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Cortical pitch representations of complex tones in musicians and non-musicians

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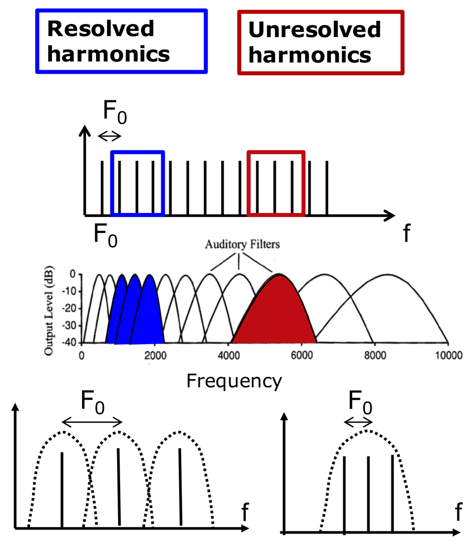
Introduction

Musicians have been shown to have an enhanced pitch-discrimination ability compared to non-musicians for complex tones with either resolved or unresolved harmonics [1, 2, 3, 4, 5]. It is unclear whether this perceptual enhancement can be ascribed to an enhanced neural representation of pitch at central stages of the auditory system.

The aim of this study was to clarify whether (i) cortical responses increase with harmonic resolvability, as suggested in previous studies [6, 7], and whether musicians show (ii) differential neural activation in response to complex tones as compared to non-musicians and/or (iii) a finer fundamental frequency (F0) representation in the auditory cortex. Assuming that the right auditory cortex is specialized in processing fine spectral changes, we hypothesized that an enhanced F0 representation in musicians would be associated with a stronger right-lateralized response to complex tones compared to non-musicians.



Method - Experiment I: Behavioral pitch discrimination

- 31 listeners (15 non-musicians and 16 musicians with more than 8 years of formal musical training) participated in Experiment I and II.

STIMULI

- low-frequency (**LF**: 0.3-1.5 kHz) filtered complex tones
- high-frequency (**HF**: 1.5-3.5 kHz) filtered complex tones

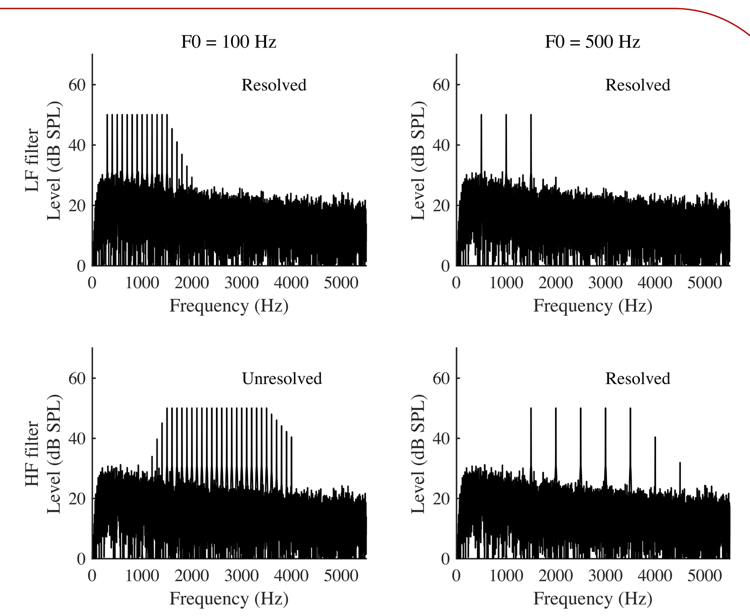


Figure 1 The 4 complex tones used in Experiment I. The level of each harmonic was fixed at 50 dB SPL. The tones were embedded in threshold equalizing noise (TEN) at 45 dB SPL/ERB.

PARADIGM

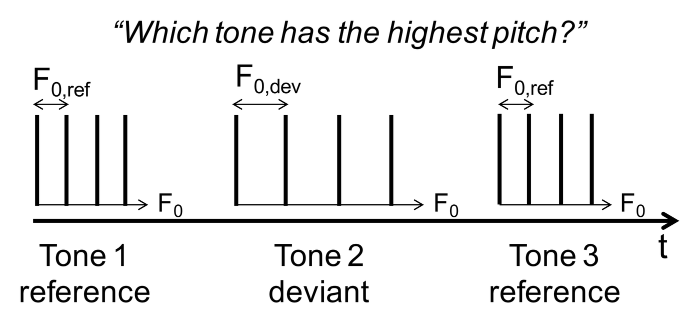


Figure 2 Three-alternative forced choice (3AFC) paradigm for Experiment I. After the presentation of the three tones, the listener was asked to identify the deviant tone.

