EVOLUTION OF LANGUAGE SYNTAX AND MUSICAL RHYTHM: FLEXIBLE MOTOR AND COGNITIVE CONTROL

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From theoretical as well as empirical perspectives, there is an increasing number of evidences for a close relationship between language syntax and musical rhythm (e.g., Fitch, 2013; Gordon, Jacobs, Schuele, & McAuley, 2015), although this link seems not to be intuitive and tends to be neglected so far. In the current paper, I indeed argue for the strong link between language syntax and musical rhythm by showing that the same neurocognitive mechanisms implemented in the cortico-basal ganglia-thalamocortical (CBGT) circuits are involved in and necessary for flexible motor and cognitive control crucial for both domains. Moreover, I propose that phylogenetic changes in the CBGT circuits led to the gradual transition from goal-directed, reward-based motor control to more flexible motor and cognitive control.

First of all, several neuroimaging and neuropsychological studies point out critical role of the CBGT circuits for processing musical rhythm and language syntax. Concerning musical rhythm processing, the motor CBGT circuit including the supplementary motor area (SMA) and the putamen is indicated in continually predicting the next beat (Grahn & Rowe, 2013) as well as hierarchical structuring of rhythm (Asano, 2019). In addition, Parkinson's disease (PD) patients show impaired beat-based encoding of rhythm mainly in performing perceptual tasks (for a review, see Leow & Grahn, 2014). The executive CBGT circuit including the prefrontal cortex and the caudate is activated in finding the beat (Kung, Chen, Zatorre, & Penhune, 2013) as well as processing breaches of expectation (Schiffer & Schubotz, 2011).

As for language syntax, morphosyntactic and phrasal syntactic processing such as word order violation processing (Moro et al., 2001) and syntactic ambiguity resolution (Stowe, Paans, Wijers, & Zwarts, 2004) recruit the executive circuit. The putamen (but not the SMA) was indicated in processing phrase structure violation (Friederici, Rüschemeyer, Hahne, & Fiebach, 2003) and increasingly larger constituent structure (Moreno, Limousin, Dehaene, & Pallier, 2018). Moreover, PD, Huntington's disease (HD), and focal basal ganglia patients display problem in inhibiting an overlearned syntactic representation and selecting an alternative (for reviews, see Friederici & Kotz, 2003; Kotz, Schwartze, & Schmidt-Kassow, 2009). Especially, HD patients and even their asymptomatic relatives showed abnormal processing sentences with center-embedding (García et al., 2017). Processing sequences with center-embedding also activates the caudate (Bahlmann, Schubotz, & Friederici, 2008).

That is, the CBGT circuits are involved in and necessary for processing musical rhythm and language syntax although the former primarily relies on the motor circuit and the latter on the executive circuit.

The basal ganglia are known to contribute as a 'control center' working together with the cortico-thalamic pattern generators in both motor and cognitive domains: 1) assisting execution of cortically driven predictable and automatic motor and cognitive patterns; and 2) adapting to unusual circumstances by interrupting and altering the automatically running motor and cognitive representations (Graybiel, 1997; Marsden & Obeso, 1994). Those dual functions of the basal ganglia facilitate flexibility and adaptation in motor and cognitive control. Indeed, motor and cognitive flexibility is crucial for processing musical rhythm and language syntax. For example, in continually predicting the next beat, execution of the current time interval represented in the SMA should be assisted by suppressing the alternative representations. In processing breaches of expectation caused by structural violations, structural ambiguity, and center-embedding, automatic cortical representations should be suppressed to choose an alternative one. Thus, I suggest that flexible control implemented in the CBGT circuits is the common basis of musical rhythm and language syntax.

Goal-directed, reward-based adaptation in motor control through the basal ganglia is wide-spread in animals. However, mice with humanized Foxp2 shows change in the basal ganglia (increase in total dendrite length of the striatal medium spiny neurons) and significantly more rapid switching of their behavioral strategy (Enard, 2011; Scharff & Petri, 2011; Schreiweis et al., 2014). Further, between-species difference in dopaminergic innervation of the caudate is reported (Raghanti et al., 2016). Thus, I claim that phylogenetic changes in the CBGT circuits led to increasingly more flexible motor and cognitive control in humans, making the brain partly ready for processing musical rhythm and language syntax.

References

Asano, R. (2019). *Principled Explanations in Comparative Biomusicology – Toward a Comparative Cognitive Biology of the Human Capacities for Music and Language*. University of Cologne.

