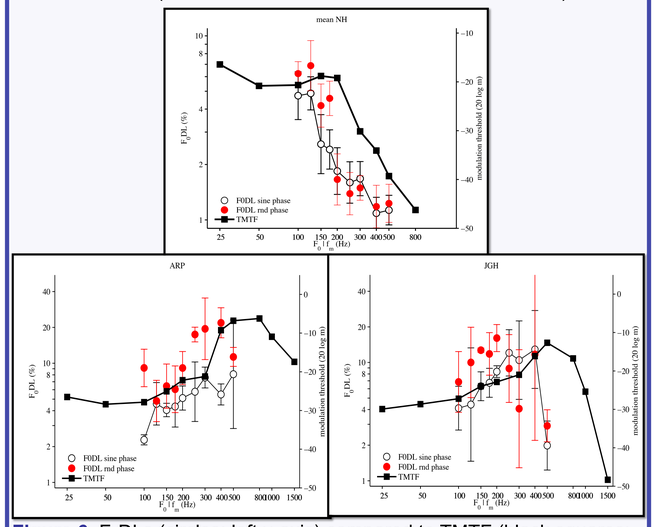


Figure 6. F_0DLs (circles; left y-axis) compared to TMTF (black squares; right y-axis) for 4 NH (upper panel) and 2 HI listeners (lower panel).

Summary

- NH: performance in F_0DLs improves with resolvability
- HI: large variability in F_0DLs; resolvability did not imply better performance in F_0DL.
- TMTF shows enhancement of envelope coding (not due to more components within the filter) for 2 HI listeners, who also show improved pitch discrimination abilities at low F_0s.

Conclusion

- Resolvability alone could not explain the trend in F_0DLs. Pitch discrimination of unresolved complex tones seemed to rely on temporal envelope cues (Kale et al., 2014): enhanced temporal coding was consistent with lower pitch discrimination thresholds and limitations in coding fast amplitude fluctuations was consistent with poor pitch discrimination.
- Future work: measure basilar membrane input/output function. Hypothesis: reduction of compression with SNHL should correlate with enhancement of envelope coding.

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