Primary Auditory Cortex is Necessary for Fine-grained Loudness Perception

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1. Introduction

1.A. Loudness perception is critical for understanding speech and appreciating music.
- The loudness of a sound source and its change over time convey information about source size, location, trajectory, and identity.
- Humans and animals use loudness to convey meaning and emotion.
- Musical dynamics (i.e. changes in loudness) are important for musical aesthetics.

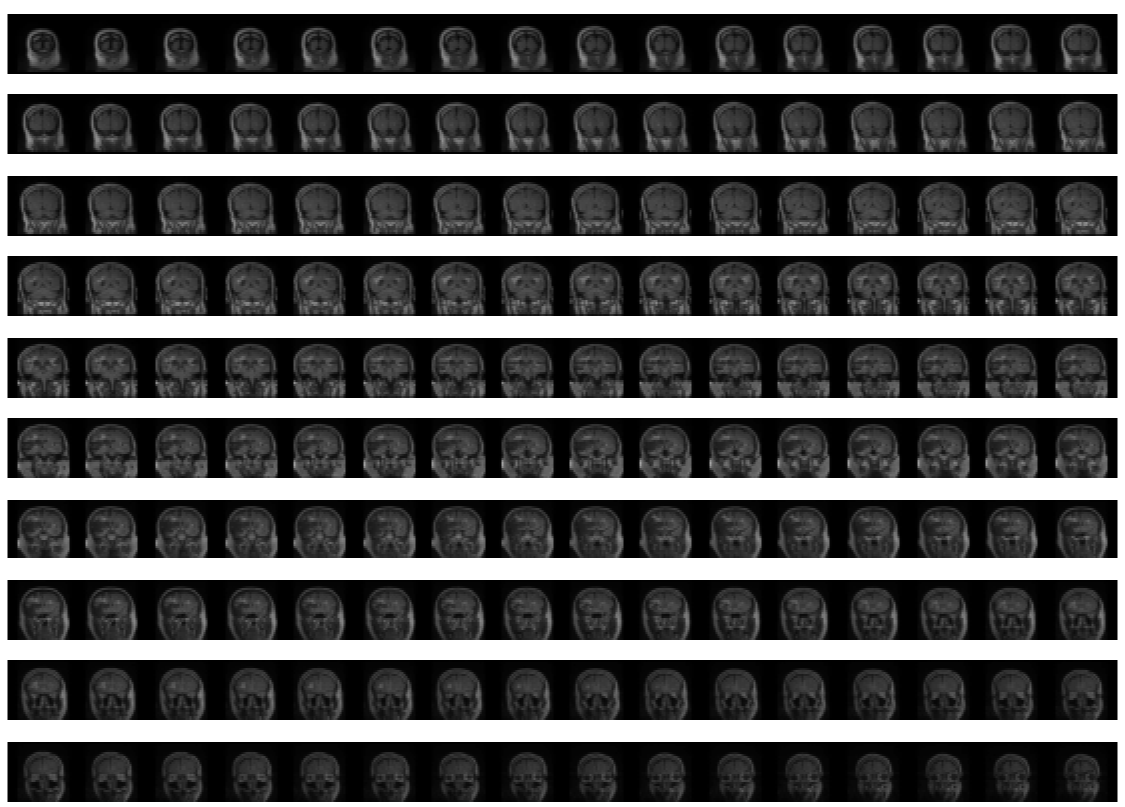
1.B. Humans demonstrate remarkably high perceptual acuity for changes in loudness.
- At normal overal listening levels, pure-tone intensity discrimination thresholds are less than 1 dB for standard audiometric frequencies (0.2 - 8 kHz) (Yost, 2007).

1.C. It is well known that damage to the peripheral auditory system causes deficits in pure-tone detection as well as pitch and loudness discrimination.

1.D. However, the extent to which the auditory cortex plays a critical role in processing these basic features of sound remains unclear.

2. Participants

2.A. Case A1+



46 year-old mixed-handed male who suffered ischemic infarcts of right and left middle cerebral arteries in 1980 and 1981, respectively, leaving complete or near-complete lesions of primary auditory cortex bilaterally. His second stroke (left hemisphere) was followed by a three-week period of profound deafness during which the patient did not respond to sound. He subsequently began to experience sound as "buzzing noise," though pure-tone thresholds remained markedly elevated. Two months after deafness onset, pure-tone thresholds reamined mildly elevated. Eight years after onset, pure-tone detection thresholds were within clinically-defined normal limits, though the patient reported difficulty in noisy situations and no longer enjoys listening to music.

Figure 1. T2 fluid-attenuated inversion-recovery (FLAIR) sequence obtained with a Siemens TIM Trio 3T scanner. Continguous sections were 1.0mm thick; in-plane resolution is 0.94mmx0.94mm. TE=494ms, TR=6000ms, IT=2100ms, flip angle = 120 degrees.

2.B. Normal Controls

- 11 age-matched (mean age = 41.5 ± 6.3) right-handed normal control participants (7 female) with clinically-normal pure-tone audiograms and no reported history of neurological disease.