CONDITIONS

- The smallest detectable ΔF_0 was measured at two points on the psychometric function (difficult D: 60%; easy E: 90%) for the **HF** complexes and at 75% for the **LF** complex tones.

Table 1 Summary of the 6 conditions tested in Experiment I and II (2 task-difficulty levels; 2 resolvability levels). **Blue**: LF-filtered complex tones; **Red**: HF-filtered complex tones.

		resolvability (F0s)	
		100 Hz	500 Hz
task difficulty	90%	Unresolved Easy (E)	Resolved Easy (E)
	75%	Resolved Medium difficult	Resolved Medium difficult
	60%	Unresolved Difficult (D)	Resolved Difficult (D)

Method - Experiment II: functional MRI (fMRI)

- Measure neural activation during a pitch-discrimination task
- 6 pitch conditions (same as in Experiment I, see Table 1) and 1 noise condition with TEN.
- ΔF_0 between reference and deviant individually set at the listener's threshold (from Experiment I)
- Event-related paradigm with sparse sequence (TR = 10 s, TA = 2.5 s, 38 isotropic slices of 3 mm³, 3T Philips Achieva). Data acquired at DRCMR.

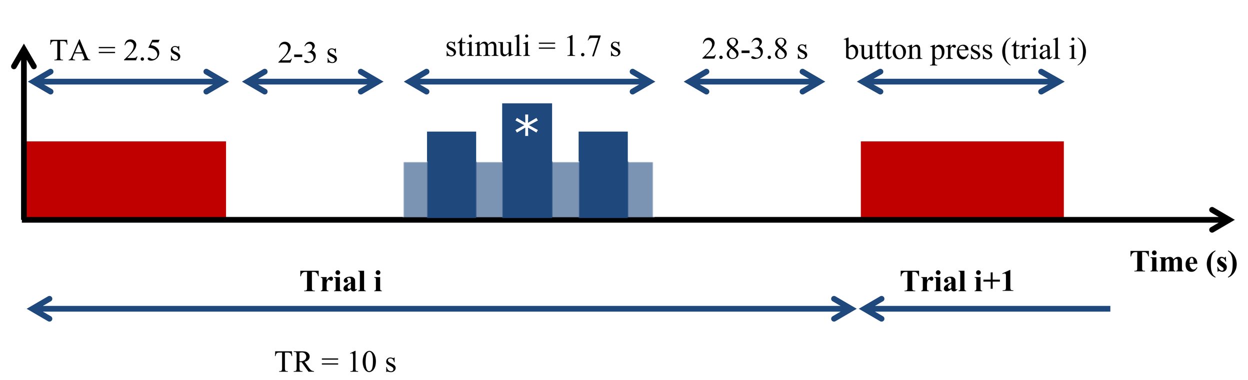
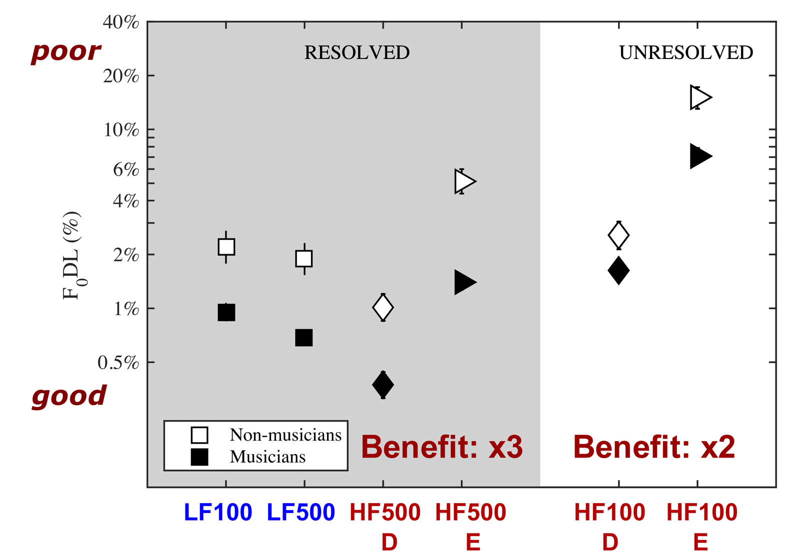


Figure 3 Stimulus presentation for Experiment II. The stimuli were presented in the silent interval between two acquisitions. The stimulus onset was jitteres across trials. The deviant stimulus (asterisk) was randomly presented among the references. Each condition was repeated 6 times per run for a total of 42 trials/run. Six runs were carried out for each listener (about 45 minutes).

