Fine temporal coding in the auditory system: a model for vibrato perception

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Our auditory system has an exquisite sensitivity for temporal and pitch features of natural sounds. Resolutions of much less than one percent are very common in these domains. However, time and pitch are not always independent magnitudes. Rapidly changing sounds, such as chirps, flutters or vibratos evoke pitch percepts that depend on the time course of the instantaneous frequency of the signal. The mechanisms underlying the pitch assignment for these kind of signals are still unknown. Pitch theories roughly group into two main domains: place-rate and temporal autocorrelation theories [1]. Place theories fail to predict the time dependence of the perceived pitch for rapidly changing sounds, since identical excitation patterns in the auditory nerve could lead to different pitch percepts. Temporal coding of instantaneous frequency could be performed, in principle, by auditory nerve fibers, but it is still not clear how this information is assembled across fibers yielding a single pitch percept. Moreover, autocorrelation models fail to predict some new results in the perception of asymmetrical vibratos [2].

We propose a new approach to this problem, based in a recent work [3], where the authors suggest that the auditory system may use a *reassigned* representation of sound stimuli, in which time and frequency localization is computed using phases of oscillations. This representation maps frequencies physically present in sound to new values called *instantaneous frequencies*. This task could be implemented neurally using the time interval between action potentials in the nerve fibers. In this way, an estimation of the instantaneous frequency is obtained for each auditory channel. If these estimations are very similar in a group of neighboring channels, we say that there exists a high degree of *consensus* (following [3]). We give a way of computing consensus locally in each auditory channel employing only phase information. The model then predicts principal pitch in vibrato as a weighted average of the instantaneous frequencies extracted, with a perceptual weight proportional to consensus and to a compressive function of channel amplitude. Also, we provide a biologically plausible neural circuit that could perform a rate code of the consensus across the temporally coded instantaneous frequencies in the different channels.

In order to test our model, a psychophysical experiment using vibratos with portions of fast and slow varying frequency was performed. Although synthetically generated, examples of similar frequency profile could be found for instance in South Indian music [4].

We were able to adjust our perceived pitch experimental data tuning a single free parameter in our model, and to predict data obtained in previously reported vibrato experiments [5,6], using the same parameter value.

Even when we are treating a particular example of a rapidly changing sound and we are not claiming that this is a new pitch perception paradigm, our model addresses a long standing issue in auditory processing: how the information conveyed by the tonotopic organization (rate-place code) and the fine temporal coding of the auditory nerve fibers could be combined in order to give a single pitch percept.

References:

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