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Musical Pitch with Cochlear Implants: Tones vs. Intervals & Temporal vs. Place Cues

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ARI

Single-Tone vs. Interval Discrimination

Motivation

Most users of cochlear implants (CIs) struggle with music perception, but still listen to and enjoy music.

Many CI listeners do not detect the musically crucial semitone (ST) step when measured with single tones (e.g., [1]). We hypothesized that *single-tone sensitivity is not the best predictor of musical pitch* and compared single-tone with interval discrimination sensitivity.

Methods

- Harmonic complex (HC) tones with 1 to 10 components, incl. the fundamental frequency (F0)
- 400 ms per HC with 500-ms gap
- Tone intervals (cf. Fig. 1) match interval differences (cf. Fig. 2)
- Interval-change in low *or* high voice
- 2-IFC same/diff. task w/ feedback
- 3 MED-EL CI listeners with FS4 [2]
- Sensitivity in terms of *d'* [3]

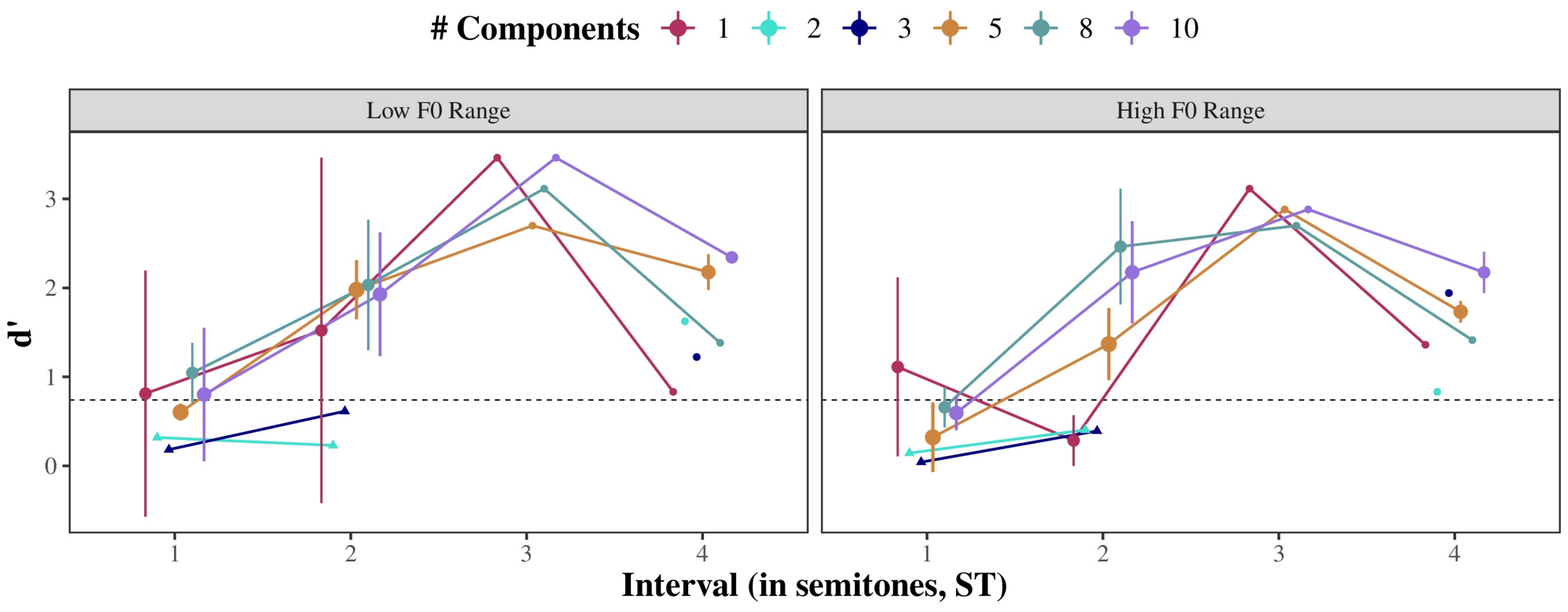


Fig. 1

Single-tone discrimination *d'* scores as a **function of musical interval**, tested for HC tones with 1 to 10 components (colors, always including the F0). Two F0 ranges were tested and, per range, the two tones always had the same geometric mean F0, regardless the musical interval. In total, **F0s ranged from 112 to 325 Hz**.
Per condition, markers denote the number of repetitions (circle: 48; triangle: 144) and the marker size denotes the number of data points. Error bars show standard errors. Scores above the dashed line are better than chance.

