

# Neuromodulatory effects of movement during auditory-motor tasks

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**Abstract.** From a neuroscience of music perspective, the embodied music cognition paradigm poses some challenges difficult to overcome. Neuroimaging techniques are highly sensitive to movement, which prevents them from being suitable for recordings involving auditory-motor tasks due to volume conduction effects. Nevertheless, with the advent of portable devices and new mathematical methodologies for high dimensional (and complex) data, this problem becomes more manageable. We investigated the neuromodulatory effects of gestures synchronized to auditory stimuli by analyzing the higher-order structure of our data. The proposed method based on basis functions approximations, effectively separates mixtures of neural signatures and allows a reduction of motion artifacts with minimum loss of information. Our findings partially resonate with the hypothesis that auditory event-related potentials are characterized by a reduction of the waveform's complexity through a suppression of spontaneous fluctuation of neuronal activity in correspondence to certain spectral subbands. Synchronizing movements to sound may influence the processing of information through parsimonious engagement of neural resources. A broader discussion of modulating effects of motor input on cognition is beyond the scope of the present contribution. However, the current data shows that auditory-motor coupling is not necessarily a mere distractor, but may sometimes be key at integrating sensory input.

## Background

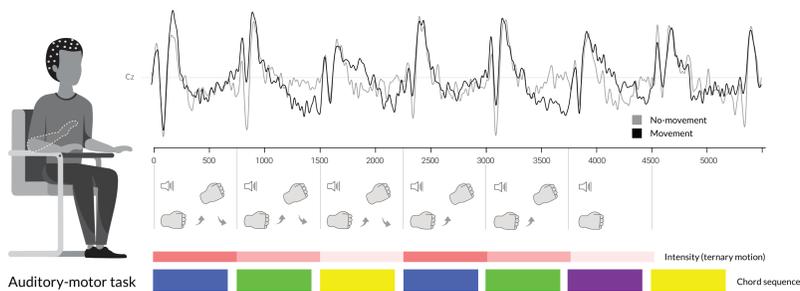
Embodied music cognition puts the emphasis on the role of the **body as a mediator for meaning formation** [1]. The idea that movement can shape auditory rhythm perception derives from previous behavioral studies [2, 3], and relate to the assumption that rhythm perception is closely linked to the vestibular system.

However, the **neurobiological basis of auditory-motor integration** incorporating rhythmical and harmonic information remains relatively unexplored. In non-invasive EEG/MEG recordings, neuronal oscillations are usually modulated by the effect of a spatial synchronization and, unfortunately, affected by artifactual events outside the brain. Non-linearities become apparent during the signal reduction. Thus, recordings involving movement represent an additional challenge to unveil the neural mechanisms behind the paradigm of embodied music cognition.

## Research questions

- Which spatial and local signatures in the brain characterize the duality between movement and a non-movement state during the performance of an auditory task?
- How is the neural substrate of listening to auditory stimuli modulated by synchronous movements?
- Will synchronous movements to a metric pattern influence the perception of the progression of harmonic sequences?

## Experimental design



**Figure 1:** An illustrative scheme representing the experimental setting. The participants were instructed to tap the right hand on a table, synchronizing with the presentation of 6 chords (composed of Shepard tones) in one condition and listening to the same sequence in a condition without any movement involved. The seventh chord has the role of a probe as in Krumhansl's experiments. We used the probe to evaluate the effects of a binary and ternary tapping. The EEG data was acquired at the Art Science Interaction Lab of the IPEM Institute (Ghent University). The measurements were taken with a 64-channels Ego™mylab EEG system. EEG data were epoched and classified for each tone presentation.

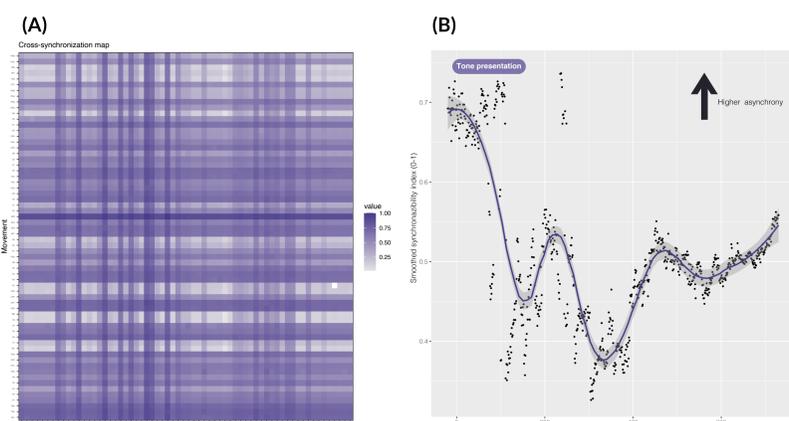
## Statistical methodologies

### Cross-phase analysis and brain-to-brain synchronizability

Let  $x_i(t), y_j(t)$  ( $i, j = 1, \dots, n$ ) be two EEG signals with  $n$  representing the number of channels. In order to capture how both signals differ in terms of synchronization consider

$$\varphi_{i,x}(t) = \arctan \mathcal{H}\{x_i(t)\}/x_i(t) \quad \varphi_{j,y}(t) = \arctan \mathcal{H}\{y_j(t)\}/y_j(t),$$

