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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).]

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

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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 (NH), older near-normal-hearing (NHo), and older hearing-impaired (Hlo) 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 Hlo 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 Hlo 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 Hlo 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.

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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

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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.

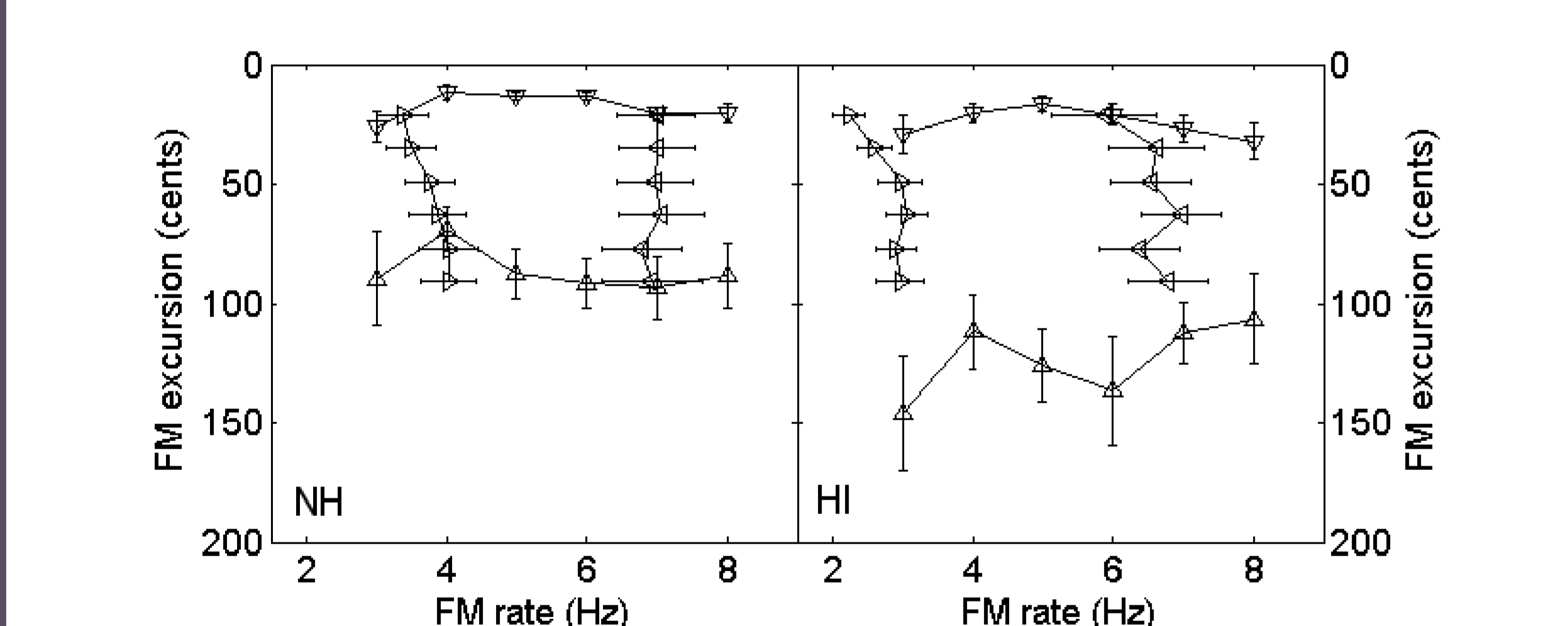
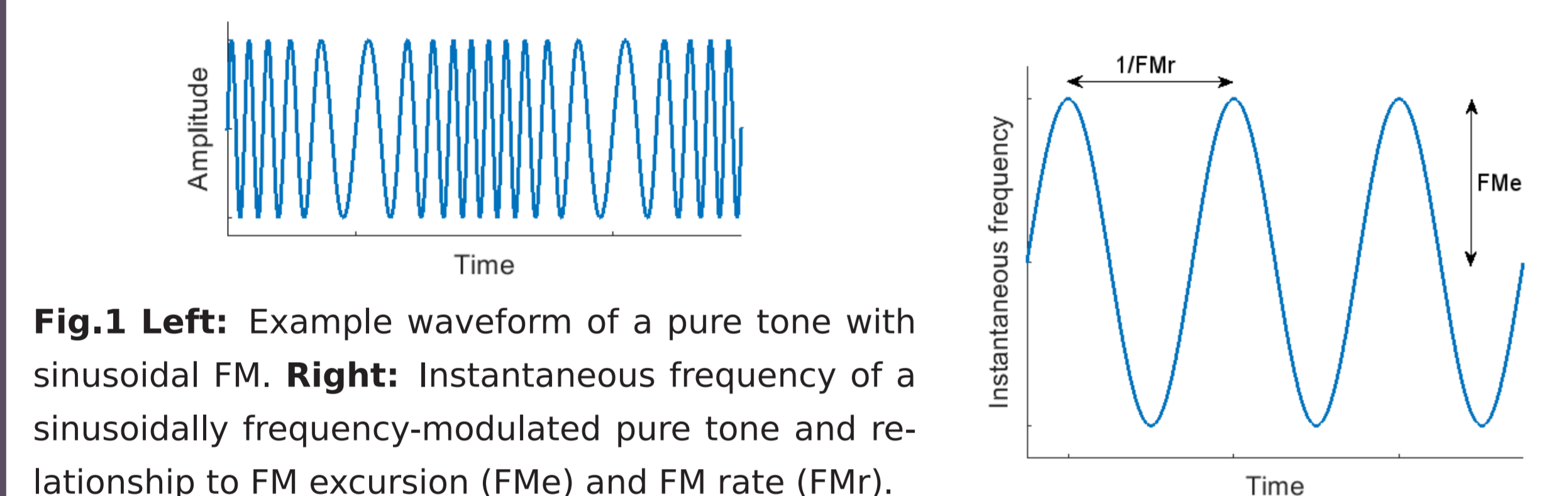