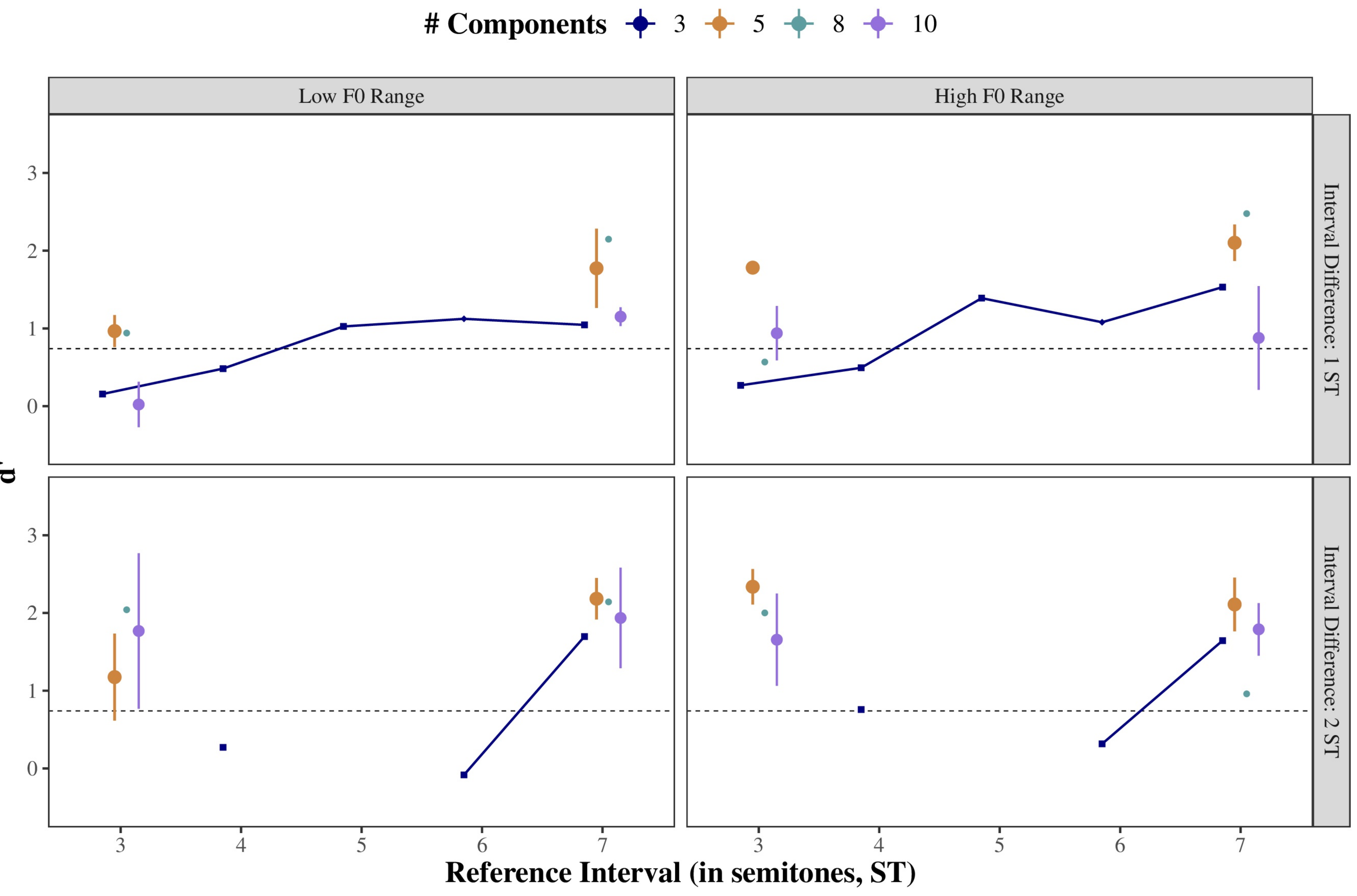


Fig. 2

Interval discrimination *d'* scores as a **function of reference interval (RI)**, tested for HC tones with 3 to 10 components (colors, always including the F0). The same F0 ranges as in Fig. 1 and **two interval differences** were tested. In total, **F0s ranged from 99 to 365 Hz**. Square markers denote 96 repetitions per condition. All other aspects as in Fig. 1.
The following example condition further explains the two types of interval involved: A 3-semitone RI combined with a 2-semitone interval difference means that a minor third had to be discriminated from a perfect fourth.