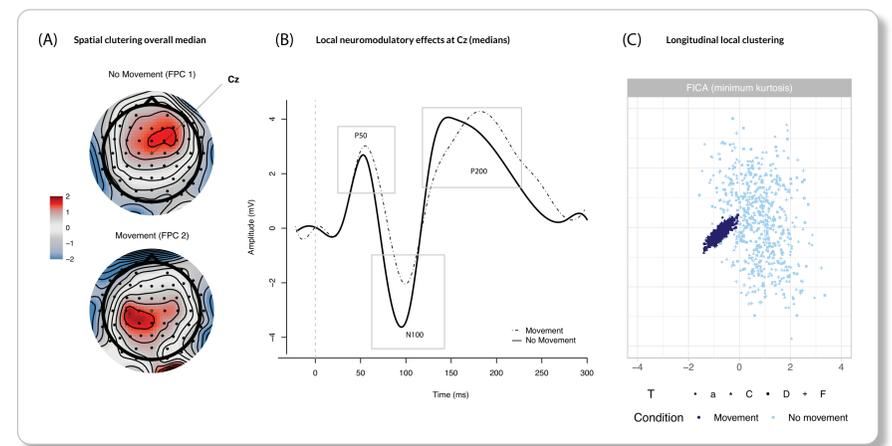
where  $\mathcal{H}(\cdot)$  denotes the Hilbert transform and  $\varphi_{i,x}, \varphi_{j,y}$  is the instantaneous phase of  $x_i(t), y_j(t)$  respectively. The continuous relative phase is usually estimated as  $\phi_{ij,xy}(t) = \varphi_{i,x}(t) - \varphi_{j,y}(t)$  for each  $i, j \in T$ . If we take the derivative with respect time, then we have  $\omega_{ij,xy}(t) = d\phi_{ij,xy}/dt$ . By calculating the  $L^2(T)$  norm for each  $(i, j)$  of  $\omega_{ij,xy}$ , we get a score matrix  $S \in \mathbb{R}^{n \times n}$  that accounts for the level of synchronizability over all crossed signal components (see figure 2A). The Hilbert Schmidt norm of  $S$  gives us the global level of synchronization between the two signals (Figure 2B).



The proposed **synchronizability index** is a measure to quantify globally phase differences between two brain states. Its reliability greatly depends on robust brain signal estimators. In this example, all calculations are conducted on the overall medians for each condition in a cumulative way.

## Statistics on Hilbert Spaces

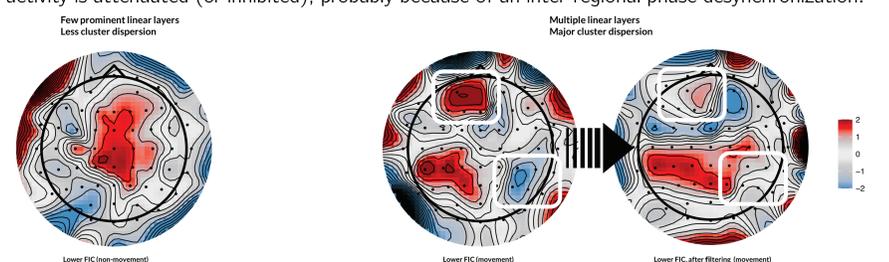
We use an object-oriented approach to conduct all statistical analyses [8]. Thus, our data consists of a set of sample functions usually reconstructed fitting a B-spline or Wavelet basis on the scalar data. For a greater data interpretability, we exploit the properties of the **functional independent component analysis (FICA)** proposed in [6, 7, 5]. Some eigenfunctions of the FICA model have discriminating properties that, when projected onto the data, reveal new insights on the embodied neural architecture and its spatial distribution.



**Figure 2:** (A) Scalp topographies of the first functional principal components depicted by spatial interpolation. Maximal activation is recorded at the frontocentral right cluster for the non-movement condition and the left centroparietal cluster for the movement condition. As an illustrative example, (B) shows the neuromodulatory effects in phase and amplitude in channel Cz in terms of overall median. Differences are evinced by the attenuation of amplitude at component N100 and phase synchronization delay of the wave components. (C) depicts channel-referenced longitudinal functional EEG data reduced with FICA for one single subject.

## Results and closing remarks

- The analyzed embodied condition exhibits a complex brain architecture characterized by predominant lower frequencies produced in frontal and left-temporal regions. The centro-parietal oscillatory activity is attenuated (or inhibited), probably because of an inter-regional phase desynchronization.



- Some preliminary functional analysis of variance (FANOVA) testing also reveals significant differences between pairwise brain regions for both conditions.
- The synchronizability index supports these differences and allows to quantify the degree of asynchrony between the two brain states. Even when filtering lower frequencies on the movement dataset, the level of asynchrony increases.

Our findings can be explained with reference to theories that assume suppression of waveform complexity due to motor involvement [4]. The question that remains to answer is whether such a brain state is globally efficient for processing and integrating musical information, so that the performance during auditory perception can be enhanced through auditory-motor coupling.

## References

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