Bahlmann, J., Schubotz, R. I., & Friederici, A. D. (2008). Hierarchical artificial grammar processing engages Broca's area. *NeuroImage*, *42*(2), 525–534. https://doi.org/10.1016/j.neuroimage.2008.04.249

Enard, W. (2011). FOXP2 and the role of cortico-basal ganglia circuits in speech and language evolution. *Current Opinion in Neurobiology*, *21*(3), 415–424. https://doi.org/10.1016/j.conb.2011.04.008

Fitch, W. T. (2013). Rhythmic cognition in humans and animals: distinguishing meter and pulse perception. *Frontiers in Systems Neuroscience*, *7*, 68. https://doi.org/10.3389/fnsys.2013.00068

Friederici, A. D., & Kotz, S. A. (2003). The brain basis of syntactic processes: functional imaging and lesion studies. *NeuroImage*, *20*(SUPPL. 1), S8–S17. https://doi.org/10.1016/j.neuroimage.2003.09.003

Friederici, A. D., Rüschemeyer, S.-A., Hahne, A., & Fiebach, C. J. (2003). The role of left inferior frontal and superior temporal cortex in sentence comprehension: localizing syntactic and semantic processes. *Cerebral Cortex*, *13*(2), 170–177. https://doi.org/10.1093/cercor/13.2.170

García, A. M., Bocanegra, Y., Herrera, E., Pino, M., Muñoz, E., Sedeño, L., & Ibáñez, A. (2017). Action-semantic and syntactic deficits in subjects at risk for Huntington's disease. *Journal of Neuropsychology*. https://doi.org/10.1111/jnp.12120

Gordon, R. L., Jacobs, M. S., Schuele, C. M., & McAuley, J. D. (2015). Perspectives on the rhythm-grammar link and its implications for typical and atypical language development. *Annals of the New York Academy of Sciences*, *1337*(1), 16–25. https://doi.org/10.1111/nyas.12683

Grahn, J. A., & Rowe, J. B. (2013). Finding and feeling the musical beat: Striatal dissociations between detection and prediction of regularity. *Cerebral Cortex*, *23*(4), 913–921. https://doi.org/10.1093/cercor/bhs083

Graybiel, A. M. (1997). The Basal Ganglia and Cognitive Pattern Generators. *Schizophrenia Bulletin*, *23*(3), 459–469. https://doi.org/10.1093/schbul/23.3.459

Kotz, S. A., Schwartze, M., & Schmidt-Kassow, M. (2009). Non-motor basal ganglia functions: A review and proposal for a model of sensory predictability in auditory language perception. *Cortex*, *45*(8), 982–990. https://doi.org/10.1016/j.cortex.2009.02.010

Kung, S.-J., Chen, J. L., Zatorre, R. J., & Penhune, V. B. (2013). Interacting Cortical and Basal Ganglia Networks Underlying Finding and Tapping to the Musical Beat. *Journal of Cognitive Neuroscience*, *25*(3), 401–420. https://doi.org/10.1162/jocn_a_00325

Leow, L.-A., & Grahn, J. A. (2014). Neural Mechanisms of Rhythm Perception:

Present Findings and Future Directions. In H. Merchant & V. de Lafuente (Eds.), *Neurobiology of interval timing* (pp. 325–338). New York: Springer New York. https://doi.org/10.1007/978-1-4939-1782-2_17

Marsden, C. D., & Obeso, J. A. (1994). The functions of the basal ganglia and the paradox of stereotactic surgery in Parkinson's disease. *Brain*, *117*, 877–897.

Moreno, A., Limousin, F., Dehaene, S., & Pallier, C. (2018). Brain correlates of constituent structure in sign language comprehension. *NeuroImage*, *167*, 151–161. https://doi.org/10.1016/j.neuroimage.2017.11.040

Moro, A., Tettamanti, M., Perani, D., Donati, C., Cappa, S. F., & Fazio, F. (2001). Syntax and the Brain: Disentangling Grammar by Selective Anomalies. *NeuroImage*, *13*(1), 110–118. https://doi.org/10.1006/nimg.2000.0668

Raghanti, M. A., Edler, M. K., Stephenson, A. R., Wilson, L. J., Hopkins, W. D., Ely, J. J., … Sherwood, C. C. (2016). Human-specific increase of dopaminergic innervation in a striatal region associated with speech and language: A comparative analysis of the primate basal ganglia. *Journal of Comparative Neurology*, *524*(10), 2117–2129. https://doi.org/10.1002/cne.23937

Scharff, C., & Petri, J. (2011). Evo-devo, deep homology and FoxP2: implications for the evolution of speech and language. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*(1574), 2124–2140. https://doi.org/10.1098/rstb.2011.0001

Schiffer, A.-M., & Schubotz, R. I. (2011). Caudate nucleus signals for breaches of expectation in a movement observation paradigm. *Frontiers in Human Neuroscience*, *5*, 38. https://doi.org/10.3389/fnhum.2011.00038

Schreiweis, C., Bornschein, U., Burguière, E., Kerimoglu, C., Schreiter, S., Dannemann, M., … Graybiel, A. M. (2014). Humanized Foxp2 accelerates learning by enhancing transitions from declarative to procedural performance. *Proceedings of the National Academy of Sciences*, *111*(39), 14253–14258. https://doi.org/10.1073/pnas.1414542111

Stowe, L. A., Paans, A. M. ., Wijers, A. A., & Zwarts, F. (2004). Activations of "motor" and other non-language structures during sentence comprehension. *Brain and Language*, *89*(2), 290–299. https://doi.org/10.1016/S0093-934X(03)00359-6