Fig.2 Average FM excursion and rate values producing a sung vowel percept in NH (left panel) and HI (right panel) listeners, when coherent FM is applied to a complex tone [3].

Listeners

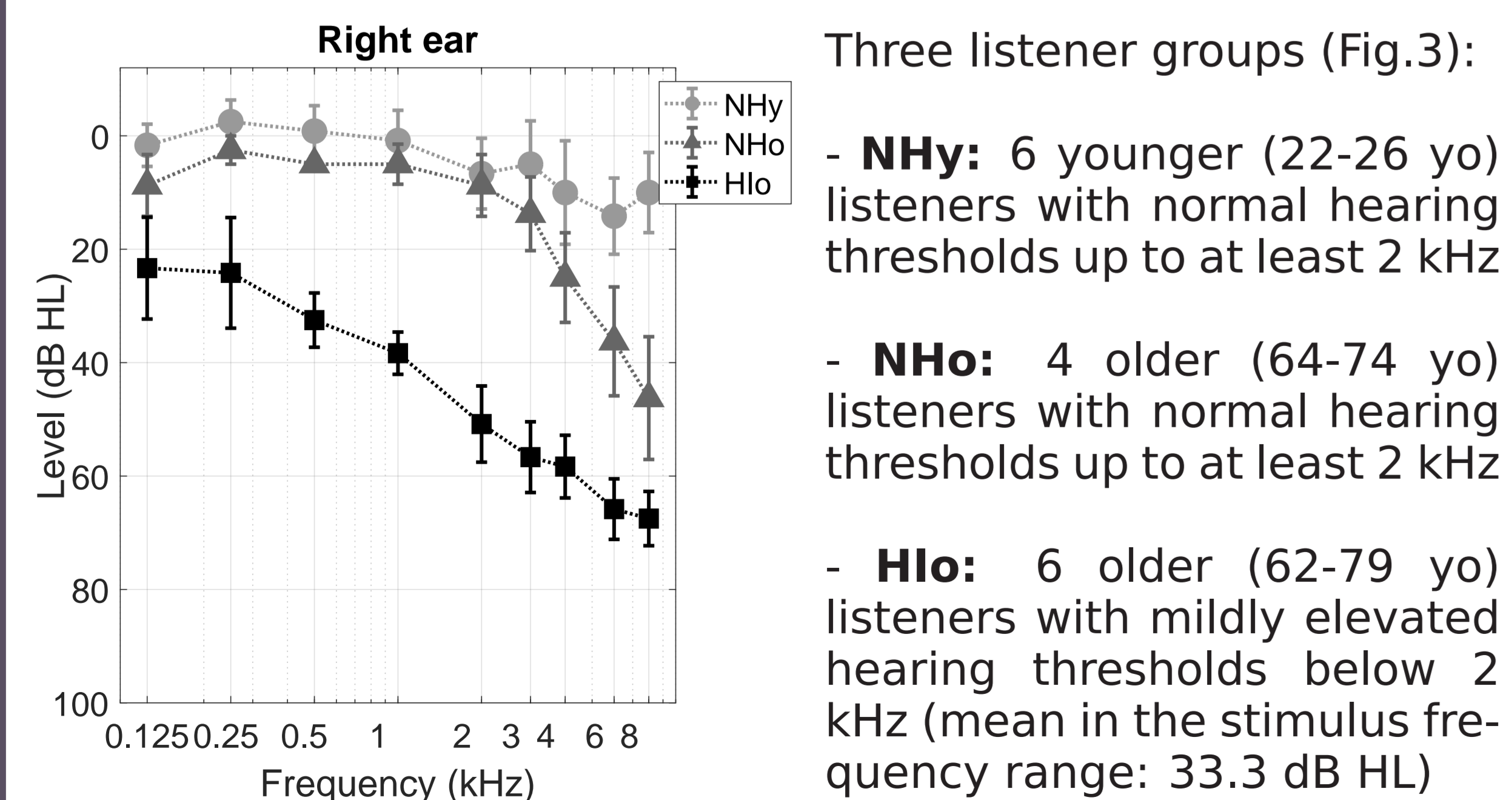


Fig.3 Mean air-conduction hearing thresholds in the right ear for the three listener groups.

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

FM excursion discrimination

Methods

- Pure-tone stimuli at $F_c = 400$ or 1000 Hz with sinusoidal FM.
- Three reference FMr values: 2, 5, and 20 Hz.
- One small (2.1% F_c) and one large (13.9% F_c at 400 Hz and 18.1% F_c 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

