DTU Library

Frequency modulation excursion and rate discrimination in normal-hearing and hearing-impaired listeners

Schindwolf, Isabel ; Vatti, Marianna; Santurette, Sébastien

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

we try to elucidate between these two mechanisms by measuring AM detection thresholds for bilateral cochlear implant (CI) users with an experimental sound processing strategy that lacked any form of dynamic processing. The probe was a 50-ms, 1.5 kHz tone modulated in amplitude at a rate of 40 Hz. AM detection thresholds were measured monaurally for the probes presented at the onset (early condition) of a 400-ms broadband (0.1-10 kHz) noise or delayed by 300 ms (late condition). The levels for the probe and the noise were fixed at -20 and -30 dB full scale (FS), respectively. The noise was presented ipsilaterally, contralaterally, and bilaterally to the test ear. On average, AM detection thresholds were 4 dB better in the late than in the early condition and the size of the temporal effect was similar for the three noise lateralities. The results were broadly consistent, both in trend and magnitude, with our previous results for NH listeners. Because CI users lack both acoustic and MOC reflexes and since we used a time-invariant sound processing strategy, the data suggest that the temporal effect on AM detection is due to central dynamic-range adaptation for both NH and CI listeners. [Work supported by the University of Salamanca, Banco Santander, MED-EL GmbH, and MINECO (BFU2015-65376-P).]

PS 375

Frequency modulation excursion and rate discrimination in normal-hearing and hearing-impaired listeners

Isabel Schindwolf[1]; Marianna Vatti[2]; **Sébastien Santurette**[1]

[1]Hearing Systems, Department of Electrical Engineering, Technical University of Denmark & Department of Otorhinolaryngology, Head and Neck Surgery, and Audiology, Copenhagen University Hospital; [2]Eriksholm Research Centre, Oticon A/S

Most natural sounds contain frequency fluctuations over time such as changes in their fundamental frequency, non-periodic speech formant transitions, or periodic fluctuations like musical vibrato. These are sometimes characterized as frequency modulation (FM) with a given excursion (FMe) and rate (FMr). Accurate processing of FM may play an important role in music and speech perception, especially in complex instrument or talker situations. While age and sensorineural hearing loss (SNHL) can affect FM detection thresholds, less is known about how they affect FMe and FMr discrimination. As discrimination tasks are closer to what listeners may use to segregate sound sources, this study investigated the effects of age and SNHL on FMe and FMr difference limens (DLs) for reference values typical of frequency fluctuations observed in speech and music signals.

FMeDLs and FMrDLs were measured in younger normal-hearing (NHy), older near-normal-hearing (NHo), and older hearing-impaired (HIo) listeners with moderate sloping SNHL, for pure tones at Fc=400 and Fc=1000 Hz to which sinusoidal FM was applied. Reference FMe values ranged from 2.1% to 18.1% of Fc. Reference FMr values were 2, 5, and 20 Hz. In a 3-alternative forced-choice adaptive procedure, listeners had to choose the interval with the highest FMe or FMr. As a measure of TFS processing ability, the highest frequency at which listeners could detect an interaural-phase-difference (IPD) of 180° was obtained.

The results were very similar for Fc=400 and Fc=1000 Hz. FMeDLs, expressed as the Weber fraction, decreased with increasing FMr and increasing FMe. Group differences were enhanced at large reference FMe values, with significantly elevated FMeDLs in HIo vs NHy listeners, and NHo listeners in between on average. For FMrDLs, the Weber fraction decreased with increasing FMe but did not vary consistently with FMr. Group differences were larger for the small reference FMe, with significantly elevated FMrDLs for NHo and HIo vs NHy listeners. IPD detection thresholds were significantly correlated with FMeDLs at slow rates and large excursions, consistent with an advantage of having access to TFS cues in these conditions.

Overall, SNHL affected the ability to discriminate changes in both FMe and FMr, while age mostly affected rate discrimination. The difficulties of HIo listeners with FMe discrimination were most pronounced at large excursions and slow rates, more related to the frequency changes present in speech formant transitions and musical vibrato. Therefore, impaired processing of FM may partly account for altered perception of such features.