Analysis

- Repeated-measures ANOVAs [4-5]
- Generalized η^2 [6-7] as effect-size measure with Huynh-Feldt [8] confidence intervals [9-10] as measure of significance ($p < .05$)

Results

- Figs. 1 & 3A - *single tones*: Only the interval is relevant.
- Figs. 2 & 3B - *intervals*: The reference interval had an effect for the low F0 range; details in Fig. 4A.
- Fig. 3C - *tones vs. intervals:* A 1-ST interval difference was detected, but not a 1-ST single-tone interval; details Fig. 4B.

Conclusion

For musically relevant ST steps, we found sensitivity for interval but not single-tone discrimination. Hence, single-tone measurements may underestimate interval discriminability.

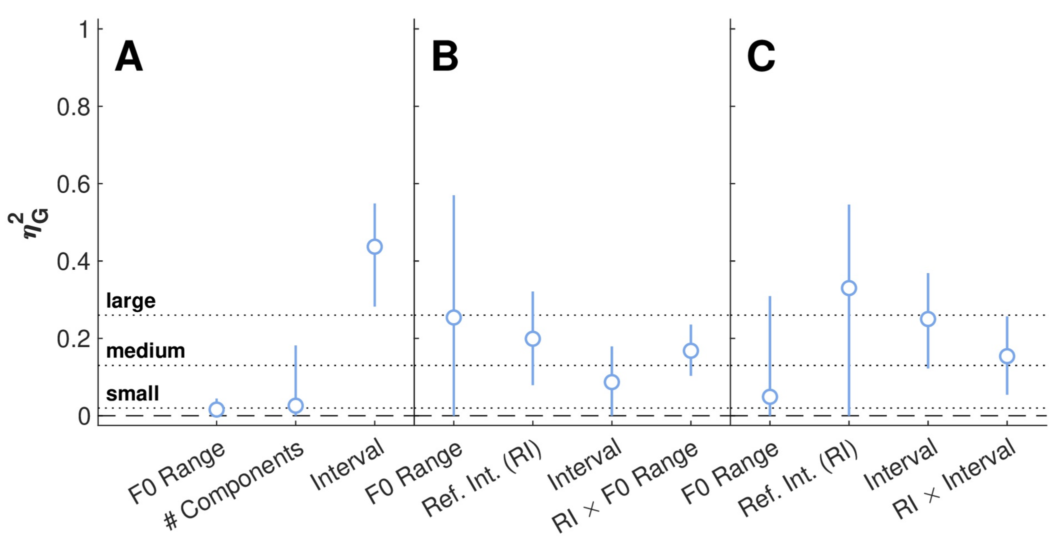
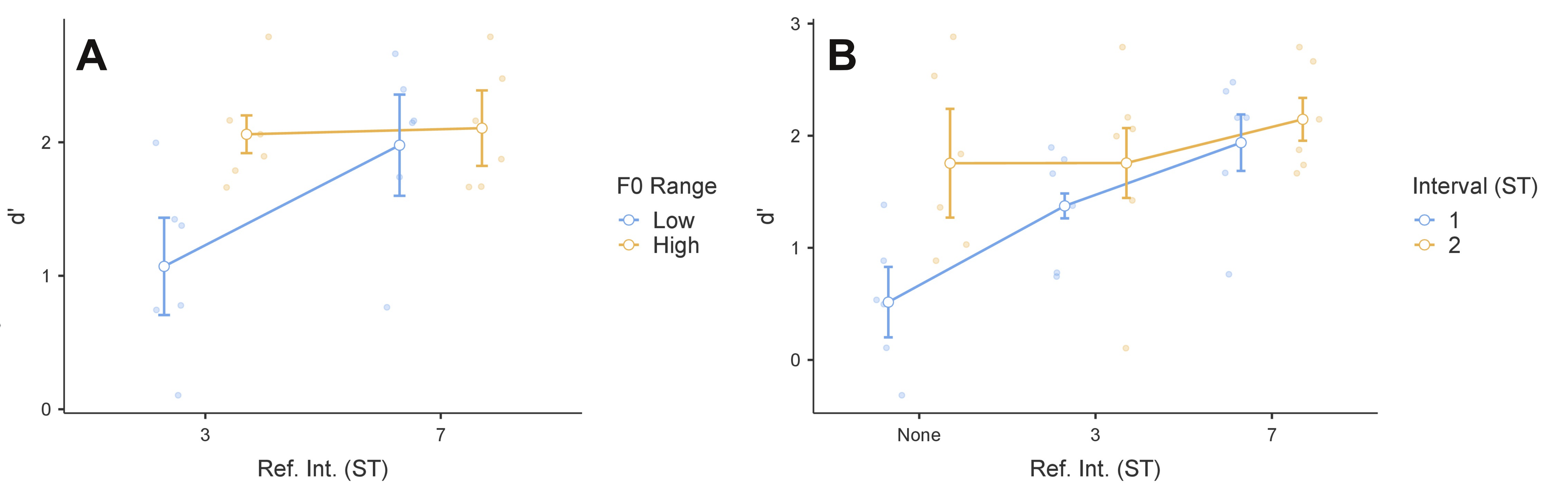