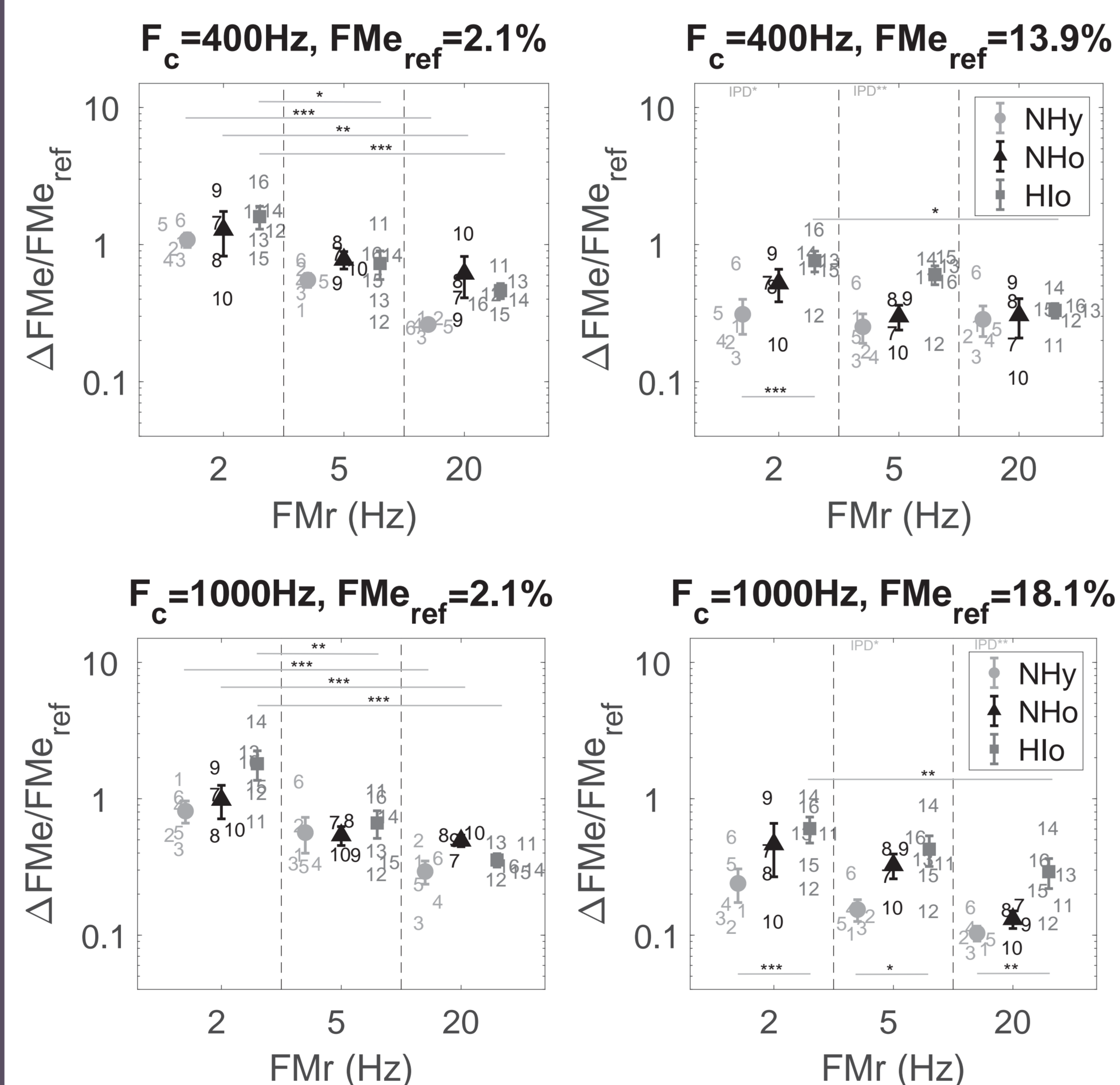


Fig.4 FM excursion difference limens (FMeDLs) expressed as the Weber fraction for a 400-Hz (top panels) and a 1000-Hz (bottom panels) carrier with three fixed FM rates (FMr) at small (left panels) and large (right panels) reference excursions. Mean and standard error for each listener group and individual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