PS 376

Individual Differences in Frequency Modulation Detection in Listeners with Sensorineural Hearing Loss

Kelly L. Whiteford; Heather A. Kreft; Andrew J. Oxenham

University of Minnesota

Background

In the peripheral auditory system, frequency may be represented by either the place of maximal excitation along the cochlea (place code), or by the precise, phase-locked firing of auditory nerve fibers, providing a pooled representation of the stimulus periodicity (temporal code). Whether pure-tone frequency modulation (FM) uses one or both of these mechanisms remains unclear. Studies in normal-hearing listeners have led to the hypothesis

Frequency modulation excursion and rate discrimination in normal-hearing and hearing-impaired listeners

Isabel Schindwolf[1,3], Marianna Vatti[2], Sébastien Santurette[1,3]

1) Hearing Systems, Department of Electrical Engineering, Technical University of Denmark; 2) Eriksholm Research Centre;
3) Department of Otolaryngology, Head & Neck Surgery, and Audiology, Copenhagen University Hospital – Rigshospitalet

PS 375

Introduction

Most natural sounds contain frequency fluctuations over time such as changes in their fundamental frequency, non-periodic speech formant transitions, or periodic fluctuations like musical vibrato. These are sometimes characterized as frequency modulation (FM) with a given excursion (FMe) and rate (FMr) (Fig.1). Accurate processing of FM may play an important role in music and speech perception, especially in complex instrument or talker situations. While age and sensorineural hearing loss (SNHL) can affect FM detection thresholds [1,2] and SNHL can affect the range of FMe and FMr values producing a sung vowel percept (Fig.2) [3], less is known about how these factors affect FMe and FMr discrimination. Moreover, reference data for FM discrimination in normal-hearing (NH) listeners remains scarce [4-6]. As discrimination tasks are closer to what listeners may use in real-life situations, this study investigated the effects of age and SNHL on FMe and FMr difference limens (DLs) for reference values typical of frequency fluctuations observed in speech and music signals.

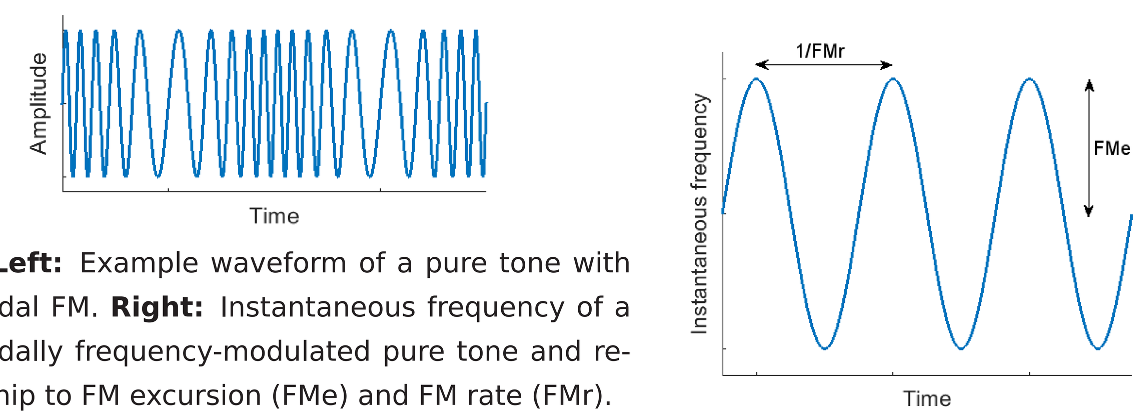


Fig.1 Left: Example waveform of a pure tone with sinusoidal FM. **Right:** Instantaneous frequency of a sinusoidally frequency-modulated pure tone and relationship to FM excursion (FMe) and FM rate (FMr).

