An Oscillator Model for Interbrain Synchrony: Slow Interactional Rhythms Entrain Fast Neural Activity

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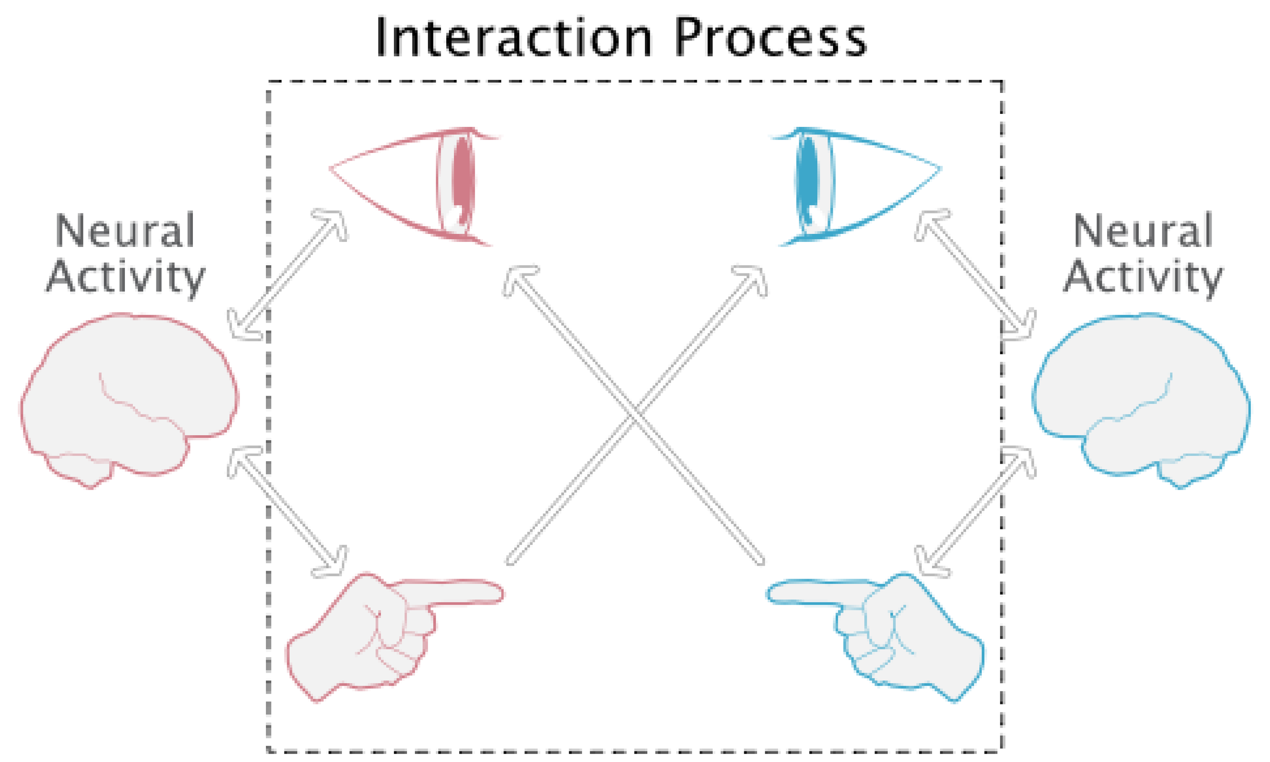
Background

Synchronization is a pervasive phenomenon in nature. With advances in neuroimaging technologies, the hyperscanning approach has allowed the simultaneous imaging of neural activities from the brains of two individuals situated in social interaction scenarios. The discovery that interbrain synchronization can occur during social interaction has led to surging interests to elucidate the mechanisms and functions for interbrain synchrony. However, it is not known how interbrain synchronization can occur since neural activities usually operates at timescales order-of-magnitudes faster than the interaction itself, and that the external communication channel could impose a dimensional bottleneck for the transmission of information across two brains [1]. The necessity for a model for interbrain synchronization was recently highlighted [2]. Using minimal oscillator models, we attempt to answer the following questions: 1) does a low-frequency channel impede synchronization between two systems operating at higher frequencies, and if so 2) what are the possible configurations by which this occur?