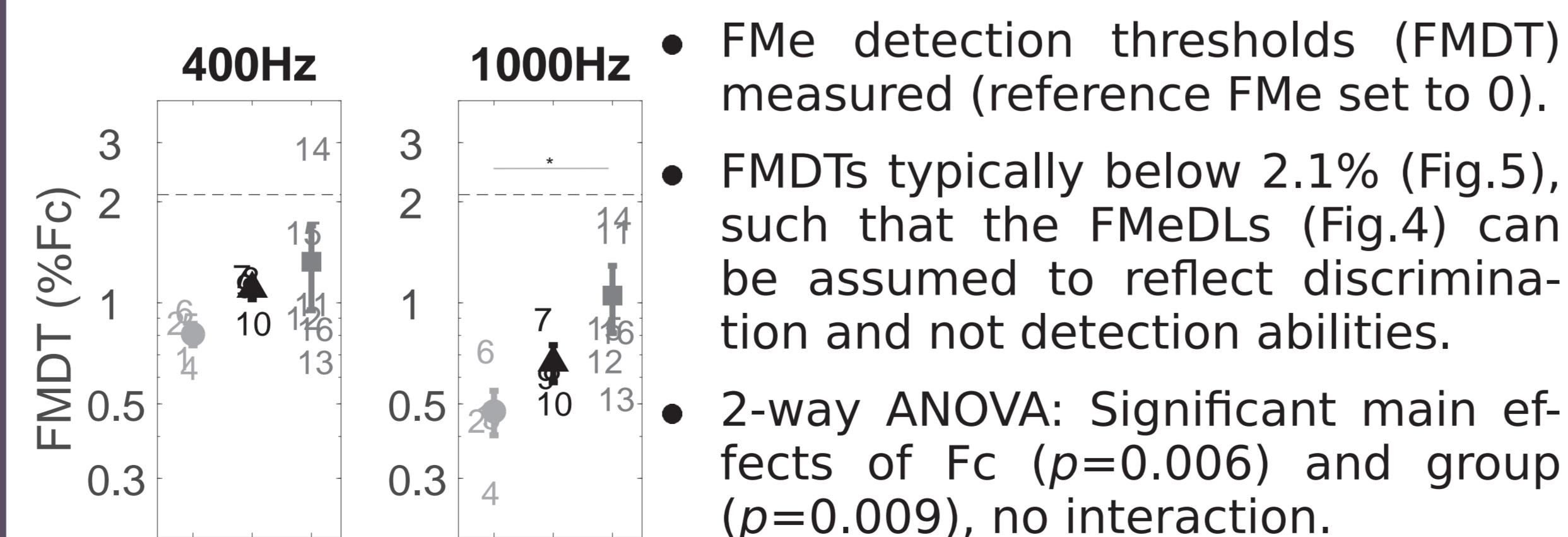


Fig.5 FM excursion detection thresholds (FMDTs) expressed in % Fc for a 400-Hz (left panel) and a 1000-Hz (right panel) carrier at a 2-Hz rate. Mean and standard error for each listener group (see Fig.4 for legend) and individual data. The dotted line marks the reference excursion of 2.1% as used in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

