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Rhythm in Music, Encoded in Neural Networks, and in the Mind

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Supplemental Material

Figure 1a-c is my representation of the functional neuroanatomy of Rhythm in Music (RiM), based on the findings of several decades of research into Beat Perception and Synchronization (BPS). Apart from the well-established “dorsal stream” network, a preliminary image of a less-well substantiated “ventral stream” is added, involved in the emergence of features related to the Gestalt character of RiM. It is challenging to bring together all these details in a single representation, only to end up with an image that just looks like the *entire brain* (figure 1 in my submission). I hope it appeals to the imagination both scientifically and artistically, although it is *misleading in a philosophical way.* Hence my proposal of *supplemental material*: constitutive details in the submission that, however, should not distract from the actual goal of the review. Research into the way in which the phenomenon of RiM is processed in the brain has yielded so much detailed knowledge that it is hardly possible to see the forest for the trees. Yet we are looking for the *forest* (to use this figure of speech for RiM) and not just its constituent parts. Our forest cannot be saved by the recruitment of many tree experts alone, even though they form an indispensable link. Just like the forest, RiM is a thoroughly familiar phenomenon that only gains its meaning in the experience itself, which requires the involvement of an *entire interactive brain.* Or in that more general statement: If we knew all the details of the brain, do we also know the “brain”, let alone the (interactive) “mind”? Philosophical minded neurologists, like Kurt Goldstein (1878-1965), emphasized that you can only understand the brain in its total ongoing service of an organism, in search for adaptation and solutions to the challenges posed by a complex living environment, beyond health and disease. A fast-growing category of people suffering from age-related diseases of the nervous system seem to be implicitly aware of this. They are happy to go along with considerations about the remaining capacities of their aging nervous system, characterized by its limitations anyway, beyond the hope for cure or symptom relief. No matter how detailed our knowledge of the brain and its constitutive parts might be, it remains an organ in its entirety in search for adaptation of the living being to a rapidly changing complex living environment.

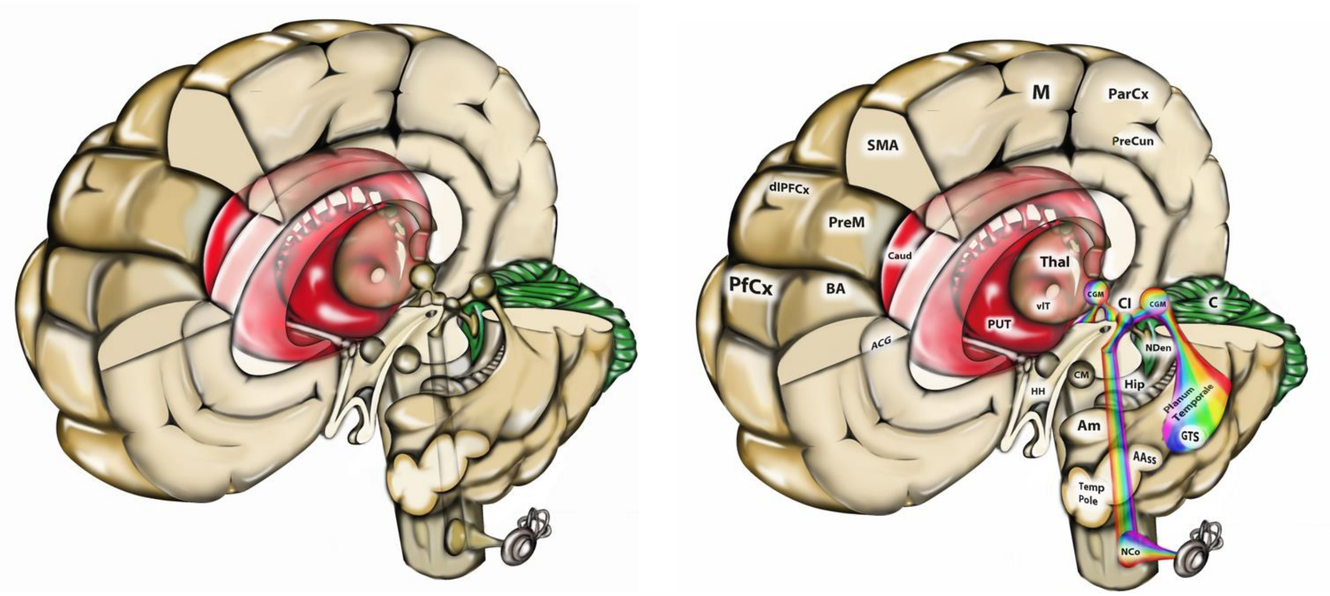
Why all this, just for the sake of an illustration? Of course, I hope this somewhat misleading image provides some support on the long road to RiM’s destiny as one of those elusive and yet thoroughly familiar phenomena, which might make it incomprehensible for artificial intelligence. But I also want to use it as a substantiation for a challenge of the recent statement of Patricia Smith Churchland (an authority I greatly appreciate) in this journal: “Neurophilosophy explores the impact of discoveries in neuroscience on a range of traditional philosophical questions about the nature of the mind” (Churchland, 2022). Our growing knowledge in the broad field of neuroscience is fascinating, indispensable for medical care and certainly can promote our insight in traditional philosophical concepts like that of the mind. But it is not *superior* to those other domains, like art and philosophy. These domains play their own indispensable role in the brain’s eternal search for adaptation of the organism to an increasingly complex living environment. I therefore propose (perhaps somewhat presumptuous) a modified version of Patricia Smith Churchland’s statement: Neurophilosophy explores the *value of discoveries in neuroscience for their possible significance for adapted representation of traditional philosophical concepts concerning the “reality” of our mental world in exchange with its living environment.*

