Social Minds Sync Alike

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In this issue of *Cell*, Zhang and Yartsev, 2019 and Kingsbury et al. (2019) provide insight into the emergence of synchronized neuronal activity between prefrontal cortices of two brains that share the same social context via electrophysiology recordings in bats and calcium-imaging in mice.

The ability of social animals to synchronize their behavior with others is crucial for their survival and reproduction. Social behaviors, ranging from coordinated courtship displays to more complex behaviors such as cooperation in groups, all involve behavioral synchronization (Nessler and Gilliland, 2009). What are the neuronal mechanisms that generate synchronous behavior? Does synchronous brain activity encode specific social interactions? And is there a dedicated neuronal network for interbrain synchronization during social interactions?

Two groups using different animal models and approaches recently studied these fundamental questions independently. Zhang and Yartsev (2019), applying a more ethologically relevant approach, studied synchrony between brains of freely behaving bats, engaging in social interactions in a dark chamber (40.6 × 33.7 × 52.1 cm), and over long periods of up to 100 min. Kingsbury et al. (2019), used a more standard lab approach by testing pairs of mice for interbrain synchrony in an open arena (32 × 20 cm) over short epochs (10–15 min). Mice were also tested in the widely used ''tube test,'' in which a pair of mice is released simultaneously from the opposite ends of a narrow tube and allowed to interact until one of them (the winner, declared ''dominant'') forces the other (loser / ''subordinate'') backward (Fan et al., 2019; Lindzey et al., 1966).

The two teams also used different methods to record brain activity in two animals, simultaneously. Zhang and Yartsev, 2019 used extracellular electrophysiology recordings (local-field-potentials, multi-unit and single-unit activity), whereras Kingsbury et al. (2019) used microendoscope calcium imaging to monitor the neuronal activity of hundreds of single cells simultaneously. Both teams recorded from the prefrontal cortex—a brain region which was implicated in a wide range of social behaviors in animals and humans (Bicks et al., 2015; Porcelli et al., 2019)—but from what seems to be a slightly different anatomical sub-region. It is not clear whether these two regions, in bats and mice, are functional homologs, or two different functional regions. Future molecular and neuroanatomical comparative studies are needed to sort this out.

Despite the methodological differences, both groups found high synchrony between brain activities that could not be fully accounted for by behavioral synchrony alone, or by shared physical stimuli (Figure 1A). Synchronous neural activity across brains could be detected even after excluding from the analysis periods when both animals presented coordinated behavior (e.g., coordinated rest-active periods), or periods when both animals experienced the same physical stimuli (visual stimuli or social vocalizations). Both groups also showed that interbrain synchrony increased with the extent of social interaction. Altogether, their findings suggest that additional factors other than synchronized behavior or common external stimuli contribute to the observed synchrony between brains in social context. Another interesting finding comes from the Zhang study, which recorded from a pair of bats sharing a compartment with a third bat (they did not record neuronal activity from the third bat). They found that high synchrony between brains of the recorded bats persisted even when one of them was only observing the two other bats interacting and was not directly involved in the social interaction (Figure 1B). This finding shows that the mere presence of two bats in a common social context was enough to synchronize their brains.

Kingsbury et al. (2019) found that the degree of interbrain correlation, at the onset of each session in the tube test, could predict the strength of dominance (Figure 1C and 1D), suggesting that brains of individuals further apart in social hierarchy are more synchronized. Moreover, they identified sub-populations of neurons in the mice's brains, each tuned to a different self-behavior in the tube test (push, approach, and retreat). Nevertheless, results from the tube test should be interpreted with caution given that the test severely restricts the behaviors of the interacting animals, and it is unclear to what extent results from this test correlate with results from other, more ethologically relevant measurements for dominance status (Fan et al., 2019; Lindzey et al., 1966).

This finding might explain synchrony between two brains engaged in synchronized behavior—but what kind of a neuronal mechanism can introduce synchrony in the same social context without any social interaction (as found in bats by Zhang and Yartsev, 2019)? Previous studies, both in animal models (Tseng et al., 2018) and in human subjects (Hasson et al., 2012), already reported on synchronized brain activity between socially interacting individuals. However, so far it was not clear what possible neuronal mechanisms can drive interbrain synchrony. A tempting possible explanation is the existence of neurons which are tuned to the behavior of others (Rizzolatti and Craighero, 2004). If such neurons