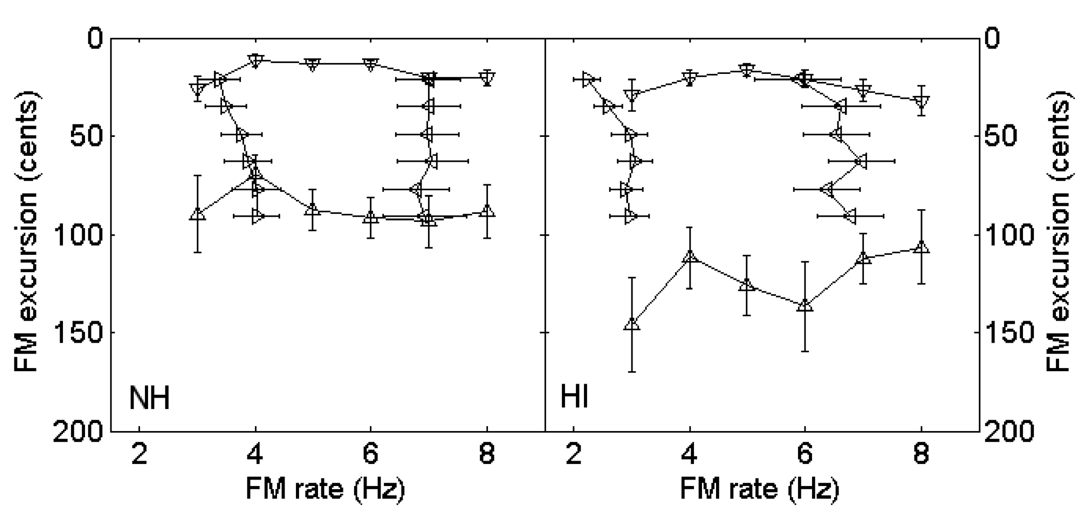
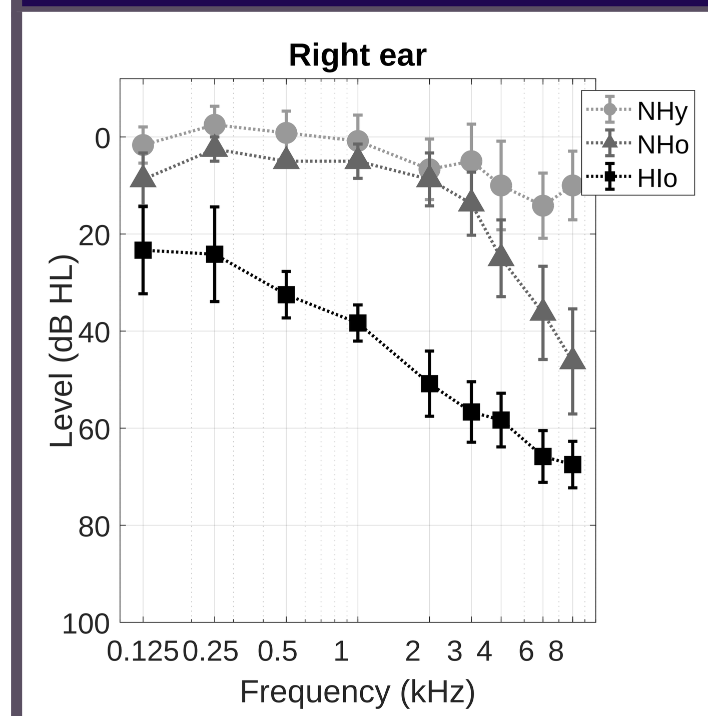


Fig.2 Average FM excursion and rate values producing a sung vowel percept in NH (left panel) and HI (right panel) listeners, when coherent FM is applied to a complex tone [3].

Listeners



Three listener groups (Fig.3):

- **NHy:** 6 younger (22-26 yo) listeners with normal hearing thresholds up to at least 2 kHz

- **NHo:** 4 older (64-74 yo) listeners with normal hearing thresholds up to at least 2 kHz

- **HIo:** 6 older (62-79 yo) listeners with mildly elevated hearing thresholds below 2 kHz (mean in the stimulus frequency range: 33.3 dB HL)

Fig.3 Mean air-conduction hearing thresholds in the right ear for the three listener groups.