Reference

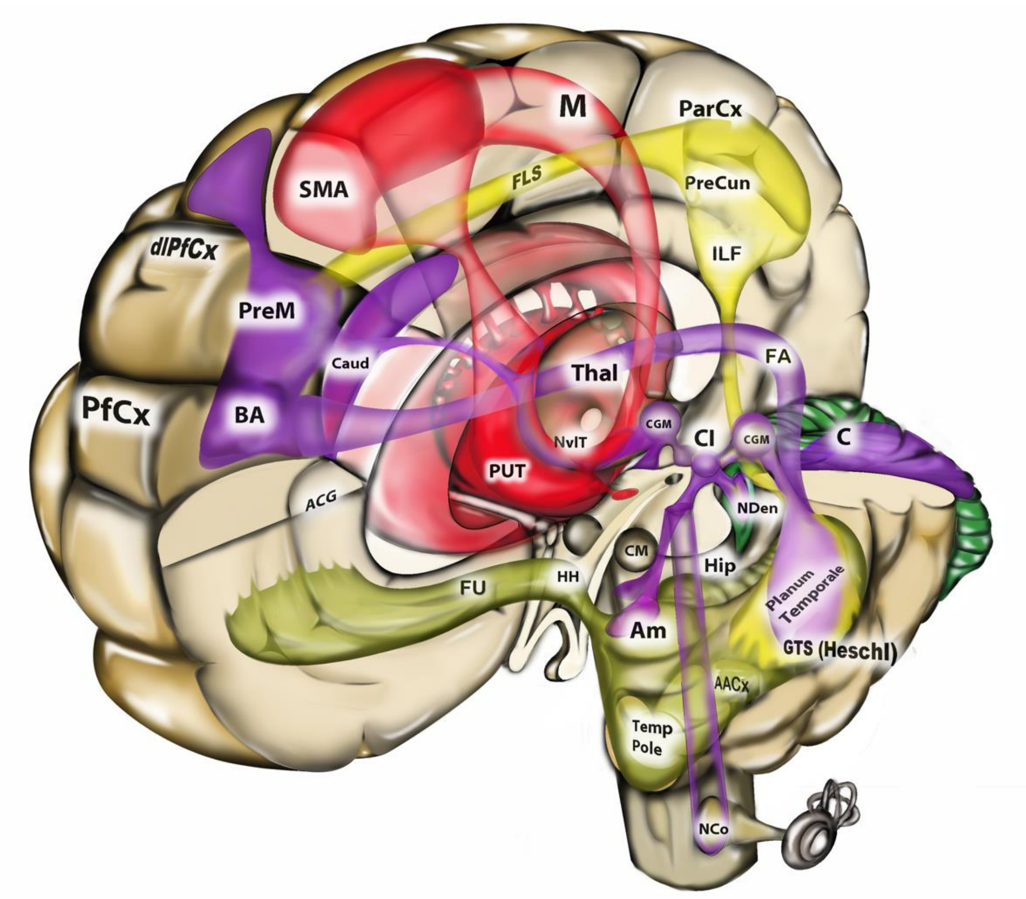
Churchland PS. What is Neurophilosophy and how did Neurophilosophy get started? Journal of Neurophilosophy 2022;1(1):1-16.