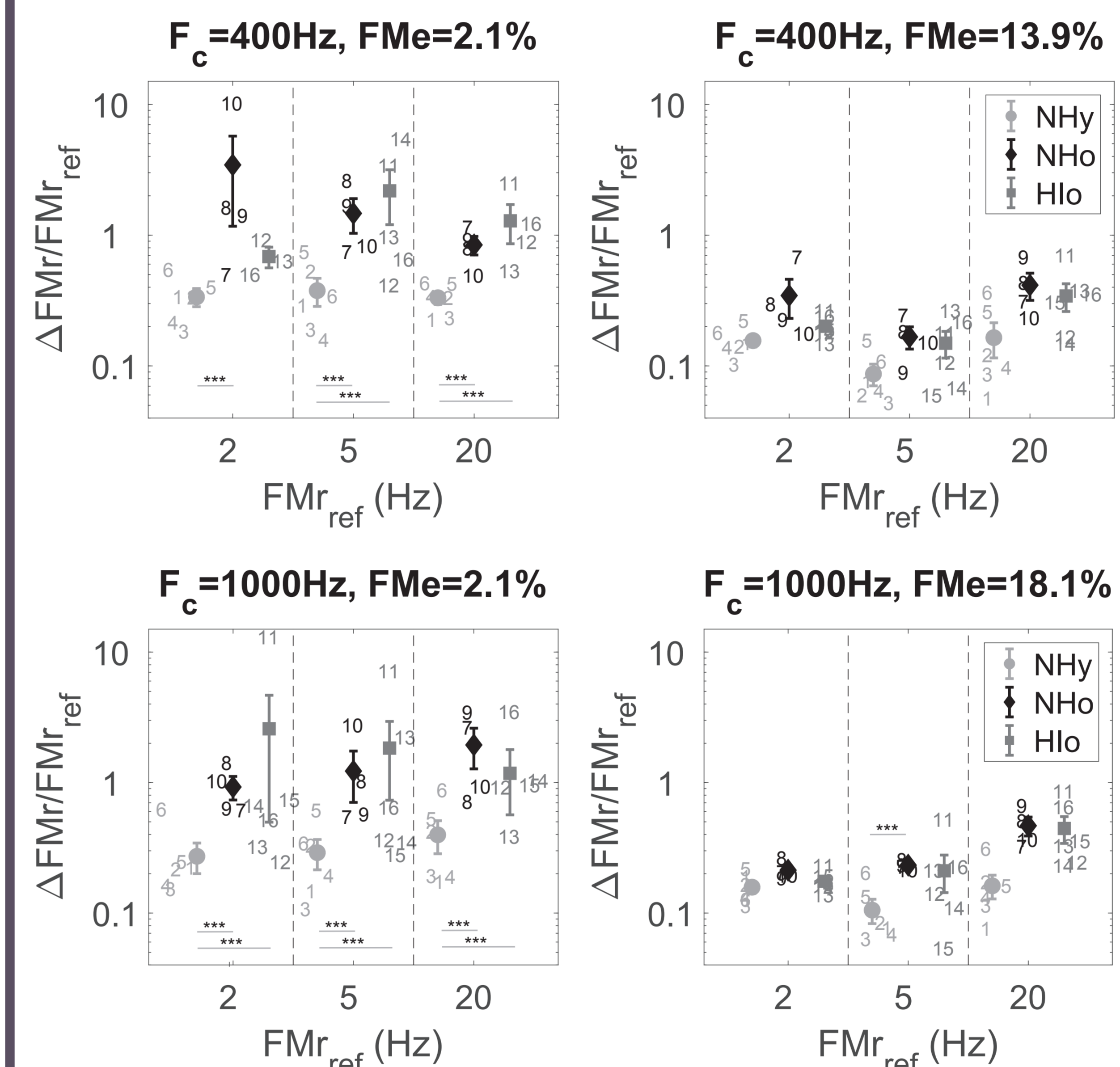


Fig.6 FM rate difference limens (FMrDLs) expressed as the Weber fraction for a 400-Hz (top panels) and a 1000-Hz (bottom panels) carrier with small (left panels) or large (right panels) excursions (FMe) at three reference FM rates. Mean and standard error for each listener group and individual data.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

Statistical analysis

4-way ANOVA on FMeDLs

- Main effects (FMe, FMr, group, F_c) 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 ($p = 0.005$).