Results - Experiment I: Behavioral pitch discrimination



- Larger benefit for musicians for resolved components (lower thresholds by a factor of 3) as compared to the benefit for unresolved complex tones (factor of 2) [3,4,5].
- ANOVA:
  - Significant effect of Group: $F(1, 185) = 24.54$; $p < 0.0001$
  - Significant effect of Resolvability: $F(1, 185) = 267.1$; $p < 0.0001$
  - Significant interaction Group X Resolvability: $F(1, 185) = 7.94$; $p = 0.009$

Figure 4 Mean pitch discrimination thresholds for complex tones filtered either in a **LF** (LF100, LF 500) or **HF** region (HF100, HF 500) for musicians (closed symbols) and non-musicians (open symbols). D: difficult task (60% point on the psychometric function; E: easy task (90% point on the psychometric function). Error bars depict the standard error of the mean.

Results - Experiment II: fMRI

A full-factorial ANOVA (3 levels of difficulty, 2 levels of resolvability) revealed:

- A significant effect of musical training (musicians > non-musicians) even if task difficulty was adjusted across participants [Fig. 5]

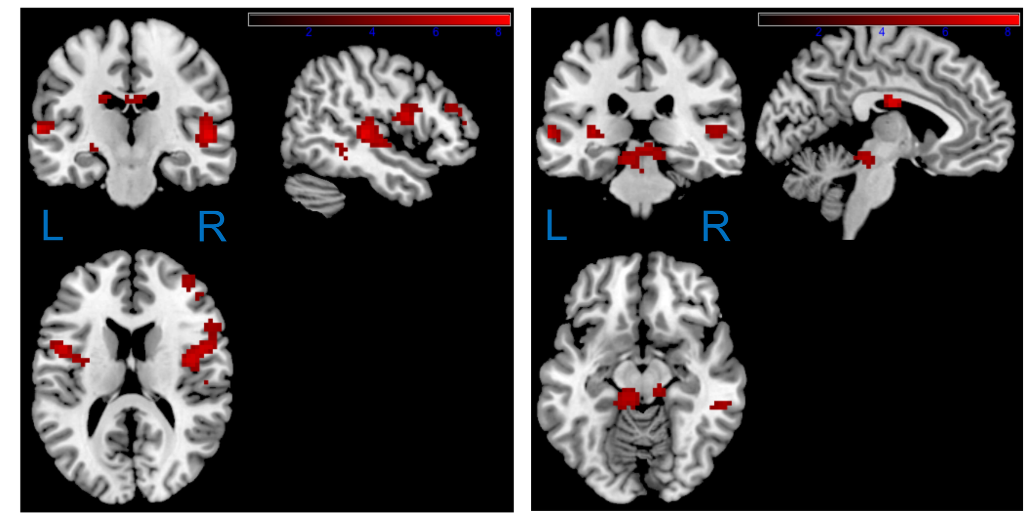


Figure 5 Musicians > non-musicians (p<0.05 FWE). Activation in right and left primary auditory cortices, inferior frontal gyrus, insula and inferior colliculus.

- A significant effect of difficulty (60% > 90%) [Fig. 6]

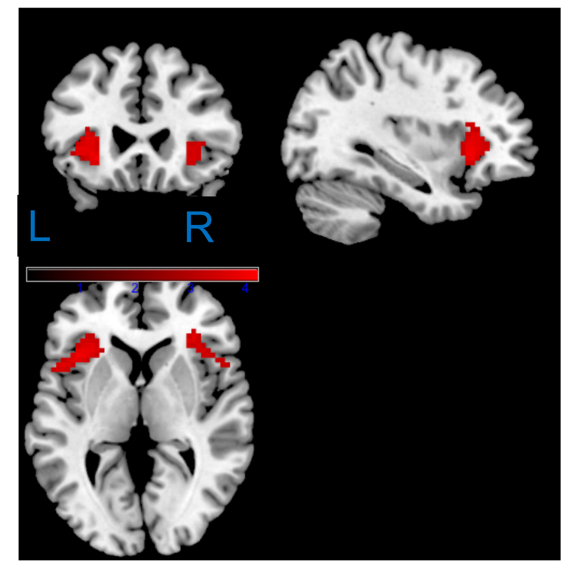


Figure 6 60%> 90% (p<0.001). Activation of the right and left insula, inferior frontal gyrus and frontal operculum (working memory network for pitch retrieval [8, 9]).