Figure 1. a: The brain dissected in a way to represent relevant parts in BPS, particularly the *planum temporale* (*insula* not visible and paramedian prefrontal cortex removed). b: Overview with tonotopic and ordered representations (in rainbow colors) of the elements in music, from the *cochlear nucleus* to the *auditory cortex*. *Olivary nucleus* not visible.

a. b.



c. **Pathways** of the processing of RiM, with beat perception related to motor (**purple**), culturally acquired (**red**) and action-relevant temporal pattern recognition (**yellow**). The ventral stream is depicted in a preliminary representation (**green**, by analogy with that in language).



Abbreviations:

Am = *Amygdala*

AACx = Auditory association cortex

ACG = anterior part of *Gyrus Cinguli*

BA = Broca's area (inside)

C = *Cerebellum*

Caud = *Nucleus Caudatus*

CGM = *Corpus Geniculatum Mediale*

CI = *Colliculus Inferior*

CM = *Corpus Mammillare*

dlPfCx = Dorsolateral Prefrontal Cortex

FA = *Fasciculus arcuatus*

FLS = *Fasciculus longitudinalis superior*

FU = *Fasciculus uncinatus*

GTS = *Gyrus temporalis superior* (Heschl)

HH = Hypothalamic-hypophysial complex

Hip = *Hippocampus*

ILF = Fasciculus longitudinalis inferior

M = Primary Motor Cortex

NDen = *Nucleus Dentatus Cerebelli*

NvlT = *Nucleus Ventrolateralis Thalami*

ParCx = Parietal Cortex

PfCx = Prefrontal Cortex

PreCun= Precuneus

PreM = Premotor Cortex (dorsal and ventral part)

PUT = *Putamen*

SMA = Supplementary Motor Cortex

Temp Pole= Temporal pole (dissected)

Thal = *Thalamus*

Additional notes to Figure 1c (references available upon request).

In purple: BPS is essentially related to the motor system, first by an intention to move, regardless of whether it is visible or it leads to action. This synchronized intention to move is based on prediction, with the involvement of the prefrontal cortex. Computations underlying prediction (and the involvement of the cortico-basal ganglia-thalamo-cortical loop, represented in red) may lead to an unwanted delay. The cerebellum compensates for this timing deficit, matching external cues and anticipating an appropriate response. This rhythm-related sensori-motor integration bypasses the decode representation in the auditory cortex, which nevertheless is also connected to the prefrontal cortex.

In red: BPS is partly acquired by cultural practices and embodied in an early face of life. This adapted way of tuning to the auditory input is integrated by computations in the basal ganglia, where the SMA-putamen connection and PfCx-Caudate connection are integrated and directed to the output system and the thalamus for feedback.

In yellow: The attribution of a rhythmic sequence to music and the recognition of a rhythmic pattern takes place on a perceptual level in the parietal cortex. To this end information is delayed from its afferent source in the lateral lemniscus and transferred in the posterior thalamus to the inferior parietal cortex. This temporal structure recognition is important to direct attention and underlies the so-called “Dynamic-Attention-Theory” and “Action Simulation for Auditory Prediction” concepts in the literature on BPS.

In green: Parahippocampal networks are involved in the formation of a temporal pattern, comparable to a spatial map as a reference for orientation in space and time. Larger parts of the paramedian cortex (including hippocampus and amygdala) are involved in the integration and attribution of an abstract encoded meaning of RiM. By analogy with language networks, the fasciculus uncinatus, connecting the auditory association cortex with Broca’s area where the building of recursive trees takes place, probably is involved in the perception and understanding of syntax by (as explored in the main text).