Embodied Model of Social Interaction

As an organism is interacting while being embodied and situated, an embodied model for social interaction would include the sensorimotor components bidirectionally coupled with the brain.



Remarks

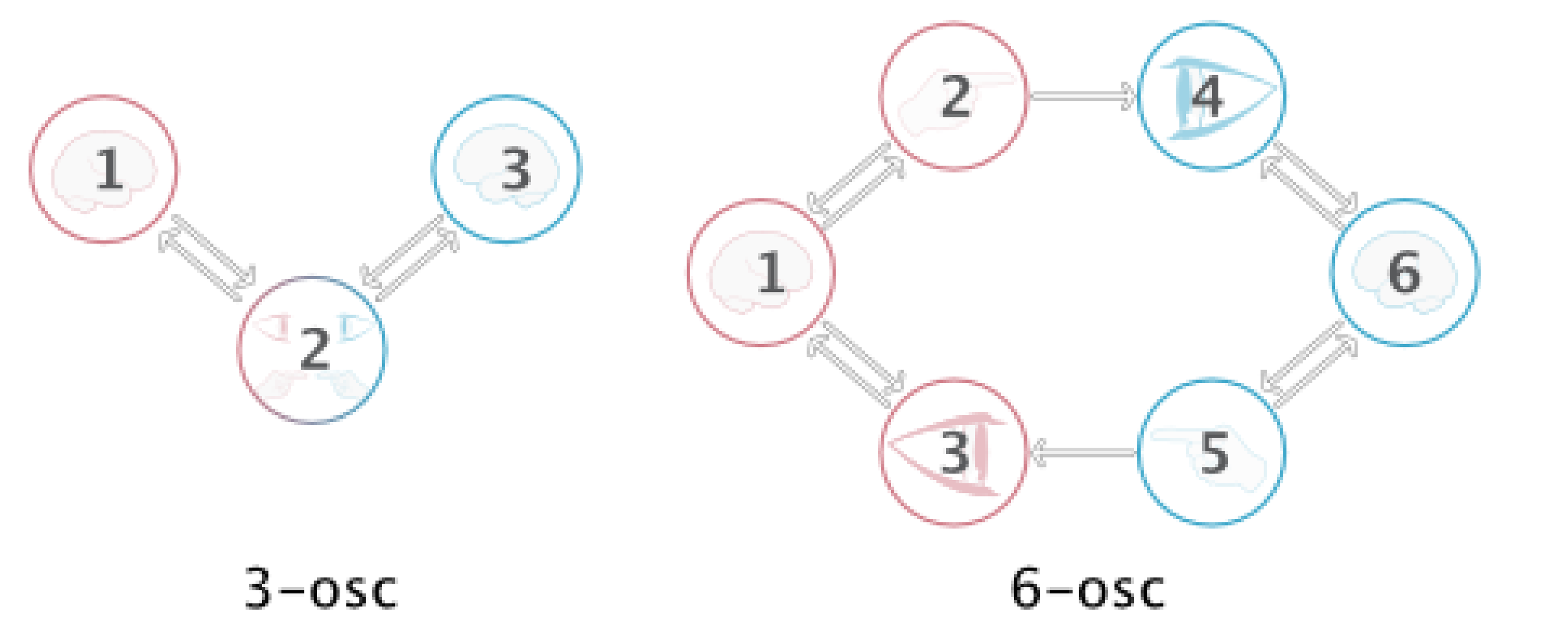
- 40 agents are evolved for 80 (3-osc)/ 180 (6-osc) generations with 2000 seeds.

Table: Parameter bounds for evolution

Parameter	Bounds
$\omega_{1,3}$	[8.0, 70.0]
ω_2	[0.5, 7.5]
K	[0, 20]

Kuramoto Oscillator Models

Kuramoto oscillators are bidirectionally coupled in the 3-osc and 6-osc models.