Fig. 3

Effect sizes [8]: **A Single tones only** (1/2-semitone (ST) int.; 5/10 comp.), **B Intervals only** (3/7-ST ref. int. [RIs] & 5 comp.), & **C Tones (RI "None") vs. intervals**. Error bars show 90% conf intervals; error bars of significant ($p < .05$ [9]) effects do *not* cross the dashed zero-effect line.

A Intervals: The F0 range affected the smaller RI only (Fig. 3B: RI x F0 Range). **B Single tones vs. intervals**: While listeners could not discriminate 1-ST intervals *per se*, they discriminated intervals differing by 1 ST for both RIs (Fig. 3C: RI x Interval).

Fig. 4



Relative Pitch: Perceptual Weighting of Temporal vs. Place Cues

Motivation

Place pitch is degraded with CIs. We hypothesized that *CI listeners rely strongly on temporal-pitch cues* and tested them on two pitch-cue weighting tests (cf. Fig. 5, [11-12]).

Method

- Auditory Ambiguity Test (AAT, Fig. 6A, [11]): 3 to 10 HC components, spectral bandwidth always 1 octave
- Pitch Perception Preference Test (PPPT, Fig. 6B-C, [12]): 2 to 5 HC components, highest component constant within trials, spectral bandwidth varies
- *No* feedback provided, rest as above

