Supplementary Online Material

To complement the manuscript
"Encoding of illusory continuity in primary auditory cortex"
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1. Supplementary Methods

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1. Supplementary Methods

In the text of the manuscript we described a statistical criterion for determining the response window within which spikes were counted for the subsequent analyses. This method has the advantage that it selects neurons that show that they can discriminate continuous from discontinuous tones in a statistically significant manner. We describe here three other methods with different advantages. All statistical tests with TNSI and TGSI yielded the same results (for both significant and not significant effects) as reported in the manuscript, regardless of which of the four procedures were used.

The second method has the advantage that all cells contributed to the analysis with no selection of neurons. The reported results based on the entire sample of neurons used this method (see the Supplementary Figures). Therefore all neurons could be considered for a broad definition of the population of AI neurons. For this method, the time window was the one that resulted in the largest mean response difference to tones with (e.g., manuscript Figs. 3B, 4B, 5B) and without a gap (e.g., manuscript Figs. 3A, 4A, 5A). To compute this, a difference PSTH (5 msec bins, 50 stimulus repetitions) was created by subtracting the discontinuous tone (without noise) PSTH from the continuous tone (also without noise) PSTH. A sliding window analysis was performed on the difference PSTH which began with 35 ms window widths that were incremented in 10 ms steps (45 ms width, 55 ms width, etc.) until the end of the recording period was reached. The first starting position was at the onset of the gap in the discontinuous tone (172 ms on Fig. 3-6), and window onset was shifted by 10 ms until all onset and window sizes were used. The starting time and window duration that caused the largest differences between continuous and discontinuous tones without noise were used. The distribution of these window positions and widths showed a broad median window width of 645 ms with a median starting position of 212 ms, following the onset of the tone (that is 40 ms after gap initiation).

A third method used a fixed 56 ms response window set at the median starting position for the analysis described in the manuscript (69 ms after gap onset). This provided the advantage of using a window that was the same duration as the interrupting noise stimulus and the gap in the tone.

We used a fourth method that did not window the response (i.e., using the entire response following the onset of the gap). This was a correlation-based method that took the absolute value of the correlation (Pearson's r) between the PSTHs for different conditions (starting at the time where the gap began, time $= 172$ ms, to the end of the 1200 ms recording period). This method has the advantage of not defining a time window, but has the disadvantage of yielding different biases in r-values depending on the overall number of spikes and background activities. Because correlation coefficients are already normalized, TNSI and TGSI were derived for the correlation analysis as follows:

$$\text{TNSI} = |r_{(\text{DTIN, T})}| - |r_{(\text{DTIN, N})}|$$

$$\text{TGSI} = |r_{(\text{DTIN, T})}| - |r_{(\text{DTIN, G})}|$$

Here DTIN is the response to the discontinuous tone with intense noise, T the response to only the continuous tone, N the response to only the noise, and G the response to only the gap in the tone. The $|r(\text{DTIN, T})|$, for example, signifies the absolute value of the correlation between DTIN and T responses.

2. Supplementary Notes

Neuronal sample characteristics. Supplementary Figure 1a shows the distribution of tone frequencies used in octaves from each neuron's BF. See the manuscript methods for a description of the range of neuronal BFs obtained.

A restriction for the data in manuscript Figure 7 was that the windowing procedure excluded neurons that could not significantly encode the gap. Supplementary Figure 1B shows that 75% of the neurons could encode the gap. This figure also shows the proportion of neurons that significantly (relative to spontaneous activity) encoded tones, noise or both.

Neuronal response properties related to induction. The results described in this section highlight how our findings cannot be explained merely by responses increasing for more stimulus sound energy. Otherwise the response to the loud noise should swamp the responses to the fainter tone, being consistent only with masking and not foreground continuity during induction. Instead, the primary contributor to induction-related-responses seemed to be whether the neurons responded more strongly to the tone or noise elements as presented individually.

First, we expected that single neuron responses encoding the induced illusory tone segment likely occurred for neurons representing that tone frequency. Accordingly the analyses reported in manuscript Fig. 7 were from responses to tones at the recording sites' best-frequency (BF). We also recorded responses to 2 kHz foregrounds, the frequency used in a previous macaque psychophysical study. This allowed us to observe how the entire population of neurons responded to inducing sounds, not only those whose BF was close to the stimulus tone frequency. Supplementary Figure 2 shows the TNSI distributions for the entire neural sample including off-BF recordings. As reported for the subpopulation of near-BF recordings in the manuscript (Fig. 7), this full sample showed significant differences in TNSI for interrupting and surrounding noise (K-S test, $p = 0.01$, distribution medians: interrupting noise, –0.15, surrounding noise, –0.34). These differences however were smaller due to the inclusion of off-BF responses, suggesting that stronger responses to the tone are associated with induction when a loud noise is presented in the gap of a discontinuous tone.