Each of the oscillators is described with the following equation:

$$\frac{\mathrm{d}\theta_i(t)}{\mathrm{d}t} = \omega_i(t) + \sum_{j=1}^{N} K_{ij} \sin(\theta_j(t) - \theta_i(t))$$

Evolutionary Algorithm

Each instance of the model is treated as an agent. The roulette wheel algorithm is utilized to maximize the synchronization index, R, between the brain oscillators:

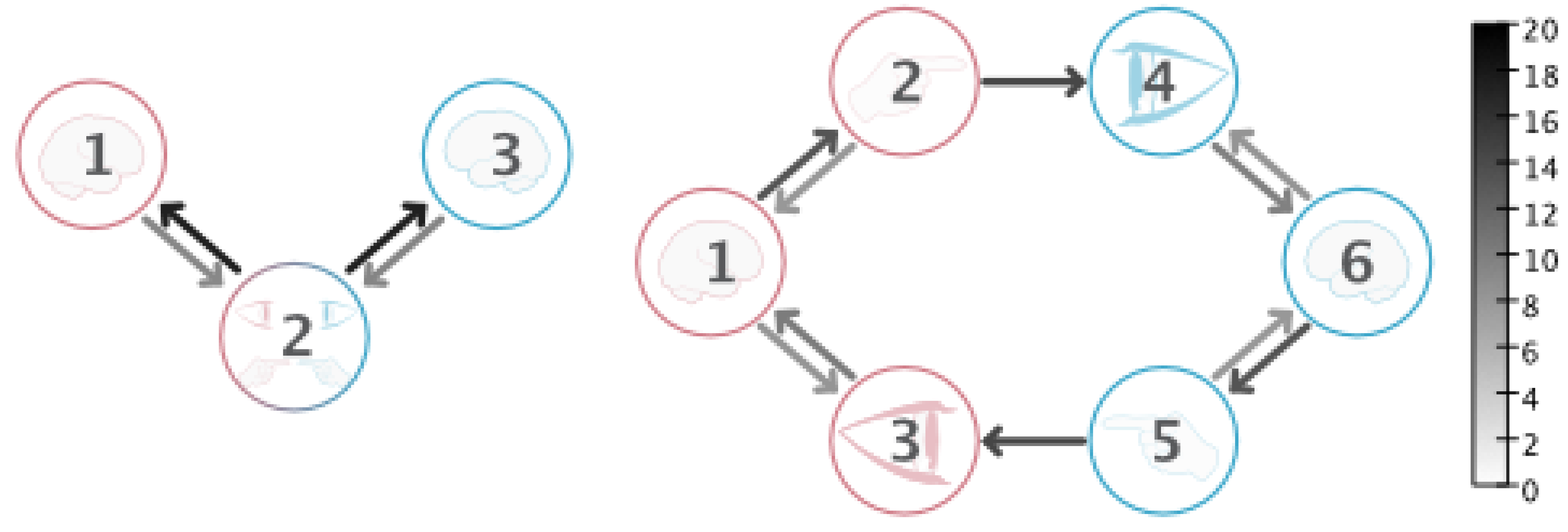
$$R = \left| \frac{1}{N} \sum_{j=1}^{N} e^{i(\theta_1(t) - \theta_3(t))} \right| \quad (1)$$