FM excursion discrimination

Methods

- Pure-tone stimuli at Fc = 400 or 1000 Hz with sinusoidal FM.
- Three reference FMr values: 2, 5, and 20 Hz.
- One small (2.1% Fc) and one large (13.9% Fc at 400 Hz and 18.1% Fc at 1000 Hz) reference FMe value.
- 3AFC FMe discrimination task with fixed FMr: Which of three 750-ms intervals had the highest FMe?
- All stimuli presented at 80 dB SPL (±1 dB level roving) in quiet and with random FM starting phase (0 or π) within each trial.

Results

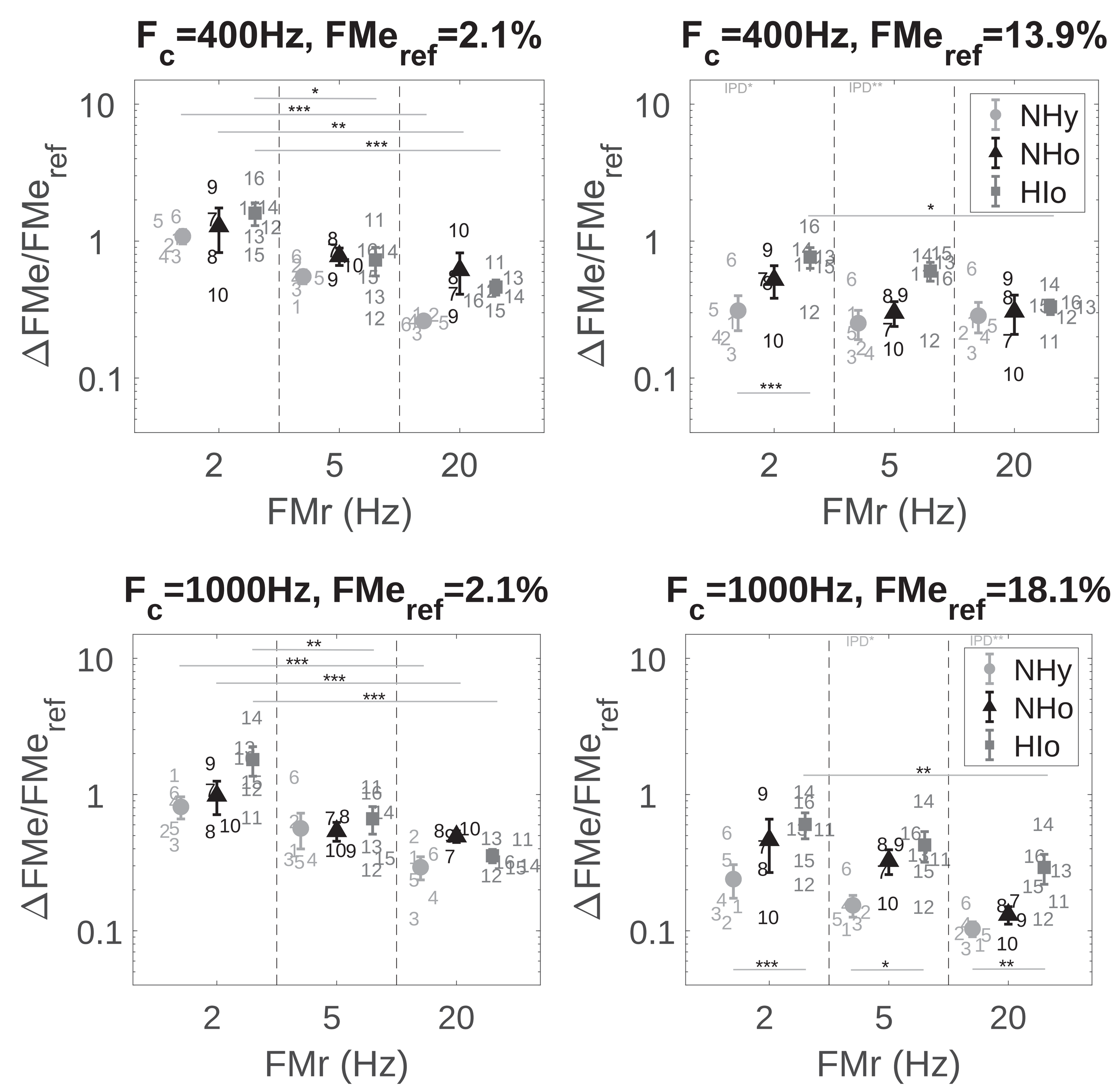
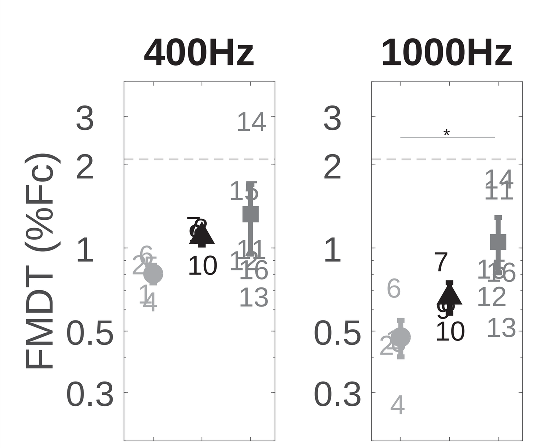