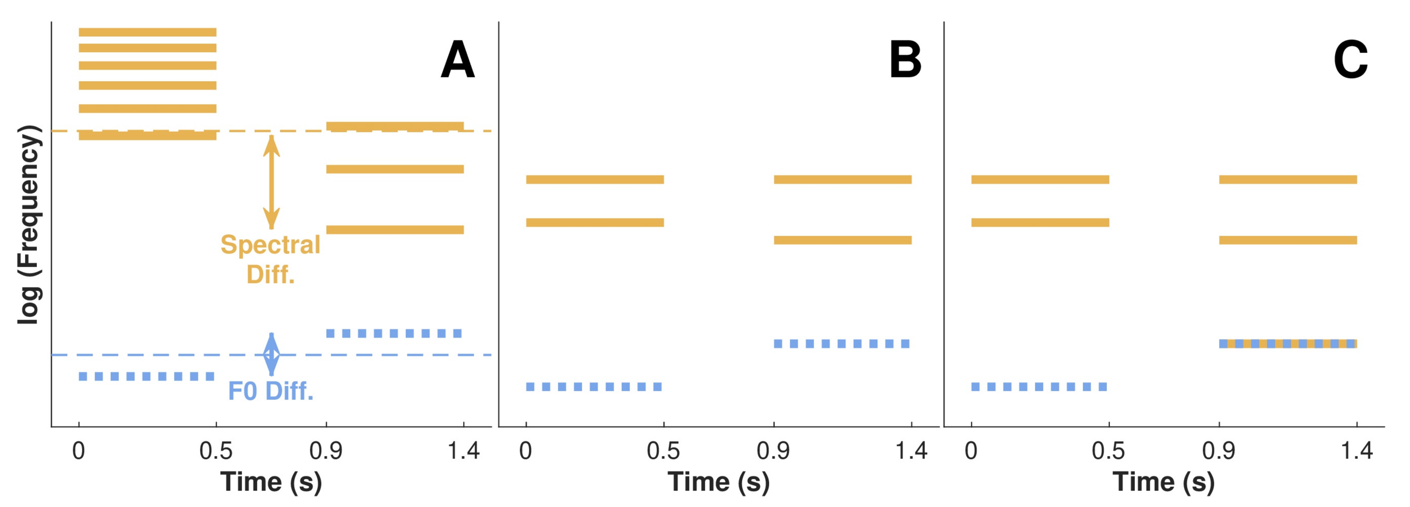


Fig. 5

A AAT [11]: The virtual-F0 "shift" (dotted lines, in blue, expressed as **F0 Difference** [%]) is opposite to the spectral shift (in yellow, expressed as **Spectral Difference** [%] of the lowest-order components). Dashed lines indicate the **Avg. F0** (blue, geom. mean, in Hz) and the **Avg. Spectral Centroid** [yellow, geom. mean, in log(Hz)]. These four parameters characterize each test trial.
B PPPT [12]: In this type of trial, the F0 is not included physically. The same four parameters as in A characterize a trial.
C PPPT: The F0 is physically included in one stimulus. All other aspects as in B.

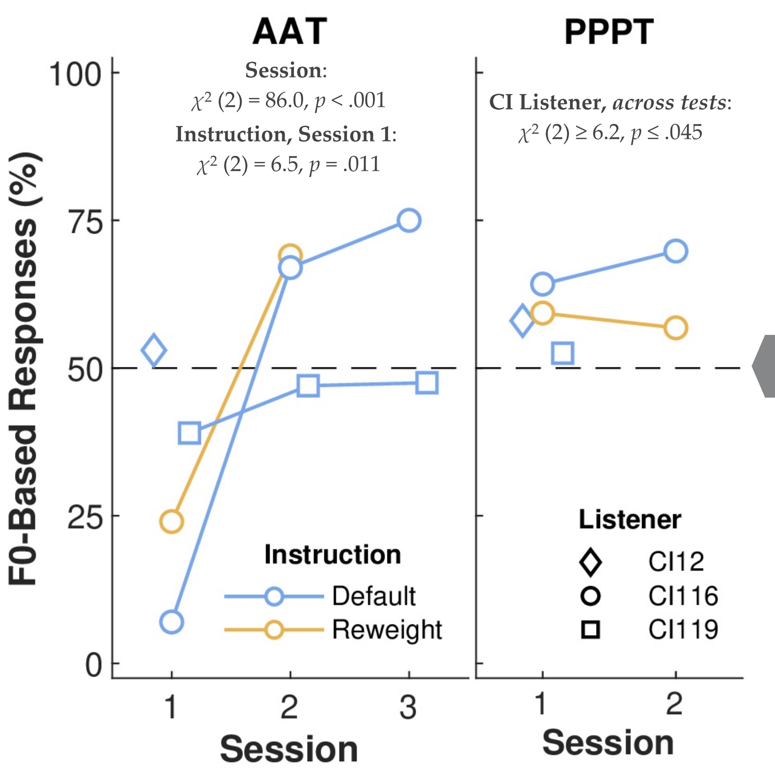


Fig. 6

Results for three CI listeners (markers) for AAT (left panel) and PPPT (right panel, cf. Fig. 5) as a function of test session. **Scores < 50% indicate spectral place-cue dominated listening** and **scores > 50% indicate temporal (missing-)F0-dominated listening.**
The **default instruction (blue)** was to indicate whether the second tone was higher or lower in pitch than the first tone. The **reweight instruction (yellow)** was to deviate from the default instruction in ambiguous cases with two opposing pitch trajectories heard simultaneously. In such cases, listeners should respond inverse to the default response.