with fitness f

$$f = \frac{1}{|1 - R|} \quad (2)$$

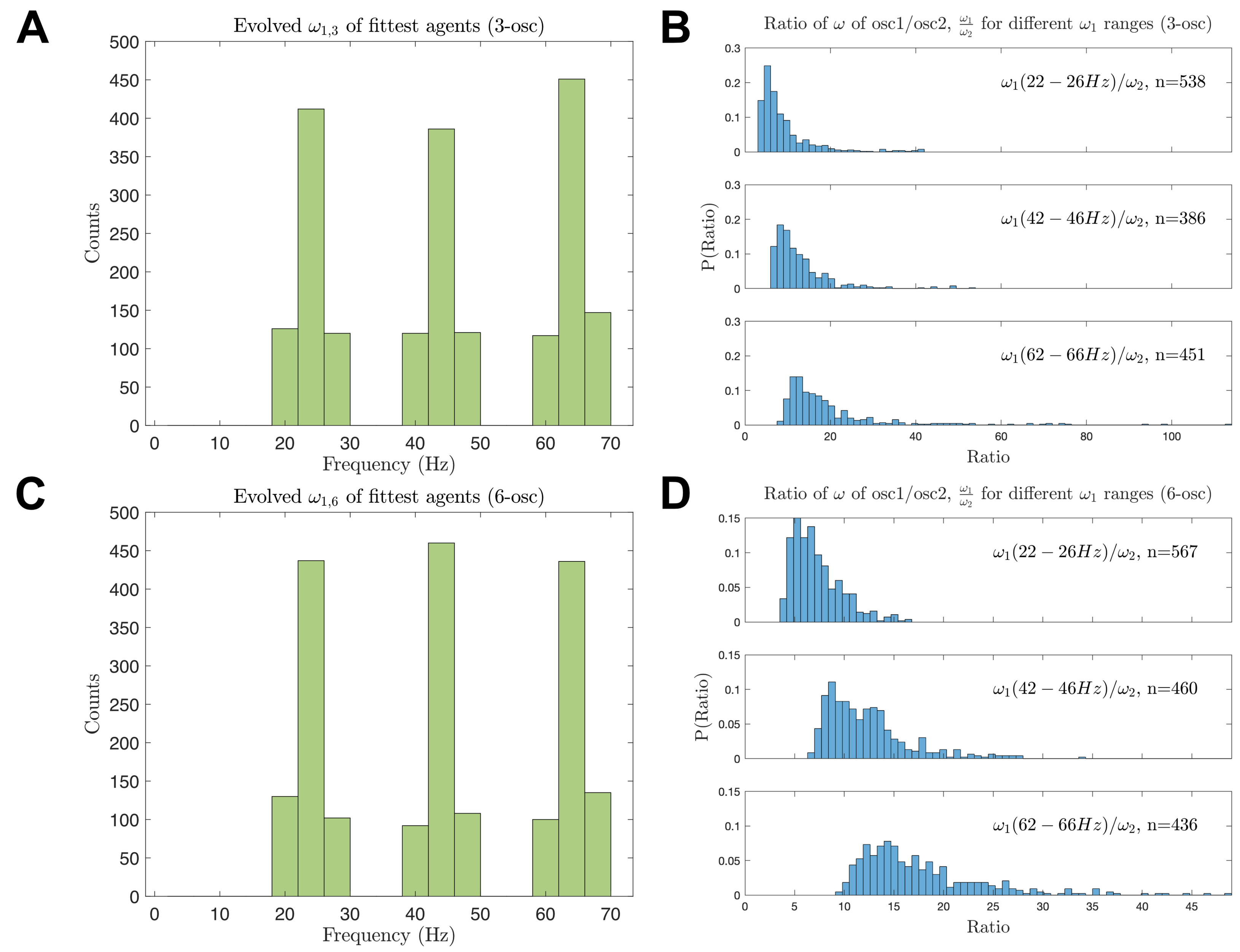
Results - Preferred coupling strengths

Evolved coupling strengths show stronger coupling from the sensorimotor oscillators.



Results - Preferred frequency ranges

Evolved frequencies show several preferred ranges of frequency and ratios between the brain and sensorimotor oscillators.



Conclusions

Using a minimal oscillator model, we have shown that interbrain synchronization is possible when mediated by a slower interaction channel. We have also shown that this occurs at certain frequency ranges and coupling strength configurations.

Future directions

The model can be extended to include more oscillators and by using more realistic models such as a neural mass model.

References

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[3] Yoshiki Kuramoto. Cooperative dynamics of oscillator communitya study based on lattice of rings. *Progress of Theoretical Physics Supplement*, 79:223–240, 1984.

[4] Ole Adrian Heggli, Joana Cabral, Ivana Konvalinka, Peter Vuust, and Morten L Kringelbach. A kuramoto model of self-other integration across interpersonal synchronization strategies. *PLoS computational biology*, 15(10):e1007422, 2019.

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