Fig.4 FM excursion difference limens (FMeDLs) expressed as the Weber fraction for a 400-Hz (top panels) and a 1000-Hz (bottom panels) carrier with three fixed FM rates (FMr) at small (left panels) and large (right panels) reference excursions. Mean and standard error for each listener group and individual data. $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.



- FMe detection thresholds (FMDT) measured (reference FMe set to 0).
- FMDTs typically below 2.1% (Fig.5), such that the FMeDLs (Fig.4) can be assumed to reflect discrimination and not detection abilities.
- 2-way ANOVA: Significant main effects of Fc (p=0.006) and group (p=0.009), no interaction.

Fig.5 FM excursion detection thresholds (FMDTs) expressed in % Fc for a 400-Hz (left panel) and a 1000-Hz (right panel) carrier at a 2-Hz rate. Mean and standard error for each listener group (see Fig.4 for legend) and individual data. The dotted line marks the reference excursion of 2.1% as used in the FMe discrimination experiment. $^{*}p < 0.05$.

FM rate discrimination

Methods

- Same stimuli and reference values as for FMe discrimination.
- 3AFC FMr discrimination task with fixed FMe: Which of three 750-ms intervals had the highest FMr?

Results

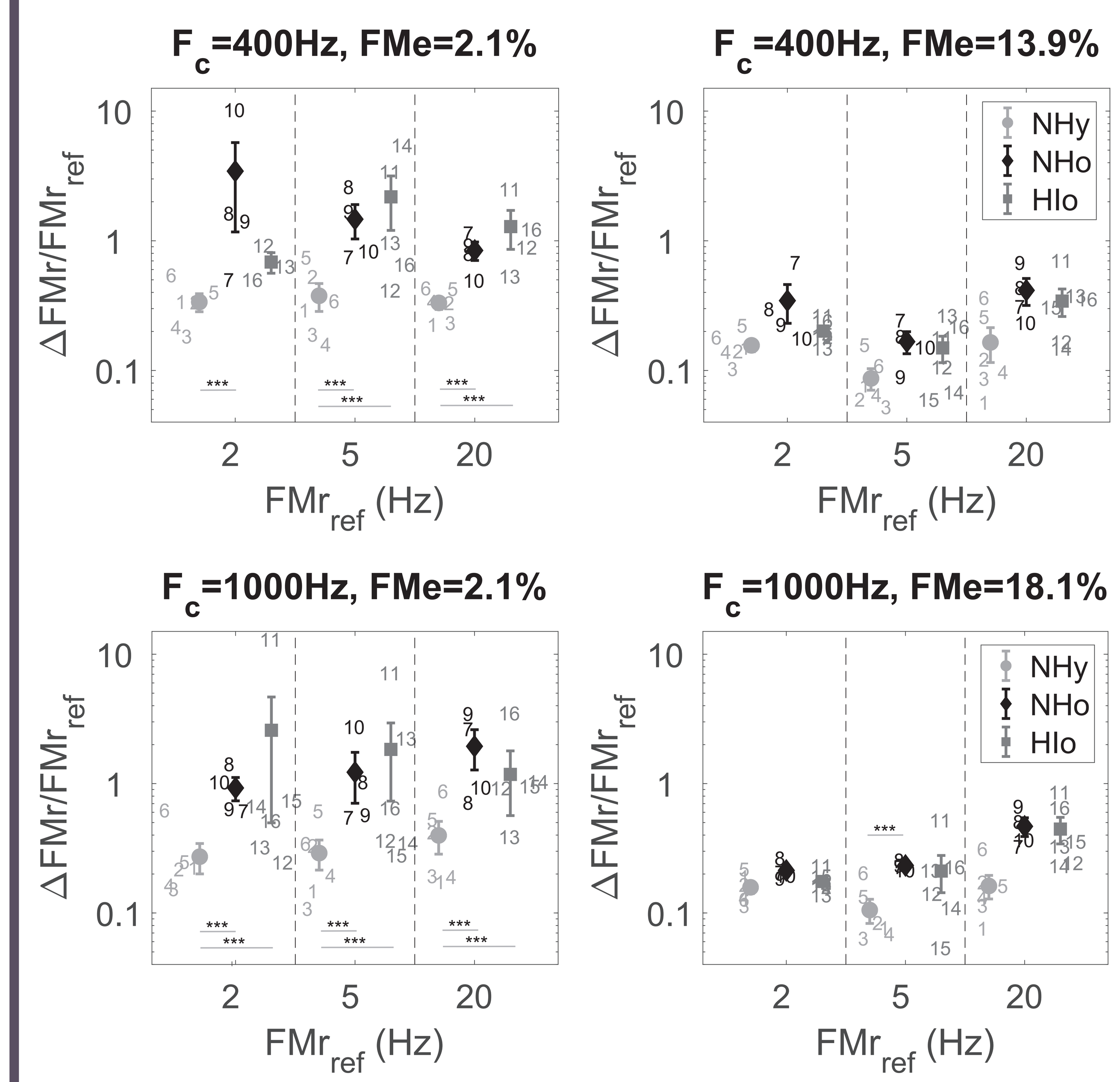


Fig.6 FM rate difference limens (FMrDLs) expressed as the Weber fraction for a 400-Hz (top panels) and a 1000-Hz (bottom panels) carrier with small (left panels) or large (right panels) excursions (FMe) at three reference FM rates. Mean and standard error for each listener group and individual data. $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

Statistical analysis

4-way ANOVA on FMeDLs

- Main effects (FMe, FMr, group, Fc) all significant (p<0.001).
- Interactions: FMe x FMr (p=0.015), FMe x group (p=0.017).

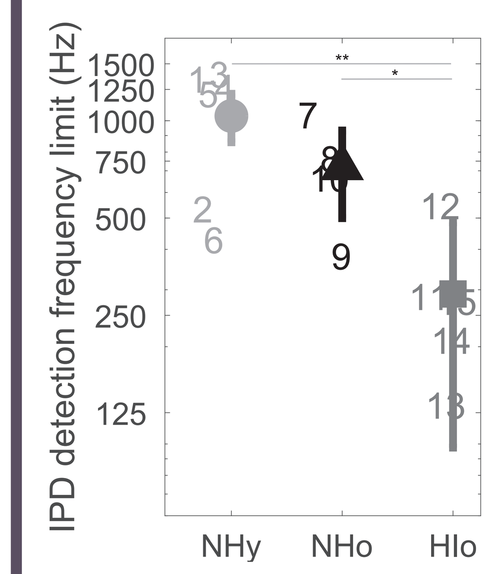
4-way ANOVA on FMrDLs

- Main effects: FMe (p<0.001), FMr (p=0.006), group (p<0.001).
- Interactions: FMe x FMr (p=0.020), FMe x group (p=0.005).