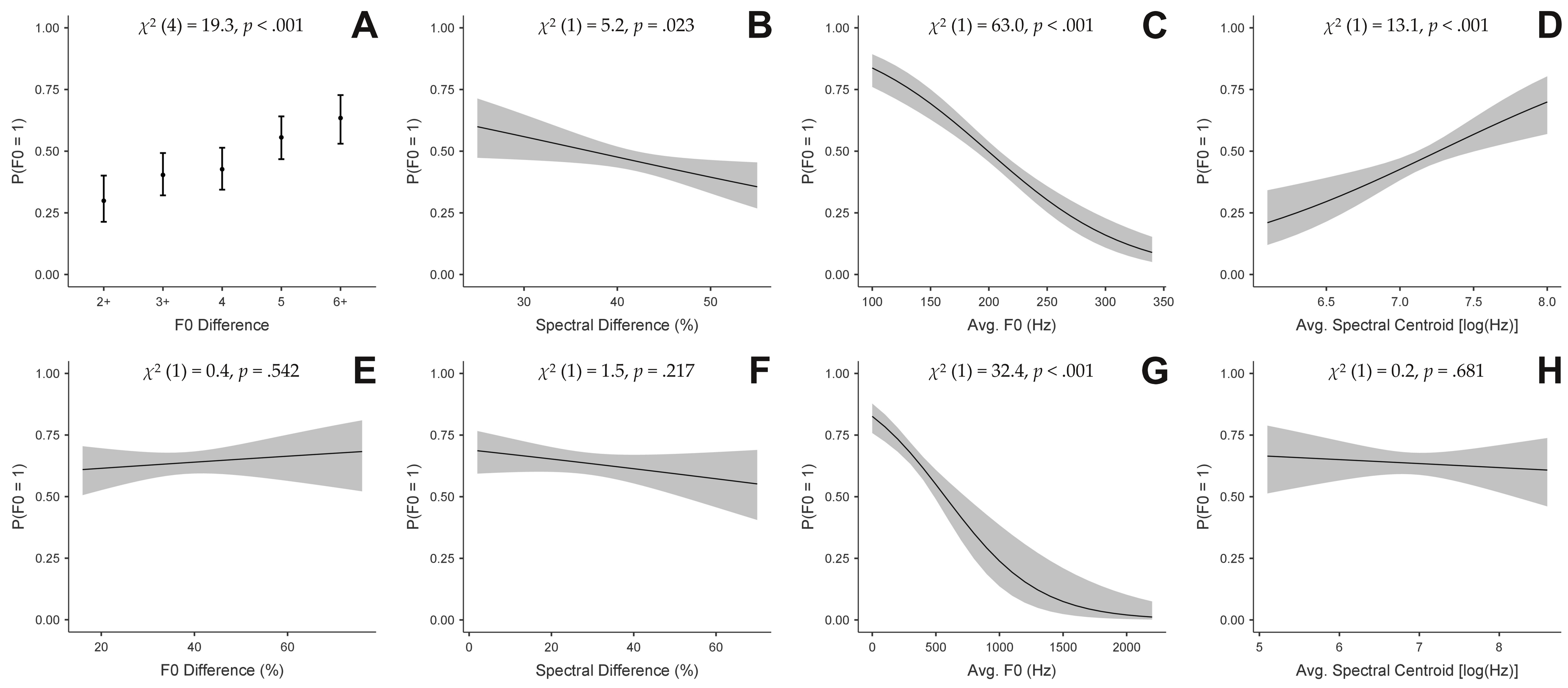


Fig. 7

Per-test "repeated-measures" logistic regression for the four trial parameters (cf. Fig. 5). **A-D AAT**. **E-H PPPT**. In all panels, **P(F0 = 1) < .50 indicates spectral place-cue dominated listening** and **P(F0 = 1) > .50 indicates indicates temporal (missing-)F0-dominated listening**. Note that the ranges on the abscissae differ between AAT and PPPT.

Results

- Fig. 6, AAT: *Short-term plasticity* towards temporal cues (cf. [13]); instruction effect
- Fig. 7: Often strong place pitch, AAT *similar to normal hearing* (panel A, cf. [11])

Conclusion

Both pitch cues contribute and their weighting is plastic in the short term.

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