

Tagging the musical beat: Neural entrainment or event-related potentials?

Giacomo Novembre^{a,b,1} and Gian Domenico Iannetti^{a,b,1}

In a recent issue of PNAS, Lenc et al. (1) report that steady-state responses (SSRs) induced by rhythmic auditory stimuli are enhanced when listeners attend to low-frequency sounds, particularly when these sounds reflect salient periodicities like the beat or the meter. Lenc et al. (1) interpret this finding as an entrainment of sensory-motor networks important for planning and controlling movements, underlying humans' spontaneous tendency to move to music and particularly to low-frequency sounds produced by instruments such as bass or drums (2).

We propose a more parsimonious interpretation of these findings: The EEG periodicities contributing to the enhanced SSRs may not reflect an actual neural entrainment but, instead, might be driven by a sequence of auditory event-related potentials (ERPs). In an earlier study, Nozaradan et al. (3) dismissed this alternative interpretation by simply reporting that only the first stimulus of the sequence elicited an ERP, whereas the following stimuli did not elicit "measurable" ERPs. The latter point, however, was merely qualitative and not supported by statistical evidence. Relevant to this discourse is a recent study disclosing that, although habituated over repetition, small-amplitude ERPs are reliably elicited even following tens of consecutive stimuli presented at 1 Hz (4). These preserved ERPs included the supramodal, biphasic negative-positive (N–P) vertex wave and the contingent negative variation (CNV), a slow-rising negativity anticipating predictable events. Notably, these ERPs are commonly evoked by auditory stimuli (5, 6).

A modulation of either of these ERPs could explain the results reported by Lenc et al. (1), because both the

N–P vertex wave and the CNV are modulated by both temporal attention and anticipation (5–7). If a participant allocates more attentional resources to the periodic events marking the beat or the meter (or to any predictable or salient event within a pattern), then the ERP amplitude associated with these events becomes larger. It follows that such time-locked modulations would enhance the power at beat- and meter-relevant frequencies (Fig. 1). Supporting this alternative interpretation, we highlight that (i) the reported SSRs had a scalp topography similar to that of both the CNV and the negative vertex wave (auditory N1); (ii) the SSRs' enhancement was contingent on attentional allocation (5, 6); (iii) remarkably, the N–P vertex wave has larger amplitude when elicited by low-frequency sounds (8); and (iv) the N–P vertex wave can also be evoked by imagery of transient auditory events that are typical of syncopated rhythms (9).

This alternative interpretation could be easily tested by analyzing the EEG data in the time domain and statistically assessing the presence of ERPs in the waveforms time-locked to each stimulus onset (4). Should this analysis reveal the presence of ERPs, two fundamental implications of the results reported by Lenc et al. (1) follow. First, the notion that these SSRs tag neural entrainment should be reconsidered: They might not reflect stimulus-induced sustained oscillatory activity, but rather repeated stimulus-evoked transient ERPs (10). Second, the cortical network underlying the results of Lenc et al. (1) and Nozaradan et al. (3) would subserve attention to, and anticipation of, salient events (5–7).

^aDepartment of Neuroscience, Physiology and Pharmacology, University College London, London WC1E 6BT, United Kingdom; and ^bNeuroscience and Behaviour Laboratory, Istituto Italiano di Tecnologia, 00186 Rome, Italy

Author contributions: G.N. and G.D.I. wrote the paper.

The authors declare no conflict of interest.

Published under the [PNAS license](#).

¹To whom correspondence may be addressed. Email: g.iannetti@ucl.ac.uk or g.novembre@ucl.ac.uk.