Presented at: 41st MidWinter Meeting of the Association for Research in Otolaryngology February 9-14, 2018, San Diego, CA — Poster #PS 375.

Contact: Isabel Schindwolf — *ischindwolf@gnresound.com*
Marianna Vatti — *mvat@eriksholm.com*
Sébastien Santurette — *ses@elektro.dtu.dk*

IPD detection



- Frequency limit for IPD detection measured at 35 dB SL (Fig.7).
- 1-way ANOVA: Significant effect of group (p=0.004).
- Correlations with low-frequency (up to 2 kHz, p=0.008) and high-frequency (from 3 kHz, p=0.020) hearing thresholds, but not with age.
- Correlations with FMeDLs only found at large reference FMe values.
- No significant correlations with FMrDLs.

Fig.7 IPD detection frequency limits in Hz for an IPD of π. Mean and standard error for each listener group and individual data. $^{**}p < 0.01$, $^{*}p < 0.05$ (Bonferroni corrected).

Summary and conclusions

- Very similar results for Fc=400 and Fc=1000 Hz in all groups for both FMe and FMr discrimination, consistent with [4,5].
- **FMeDLs**, expressed as the Weber fraction, decreased with increasing reference FMe and with increasing FMr at small reference FMe values (Fig.4). Group differences were enhanced at large reference FMe values, with significantly elevated FMeDLs in HIo vs NHy listeners, and NHo listeners typically in between.
- For **FMrDLs**, the Weber fraction decreased with increasing FMe but did not vary consistently with reference FMr (Fig.6). Group differences were larger for the small FMe, with significantly elevated FMrDLs for NHo and HIo vs NHy listeners.
- As the stimulus duration was fixed, the observed effects of FMr may have been influenced by the number of available FM cycles, which differed between conditions.
- IPD detection thresholds (Fig.7) were correlated with FMeDLs only for large reference excursions, consistent with an advantage of having access to TFS cues in these conditions.

The present results provide an estimate of FM excursion and FM rate difference limens in NH listeners. Overall, SNHL affected the ability to discriminate changes in both FMe and FMr, while age mostly affected rate discrimination. The difficulties of HIo listeners with FMe discrimination were most pronounced at large excursions and slow rates, more related to the frequency changes present in speech formant transitions and musical vibrato. Therefore, impaired processing of FM may partly account for altered perception of such features.

References:

[1] Moore, B.C.J., & Skrodzka, E. (2002). Detection of frequency modulation by hearing-impaired listeners: Effects of carrier frequency, modulation rate, and added amplitude modulation. J. Acoust. Soc. Am., 111, 327-335.
[2] Whiteford, K.L., Kreft, H.A., & Oxenham, A.J. (2017). Assessing the role of place and timing cues in coding frequency and amplitude modulation as a function of age. J. Assoc. Res. Otolaryngol., 18, 619-633.
[3] Vatti, M., Santurette, S., Pontoppidan, N.H., & Dau, T. (2014). Perception of a sung vowel as a function of frequency-modulation rate and excursion in listeners with normal hearing and hearing impairment. J. Speech Lang. Hear. Res., 57, 1961-1971.
[4] Ozimek, E., & Sek, A. (1990). Difference limens of fm signals. Acta Acust. United Ac., 71, 210-217.
[5] Plack, C.J., & Carlyon, R.P. (1994). The detection of differences in the depth of frequency modulation. J. Acoust. Soc. Am., 96, 115-125.
[6] Sheft, S., Shafiro, V., Lorenzi, C., McMullen, R., & Farrell, C. (2012). Effects of age and hearing loss on the relationship between discrimination of stochastic frequency modulation and speech perception. Ear Hearing, 33, 709.