- No effect of resolvability

A parametric analysis for the 3 levels of task difficulty (60%, 75% and 90%) revealed a significant increase of neural activation bilaterally in the auditory cortices, in the left inferior frontal gyrus and left thalamus [Fig. 7]. Additionally, a decrease of behavioral performance (% correct deviant identification) was correlated with the increase of neural activation in the inferior frontal gyrus [Fig. 8].

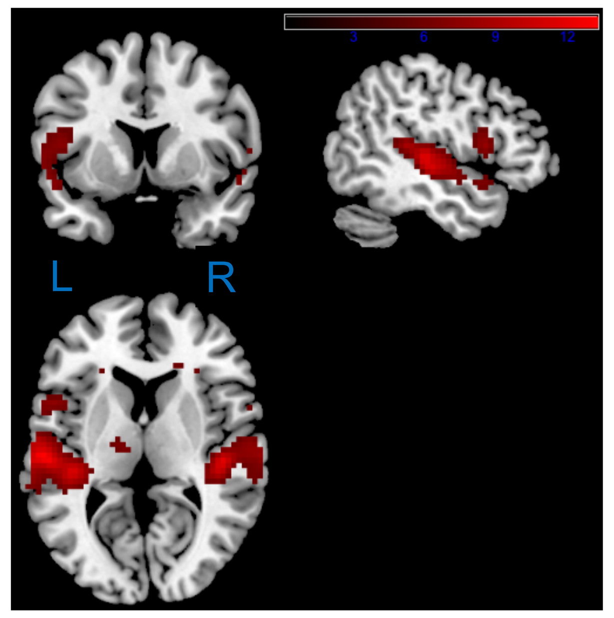


Figure 7 Effect of task difficulty (p<0.05 FWE)

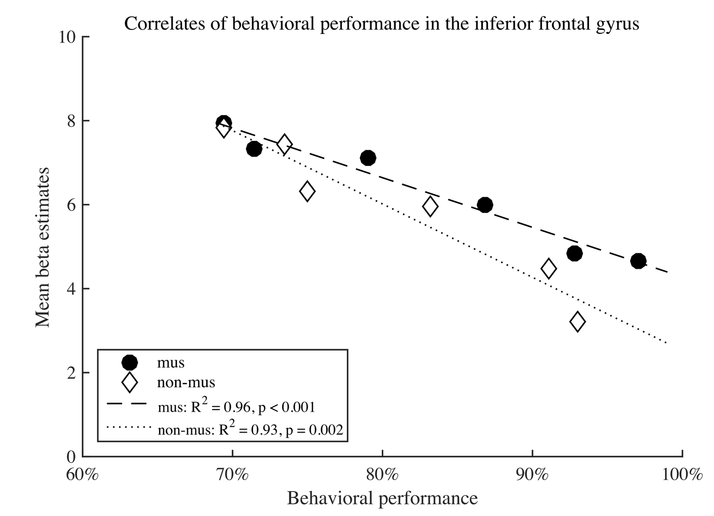


Figure 8 Correlation of mean BOLD signal in the inferior frontal gyrus and behavioral performance.

Discussion

The 10% most activated voxels for the pitch>noise contrast were selected in the primary and non-primary AC (Te1.0, Te1.1, Te1.2 and Te3). No effect of harmonic resolvability was found (see Fig. 9), in contrast to previous studies [6, 7]. This finding might be due to the fact that the level per harmonic (and not the overall level) was fixed, leading to the same S/N in all conditions. There was a significant effect of F0 (100>500, see Fig. 10) in the right Heschl's gyrus, probably driven by the higher spectral density for the 100 Hz condition.

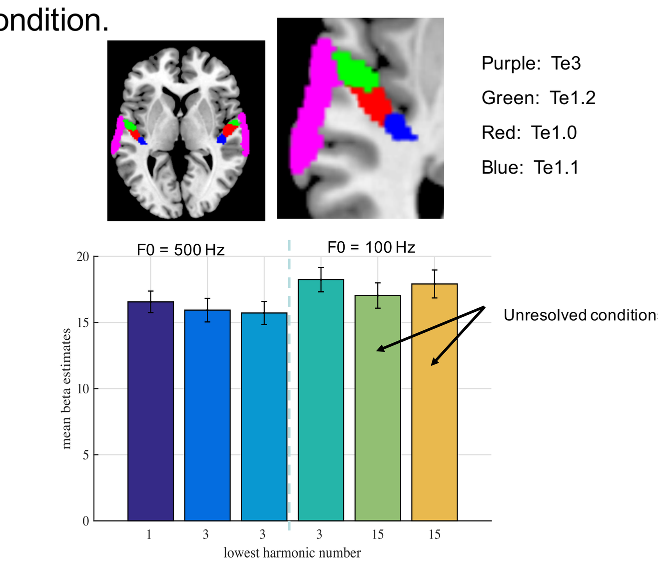


Figure 9 Mean activation of pitch-sensitive voxels in right and left auditory cortices for the 6 tested conditions.