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IPD detection

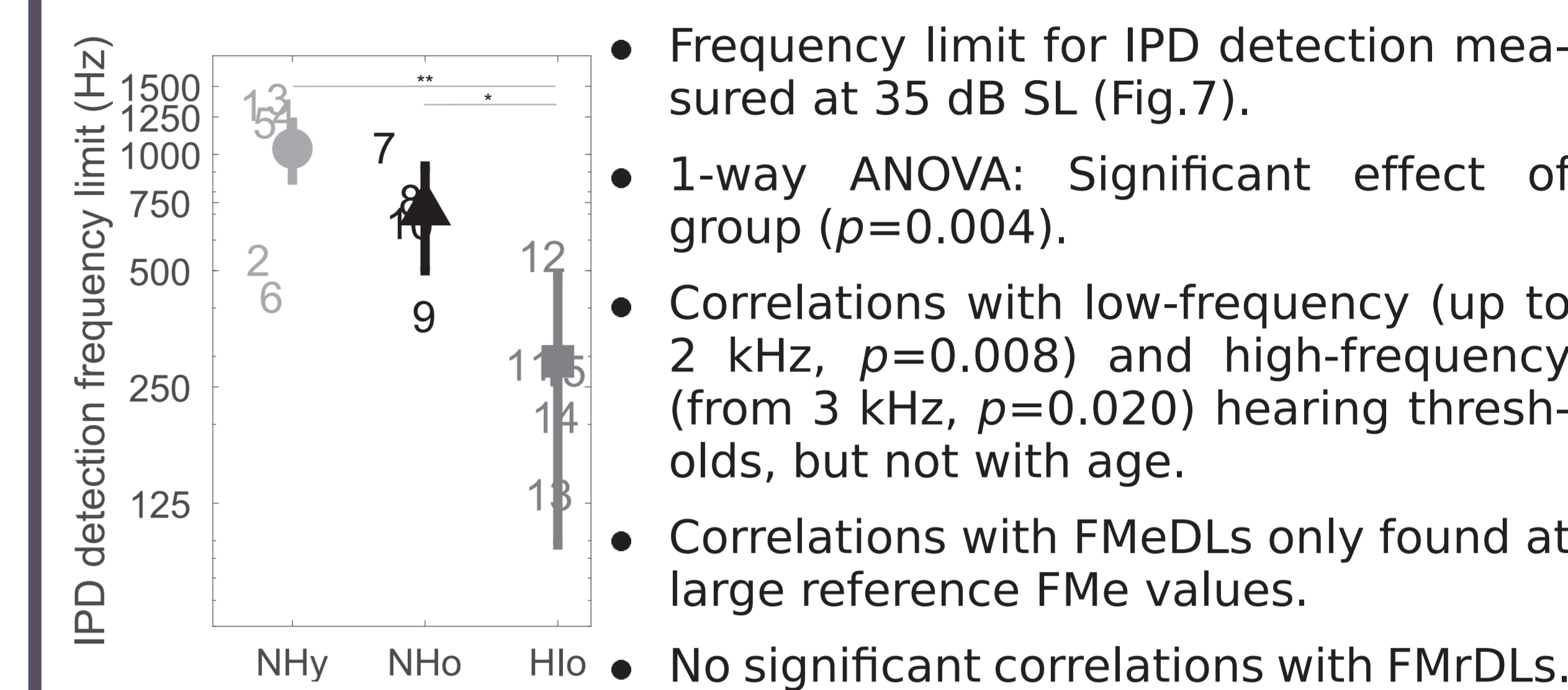


Fig.7 IPD detection frequency limits in Hz for an IPD of π . Mean and standard error for each listener group and individual data. *** $p < 0.01$, * $p < 0.05$ (Bonferroni corrected).

Summary and conclusions

- Very similar results for $F_c = 400$ and $F_c = 1000$ 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 Hlo 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 Hlo 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 Hlo 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.

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