We next quantified neuronal response properties to determine which could predict how a neuron responded to the inducing stimulus: whether consistent with induction of the tone (positive TNSI values) or as if the response were only consistent with masking (negative TNSI values). Such relationships can guide pursuits of neuronal mechanisms supporting induction vs. masking. Thus, we evaluated the relationship of the TNSI values for interrupting or surrounding noise to three neuronal response variables: (1) tone response strength, (2) tone distance from BF (in octaves), and (3) tone response strength relative to noise response strength (see Supplementary Table 1). For interrupting noise, all three variables significantly correlated with the TNSI. Here, the tone response strength relative to noise response strength showed the highest correlation. By contrast, for surrounding noise, only tone response strength relative to noise response strength correlated with TNSI, implying strong noise responses contributed toward lower TNSI values for masking surrounding noise (Supplementary Table 1). These observations support that induction of a foreground depends on neurons' ability to encode the foreground *in relation* to the interrupting sound. On the other hand, masking depended on the neurons that more strongly encode the noise and/or less strongly responded to the tone (also see Supplementary Fig. 3).

In Supplementary Figure 3 we graphically depict the relationship of neuron's responses to tones and noise in isolation to their TNSI values. The robust association between tone vs. noise preference and Tone-Noise SI values reported in Table 1 is shown graphically in Supplementary Fig. 3A-B. We observe that neurons responding better to tones showed stronger induction. These data were also analyzed categorically. For the distributions in Supplementary Fig. 3C-F, we evenly subdivided the entire sample into either tone-preferring (panels C-D) or noise-preferring neurons (E-F). For interrupting (inducing) noise we observed that the more positive trend in Tone-Noise SI values appeared to have been contributed, at least in part, by tone-preferring neurons (median: -0.02, Supplementary Fig. 3C). By comparison, the noise-preferring neurons had a significantly more negative distribution center for interrupting noise (K-S test, $p < 0.001$, median: -0.27, see panel 3E). For surrounding noise, both the tone-preferring (median – 0.27, panel 3D) and the noise-preferring (median -0.38, panel 3F) neurons had negative

median TNSI values (the difference between these two distributions only trended at the $p < 0.1$ level).

These results support that tone-preferring neurons encoded the illusory tone segment during induction (Supplementary Fig. 3C,D), whereas noise-preferring neurons primarily represented the noise (Supplementary Fig. 3C,D), which is also heard during induction. Our results cannot be explained merely by responses increasing for more sound energy, otherwise the response to the loud noise should consistently swamp the responses to the fainter tone (masking). Instead, when individual sound elements are combined into a stimulus known to cause induction, competition in the representation of one feature versus the other (in this case a continuous tone versus a noise) seemed to be resolved based on which of these features elicited the strongest response individually. This demonstrates that while the particular type of neuronal response to the inducing stimulus is difficult to predict (at least by a linear summation of responses to stimulus components, see the manuscript), it is possible to predict with some certainty whether a neuron will be consistent with induction or masking by knowing the strength of the neuron's response to the individual sound components.

3. Supplementary Table. Correlation of neural response characteristics to induction or masking. We tested the association between the TNSI for interrupting and surrounding noise to three response variables. (1) Tone vs. Noise response: the selectivity for the continuous tone or the noise when presented individually (normalized response elicited by the tone or the noise, also see Supplementary Fig. 3), (2) the tone frequency in octaves from the neuron's BF, and (3) the magnitude of the tone response in standard deviations from baseline. To evaluate the responses in (1) and (3) we counted spikes within a 56 ms window (corresponding to our shortest stimulus) around the maximal stimulus response (10 ms before and 46 ms after). Shown for each association is the correlation coefficient (r) and corresponding p-value.

| Association	Noise Type (correlation r; p)	
Tone-Noise SI and:	Interrupting	Surrounding
Tone vs. Noise response	0.20 ; 0.000***	0.15 ; 0.036*
Tone octaves from BF	-0.17 ; 0.000***	-0.01 ; 0.951
Tone response	0.14 ; 0.002**	0.00 ; 0.890

