A competition between tonotopic neural ensembles underlies pitch-related
dynamics of the auditory evoked fields

Alejandro Tabas, Bournemouth University, atabas@bournemouth.ac.uk
André Rupp, Universität Heidelberg
Emili Balaguer-Ballester, Bournemouth University, BCCN Mannheim

Auditory evoked fields observed in MEG experiments systematically present a negative transient known as the
N100m, elicited around 100 ms after the tone onset in the antero-lateral Heschl’s Gyrus. The exact N100m’s latency
is correlated with the perceived pitch of a wide range of stimulus (e.g. [3]), indicating that the transient reflects the
processing of pitch in auditory cortex. However, the neurophysiological substrate of this relationship remains an
enigma. Preceding models of pitch, focused on perceptual phenomena, failed to disclose the mechanism generating
cortical evoked fields during pitch processing in sufficient biophysical detail. In this work, we introduce a cortical
model of pitch describing, for the first time to our knowledge, how cortical pitch processing gives rise to observed
neural responses and why its latency strongly correlates with pitch.

The thalamic input is generated by a delay-and-multiply procedure based on the the principles of the autocorrelation
models [2]. A realistic model of the auditory peripheral system is used to to simulate the auditory nerve activity, which is
phase-locked to the waveform of the sound and preserves the periodicities contained in the stimuli. A set of \(N = 200\)
chopper neurons in the ventral cochlear nucleus systematically delay the auditory nerve input by \(N\) different lags \(\delta t_n\),
which are compared with the original auditory nerve activity by an array of coincidence detector units in the inferior
colliculus. The coincidence detector \(n\) spikes when the characteristic delay \(\delta t_n\) is a multiple of a periodicity present in
the sound [1]. Coincidence detectors activation is leaky-integrated by thalamic ensembles and forwarded to the cortical
model. The typical thalamic activity pattern elicited by a sound with a periodicity \(T\) presents peaks of activation in the
channels characterising \(\delta_n = kT, k \in 1, 2, \ldots\).

The cortical model transforms these harmonic thalamic patterns into tonotopic receptive-field-like representations.
Each cortical functional block is characterised by a best period \(\delta_n t\) and consist of pyramidal excitatory cells and
inhibitory interneurons. Blocks interact with each other through local AMPA and NMDA -driven excitation and
GABA-driven selective inhibition [4]. Excitatory and inhibitory ensembles \(H_{en}^c(t)\) were modelled using mean-field
approximations; AMPA/GABA and NMDA dynamics were modelled as leaky integrators with instantaneous and slow
rising times, respectively [4]. Values of the parameters were taken from the literature [4] and slightly tuned within the
biophysical range in order to achieve a suitable e/i balance. The neuromagnetic fields elicited by the cortical dynamics
were computed as a linear function of the activation of the excitatory ensembles \(\sum_n H_{en}^c(i)\).

Excitatory cells in block \(n\) receive direct input from the thalamic channel characterised by the delay \(\delta_n\). Excitatory
ensembles are connected locally to the inhibitory populations, which connect selectively to other blocks in the network.
The selective inhibition effectively shunts populations encoding the lower harmonics present in the thalamic input.
This circuitry describes a general pitch processing mechanism that explains the N100m deflection as a transient state
in the cortical dynamics: The deflection is triggered by a rise in the activity elicited by the thalamic input, peaks after the
inhibition overcomes the input, and ends when model dynamics reach equilibrium. The duration of the transient
state depends on the encoded pitch of the tone: High frequency tones have more inferior harmonics in the hearing
range, eliciting a stronger inhibition along the network and driving the system to equilibrium faster than low pitched
tones. This behaviour explains the empirically observed correlation of the N100m latency with the tone’s pitch.

Perceptual experiments were performed on pure tones, several different harmonic complex tones, and iterated
rippled noises. In all the cases, after 50-100 ms, the system reaches an state of equilibrium characterised by an
unimodal distribution of the activation centred in the ensemble parametrised by the period of the perceived pitch of
the stimulus. Moreover, neuromagnetic simulations computed with pure tones reveal N100m latency predictions that
are fully in line with the available experimental data [3].

References
[1] Balaguer-Ballester et al., E. Understanding pitch perception as a hierarchical process with top-down modulation,