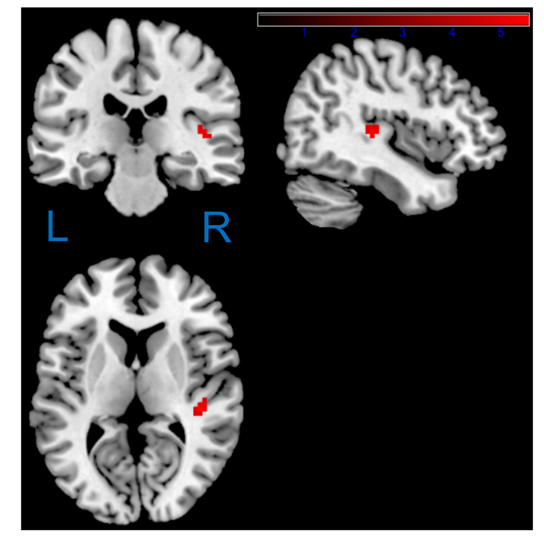


Figure 10 Contrast 100>500 (p<0.05 FWE).

The increase of activation of the pitch-sensitive voxels was significantly correlated with a finer F0 discrimination ability in musicians in the right auditory cortex (see Fig. 10).

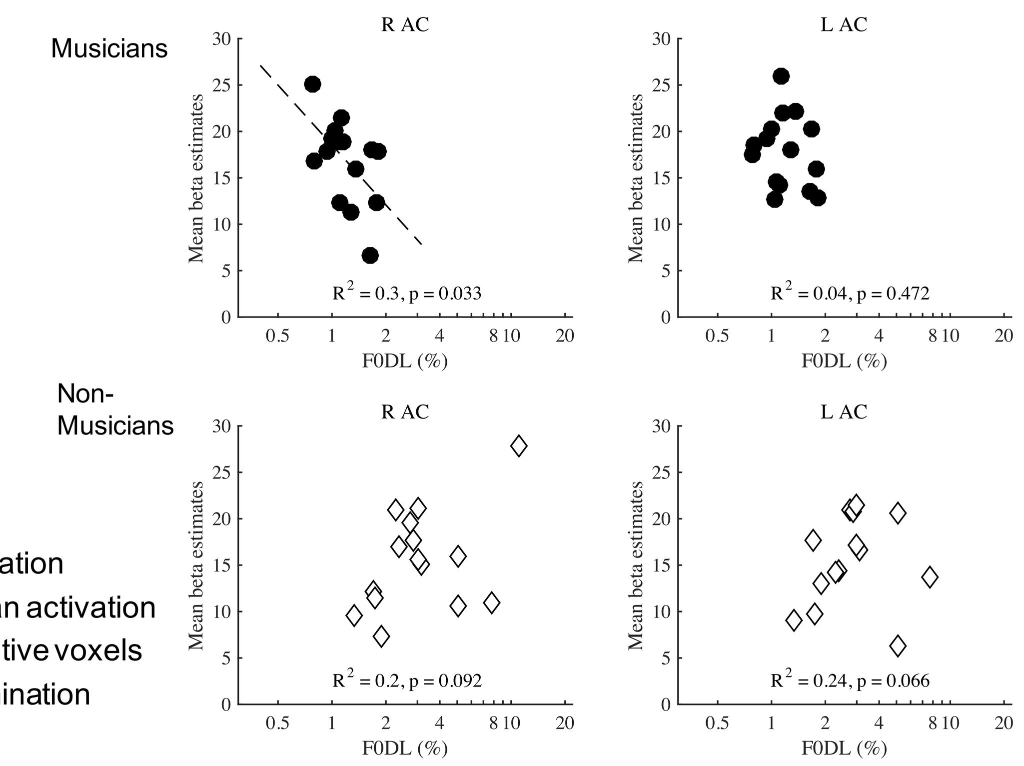


Figure 10 Correlation between the mean activation of the pitch-sensitive voxels and pitch-discrimination abilities.

Conclusions

Overall, these findings suggest an involvement of a postero-lateral region in both auditory cortices during a pitch-discrimination task with conditions of varying task difficulty. When the harmonic level was fixed above the noise, no effect of harmonic resolvability was observed. Cortical responses in musicians were larger in the right than in the left auditory cortex as compared to non-musicians and were predictive of individual pitch-discrimination abilities. These outcomes are consistent with the right auditory cortex being specialized in processing fine spectral changes.

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