Significant at * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
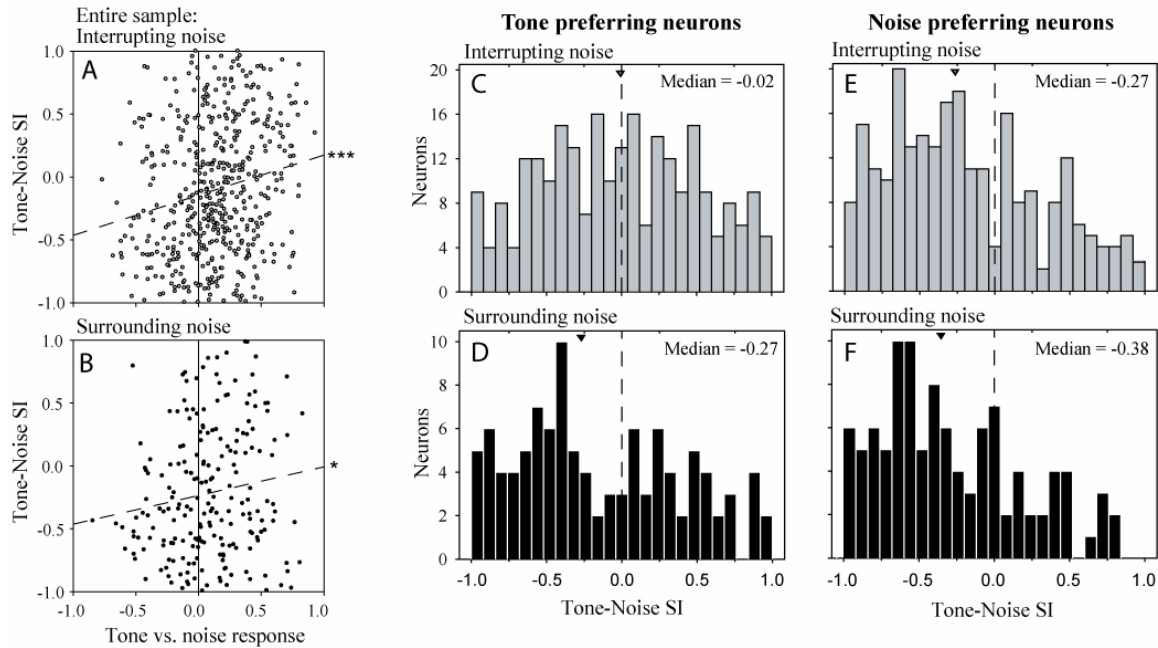
4. Supplementary Figures
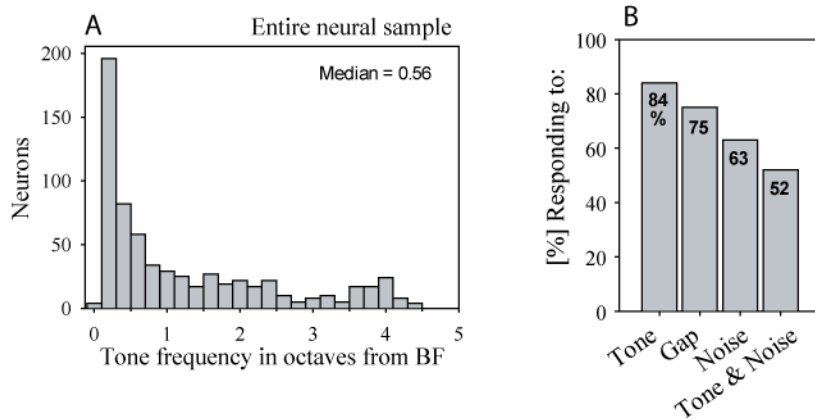
Supplementary Figure 1. Neural sample summary. (A) Distribution of the distance (in octaves) that each neuron's best frequency (BF) was from the foreground tone frequency (Hz). (B) Percentage of neurons responding significantly to the tone, to the gap in the tone, to the noise, and to both the tone and the noise. A significant response was defined as exceeding 2 standard deviations (SD) from the baseline response for 2 consecutive bins or 4 SDs for 1 bin.
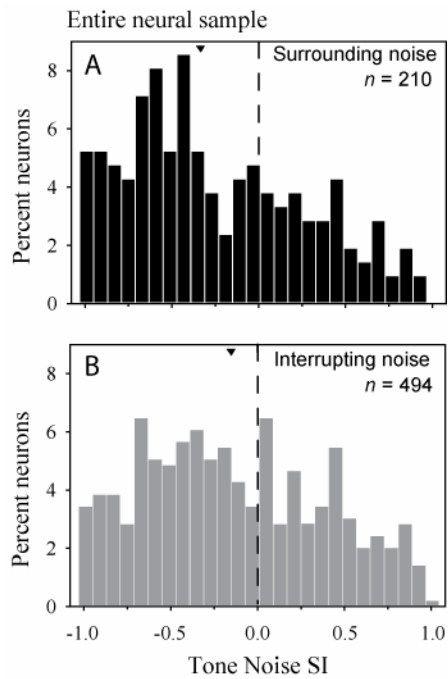
Supplementary Figure 2. Tone-Noise similarity index distributions for the entire sample. Arrowheads show medians of the distributions for (A) surrounding noise (black, median = -0.34) or (B) interrupting noise (gray, median = -0.15).

Supplementary Figure 3. Relationship of induction to a neuron's response preference for tones vs. noise. For all neurons recorded, (A,B) show the relationships between TNSI and the tone vs. noise response for interrupting or surrounding noise containing stimuli. Tone vs. noise response is the normalized response to the tone and noise presented in isolation (positive numbers mean bigger response to tone in isolation). The correlations for interrupting (A) and surrounding (B) noise are significant (*** $p < 0.001$, * $p < 0.05$). (C-F) show the TNSI distributions subdivided by neurons' preferences for tones vs. noise (positive Tone vs. Noise response, see also Supplementary Table 1). The label on top of each plot signifies whether the plot is for surrounding (D,F) or interrupting (C,E) noise. Arrowheads identify the distribution medians.

Response to Reviewers

(see next)