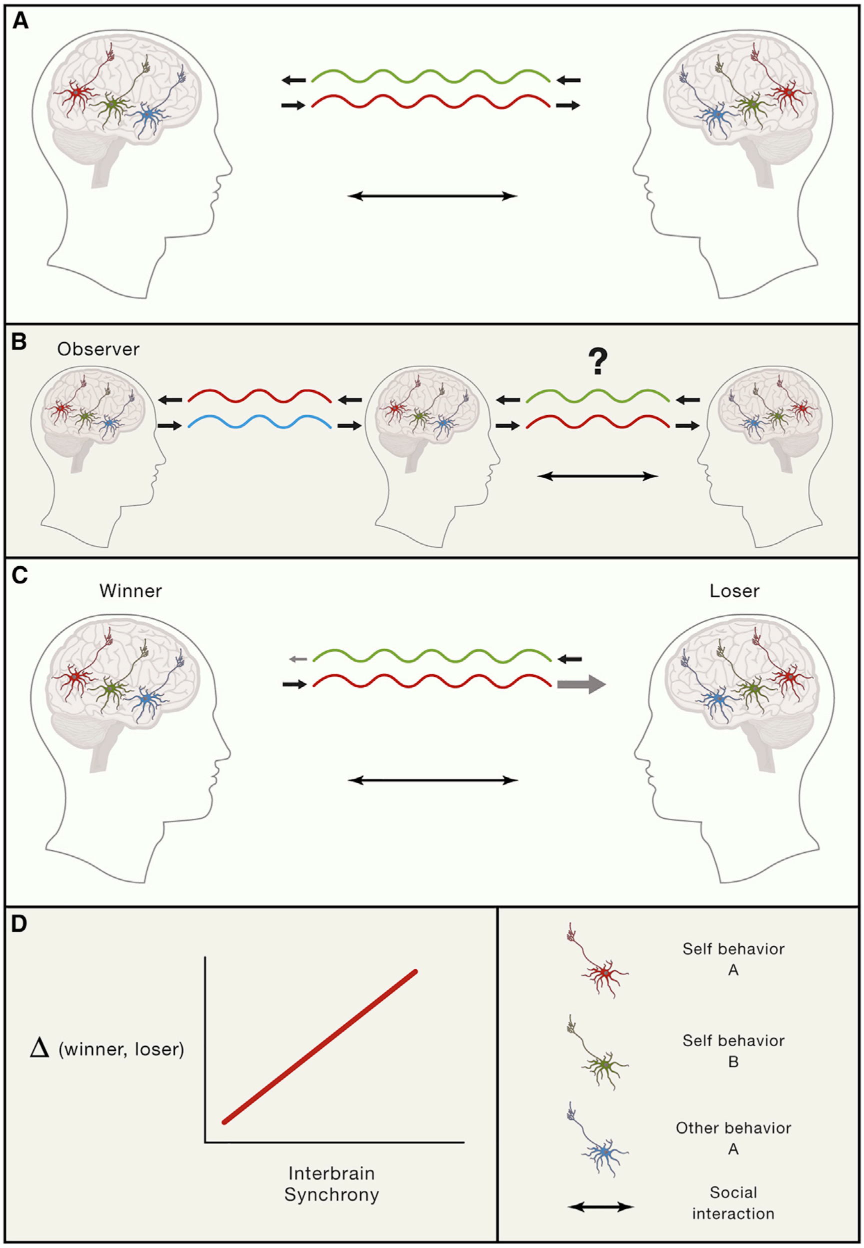

Figure 1. Interbrain Synchrony in Social Contexts

(A) Brains synchronize their activity during social interaction. Interbrain synchronization reflect co-activation of neurons that represent self-behaviors in each brain (red and green neurons). Different subpopulations of neurons are depicted in different colors: red, neurons representing self-behavior A; green, neurons representing self-behavior B; blue, neurons representing behavior A of the other.

(B) Interbrain synchronization in a social group of individuals. Sharing the same social context is enough to drive synchrony between brains of two non-socially interacting individuals. Interbrain synchrony reflects co-activation of neurons in the observer and neurons in the socially interacting (observed) individual (brain activity in the third individual was not recorded).

(C and D) Synchronization between brains with different social status is asymmetrical. An individual with a higher social status (a winner, as measured in the tube test) exerts a larger effect on an individual with a lower status, as indicated by the grey arrows.

exist, then sharing a social context would be enough to synchronize two brains. Indeed, Kingsbury et al. (2019) found a small fraction of neurons (8%) that selectively responded to a specific behavior of the opponent mouse and significantly contributed to synchrony. Despite these intriguing findings, the exact neuronal mechanism, which drives interbrain synchrony, is yet unclear.

Does synchrony play a causal role in social decision-making? In both studies, an increase in synchrony preceded the initiation of a social interaction, suggesting that synchrony between brains might have a causal role in social decision making.

One particularly important weakness in both studies is the clear sex bias; that is, both groups tested only male-male interactions. This is particularly disturbing given the crucial importance of synchronous behavior in male-female interactions during mating and given the widely reported sex differences in social behaviors and functions of the prefrontal cortex. This bias awaits correction in future studies.

Nevertheless, these exciting findings raise several important questions for future studies. For example, is synchrony between brains necessary for natural social behaviors? To be able to answer this question, we need more experiments that use tools such as microstimulation, optogenetics, or genetic manipulations, to interrogate the neuronal mechanisms and circuitry of social synchrony in ethological conditions.

Another interesting question regards the role of brain synchrony in neuropathologies of social behavior, with autism spectrum disorders being one of the archetypes of such pathologies. Can the brain of an autistic patient synchronize with another brain? Are the neuronal mechanisms that sub-serve behavior synchrony involved in the autistic pathology?

Finally, in recent years we are witnessing a dramatic change in the way we humans socially interact. The internet and its social media define new types of social contexts. Are we using the neuronal mechanism that support social synchronized behavior differently in such social contexts? And from an evolutionary perspective, will these new social contexts change the neuronal mechanisms sub-serving social behavior?

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