THE PREMOTOR ROOTS OF MUSICAL BEAT PERCEPTION AND IMAGERY: A NEUROPHYSIOLOGICAL INVESTIGATION

Giorgio Lazzari[1], Giulio Costantini[2], Laura Ferreri[1], Luigi Cattaneo[3], Virginia Penhune[4,5] & Carlotta Lega[1]

[1]Department of Brain and Behavioral Sciences, University of Pavia, Italy; [2]Department of Psychology, University of Milano-Bicocca, Italy; [3]Center for Mind/Brain Sciences (CIMeC), University of Trento, Italy; [4]Psychology Department, Concordia University, Montreal, Canada; [5]Montreal Laboratory for Brain, Music and Sound (BRAMS) and the Centre for Research in Brain, Language and Music (CRBLM), Canada

Grant 241/20

Background: Humans can flexibly extract a regular beat from complex rhythmic patterns, perceive, imagine, and synchronize with musical rhythm. Unlike many perceptual phenomena, rhythmic abilities are not based on a fixed mapping between sound features and perception but rely on top-down mechanisms that construct temporal regularity. The motor system supports such predictive timing even without overt movement, and the premotor cortex (PMC) appears crucial in generating top-down predictions about upcoming auditory events.

Aims: Despite this, the causal role, spatial specificity, and connectivity of the PMC in beat-based timing remain unclear, as do the effects of individual and contextual factors. This project addresses these issues by combining behavioral and neurophysiological methods to examine the causality, topography, excitability, and connectivity of the PMC during rhythm perception and imagery.

Methods: We conducted a series of transcranial magnetic stimulation (TMS) studies. In Study I, repetitive online TMS targeted right rostral and caudal dorsal PMC (dPMC), SMA, pre-SMA, and a sham site to assess topographical specificity and hemispheric differences in beat perception. Study II tested the causal contribution of dPMC and SMA to beat imagery. Study III combined TMS and EEG to investigate dPMC excitability and connectivity with auditory regions.

Results: Stimulation of the caudal right dPMC selectively disrupted beat perception compared with other regions, and only right-hemisphere stimulation affected performance. TMS over the same area also modulated beat imagery, particularly in individuals with lower auditory imagery ability. Combined TMS–EEG results revealed that higher right dPMC excitability predicted stronger responses to perceived or imagined strong-beat positions, indicating its role in modulating auditory processing through top-down predictive signals.

Conclusions: These findings support models emphasizing the dorsal auditory stream's involvement in auditory beat perception and imagery, highlighting the right dPMC's role in generating internal action predictions and perceptual expectations. Overall, this work advances understanding of the neural bases of rhythm and suggests that predictive motor–auditory mechanisms may have contributed to the evolution of human musicality and its social functions.

Keywords: Transcranial magnetic stimulation, TMS-EEG, Premotor cortex, Supplementary motor areas, Rhythm perception, Rhythm imagery

Publication:

Benoit, C.-E., Ferreri, L., Lega, C., & van Vugt, F. T. (2022). Editorial: Rhythm in human cognition and action: Health and pathology. *Frontiers in Psychology*, *13*, 1047825. https://doi.org/10.3389/fpsyg.2022.1047825

Ferreri, L., van Vugt, F., Bégel, V., Albouy, P., Lega, C., & Benoit, C. É. (2024). Future directions in the psychology of music. *Advances in Cognitive Psychology*, *19*(4), 1–2.

Lazzari, G., Costantini, G., La Rocca, S., Massironi, A., Cattaneo, L., Penhune, V., & Lega, C. (2025). Topography of functional organization of beat perception in human premotor cortex: Causal evidence from a transcranial magnetic stimulation (TMS) study. *Human Brain Mapping*, *46*(7), e70225. https://doi.org/10.1002/hbm.70225

Lazzari, G., Ferreri, L., Cattaneo, L., Penhune, V., & Lega, C. (2025). Imagining the beat: Causal evidence for dorsal premotor cortex (dPMC) role in beat imagery via transcranial magnetic stimulation (TMS). *NeuroImage*, *323*, 121593. https://doi.org/10.1016/j.neuroimage.2025.121593

Lazzari, G., Sacheli, L. M., Benoit, C.-E., Lega, C., & van Vugt, F. T. (2024). Pleasantness makes a good time: Musical consonance shapes interpersonal synchronization in dyadic joint action. *Frontiers in Human Neuroscience*, *18*, 1472632. https://doi.org/10.3389/fnhum.2024.1472632

E-mail contact: carlotta.lega@unipv.it