

Sound examples

www.nsi.edu/users/patel/tone_sequences

Unwrapping and detrending of phase-time series

Phase-time series for each sensor in each trial were unwrapped by π . The mean of the first six points of each phase-time series was used to normalize the mean phase of all sensor recordings within each trial by addition or subtraction of an integer multiple of π . Large discontinuities in each sensor's variation about the slope of the phase-time series were minimized by adding or subtracting multiples of 2π at regions where phase changed by more than $(\pi + 0.5)$ over four successive time points. The same regime was then followed for changes between single time points of more than $(\pi + 0.5)$. Finally, the slope of the phase-time series was removed by linear detrending. All of these operations were applied uniformly to data from all channels, subjects and frequency bands by a MATLAB program; the same parameter settings were used in all cases.

No phase tracking at frequencies other than the stimulus modulation frequency

To determine if phase tracking of pitch sequences occurred at frequencies other than the stimulus modulation frequency (41.5 Hz), phase-time series for each channel were computed in .5 Hz steps from 20 to 60 Hz and analyzed using the same criteria applied at 41.5 Hz. Only phase time-series at 41.5 Hz tracked the stimuli. To test whether a component of the observed phase pitch-tracking behavior could be due to evoked, transient ~40 Hz oscillatory neural response to tones (Pantev, C. *et al.*, 1991, Human auditory evoked gamma-band magnetic fields. *Proc. Natl. Acad. Sci. USA* **88**, 8896-9000), three additional subjects who passed hearing tests were tested using scales with and without amplitude modulation. With amplitude modulation, a consistent set of "tracking locations" was identified in each subject as above. Without amplitude modulation, no channels passed the tracking criteria in the 41.5 Hz bin, and phase-time series in this bin and surrounding bins showed no tendency to similarity with the pitch contours of the stimuli. It is noted in passing that power analyses revealed a response at ~39 Hz in each subject which exceeded baseline power in a few sensors and a few trials, but never passed the trial criterion. No phase tracking was seen at this frequency.

Phase tracking patterns are not an artifact of noise or of phase averaging

We tested the possibility that phase tracking was equally accurate in the four conditions, and that the observed pattern of correlation arose from a) random phase noise differentially affecting the correlation statistics of each condition, or b) averaging phase information over 2-second epochs (~5 tones). A critical assumption of the first explanation is that the amount of "noise" is similar in the four conditions. We tested this by examining the absolute deviation of the phase-time waveform at each phase-bank sensor from the pitch-time contour of its corresponding stimulus, yielding a measure of the mean amount of phase noise per contour point ("mean error") for each sensor and sequence. If the explanation is correct, the mean error in the four conditions should be similar, and a regression of mean error on stimulus condition should have a slope that is not significantly different from 0. Instead, all 5 subjects had highly significant negative

regressions of mean error on stimulus condition, suggesting a neural origin for the pattern of correlation between phase tracking and stimulus condition. [F-values for the regression = 153.5, 23.7, 70.2, 224.1, 256.6 for Subjects 1–5, respectively, all $p < .0001$. All subjects had mean errors that descended with condition in the sequence random $> 1/f > 1/f^2 >$ scales, and this pattern was also highly significant across subjects (Friedman 2-way ANOVA, $\chi^2 = 15.00$, $df = 3$, $p = .0018$).

We tested the second explanation by simulating perfect tone-by-tone phase tracking for each sequence and computing an average phase for each consecutive 5-tone group within a sequence. Correlations were then computed between the resulting phase-time waveforms and their corresponding resampled pitch-time waveforms. Each subject showed highly significant differences in this correlation among conditions (all $p < .0001$, Kruskal-Wallis ANOVA), with increasing correlations in the order Random $< 1/f <$ Scales $< 1/f^2$. Across subjects, this latter pattern was highly significant (Friedman 2-way ANOVA, $\chi^2 = 15.00$, $df = 3$, $p = .0018$). Posthoc multiple comparison tests showed that the $1/f^2$ and Scale conditions were not significantly different from each other. Since phase averaging produces a different pattern of correlations than we observed, it cannot account for our data.

Justification of >12 cm criterion for coherence analyses.

To determine the distance above which coherences no longer vary as a function of intersensor distance, the relationship between coherence and intersensor distance over all recordings from each subject was analyzed. In every subject, there was a highly significant negative relationship between coherence and intersensor distance when considering the group of distances up to 12 cm using either linear or nonlinear regression analyses; there were no significant relationships between coherence and distance in the group of distances greater than 12 cm in any subject using the same analyses.

The pattern of coherence is distinct from the pattern of phase tracking

To check that the pattern of coherence across conditions was not simply due to phase correlations of sensors with the stimulus, the coherence analysis was repeated with sensor-pair phase coherences replaced by the average correlation of each sensor-pair with the stimulus. Mean correlation rank increased monotonically in the order Random $< 1/f < 1/f^2 <$ Scales, as in Figure 2(c) (Kruskal-Wallis ANOVA, $H = 52126.3$, $p < .0001$, $df = 3$; all posthoc multiple comparisons significantly different at the .05 level, and ~10 times the effect size seen in Figure 3(a)), showing that the coherence results are distinct from the brain responses which actively track the stimulus.