3. Methods

3.A. Stimulus delivery and data collection.
- Participants sat a double-walled sound-attenuated booth and faced a computer monitor on which instructions and feedback were given.
- Participants entered responses via a computer keyboard.
- All stimuli except pure-tone audiometry in normal controls were generated using MATLAB, DA-converted by 24-bit soundcard (Fs=32kHz), attenuated (TDT PA4), buffered (TDT HB6), and presented to the participant over Sennheiser HD580 open-air headphones.

3.B. Pure-tone detection.
- In Case A1+, thresholds were measured using a 2-interval, 2-alternative forced-choice procedure with a 2-down, 1-up rule (Levitt, 1971). Each interval was indicated by a light flash. Target tone duration = 500ms. The target tone was randomly assigned to the first or second interval. Threshold was defined as the mean of the last six turnaround points after the lowest step-size had been reached.
- In controls, thresholds were measured with a modified Hughson-Westlake procedure using an Interacoustics Diagnostics Audiometer.

3.C. Pure-tone loudness discrimination.
- Threshold were measured using a 2I-2AFC procedure with a 2-down, 1-up rule. On each trial, two 500ms, 1kHz pure tones were presented, one at reference intensity (40dB SL per ear for Case A1+; 65dB SPL for normal controls). Threshold was defined as the mean of the last six turnaround points after the smallest step size had been reached.

4. Results

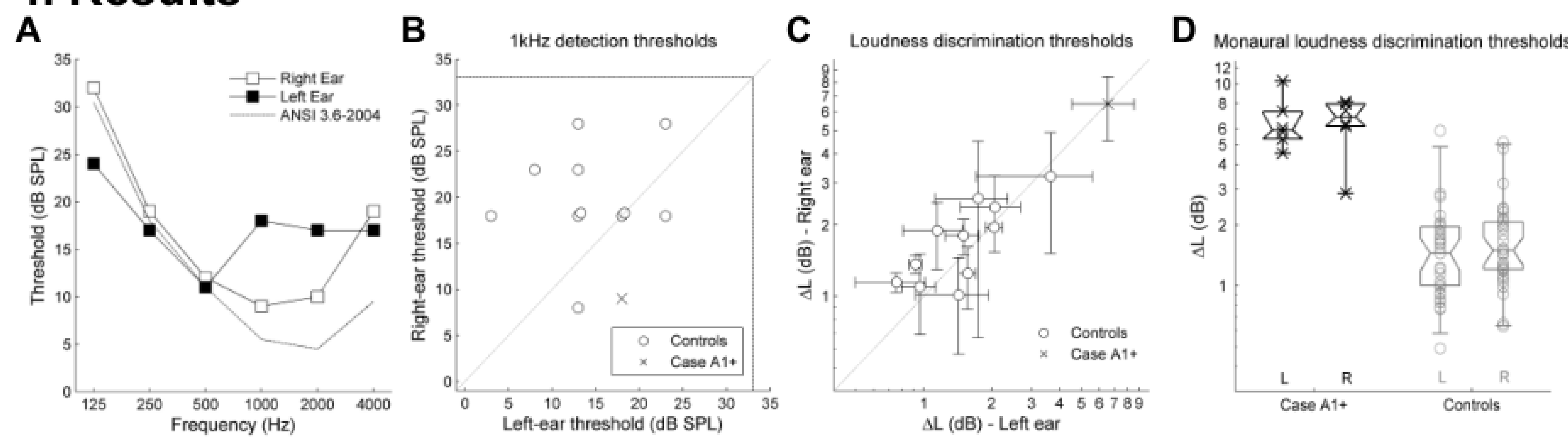


Figure 2. (A) Case A1+ audiometric thresholds are near the average as measured by the ANSI standard and well within clinically-defined normal limits. **(B)** Audiometric thresholds at 1kHz for Case A1+ and normal controls are within the normal limits. Case A1+ has thresholds that are lower than several of our normal control subjects. **(C)** Intensity discrimination thresholds for Case A1+ (X) are highly elevated compared with normal controls (O) in both ears. His average thresholds were 6.5 dB in each ear, several standard deviations above the normal means of 1.6 and 1.7 dB in the left and right ear, respectively. Error bars give the standard deviation across runs. **(D)** Individual run data for Case A1+ (X) and normal controls (O). Box-and-whisker plots give the population median, interquartile range, and estimated 95% confidence interval.

5. Discussion

5.A. In Case A1+, intensity discrimination thresholds, like pitch discrimination thresholds measured previously, were highly elevated compared to normal controls while absolute detection thresholds remained well within normal limits, suggesting that brain mechanisms for tone detection and intensity discrimination are neurologically dissociable.

5.B. Spared structures - specifically left anterior auditory association cortex and/or the auditory brainstem - can mediate coarse loudness perception.

5.C. Based on the present study and our review of the literature, we propose a hierarchical model of loudness perception in which the primary auditory cortex is necessary for fine-grained intensity discrimination and the auditory brainstem is sufficient for detection of sound.

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