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Letter

Proving Causality in Hyperscanning: Multibrain Stimulation and Other Approaches: Response to Moreau and Dumas

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Hyperscanning consists of measuring neural activity from two or more individuals simultaneously. Using this approach, it has been repeatedly shown that when multiple brains are engaged in a social interaction, their neural activities couple through interbrain synchrony (IBS) [1].

In a recent issue of *Trends in Cognitive Sciences*, we elaborated on the causal relation between IBS and social behavior [2]. We reasoned that IBS could be interpreted either as a mechanism that causally facilitates social interaction (mechanistic perspective), or as a mere consequence of two brains processing similar information during a social interaction (epiphenomenal perspective). In the second scenario, IBS would not be key for investigating the neural mechanisms that govern social interaction.

To resolve this dichotomy, we proposed to reverse the dominant hyperscanning approach. We argued that IBS should not simply be measured with hyperscanning. Instead, IBS should be directly manipulated by stimulating multiple brains simultaneously to examine the direct consequences of IBS on social interaction (see Figure 1 in [2]). This multibrain stimulation (MBS) allows scientists to make causal inferences about the relationship between IBS and social interaction (see, e.g., [3,4]).

Moreau and Dumas agree with us that MBS is a promising method to establish causality in the IBS field [5]. Yet, they claim that, besides MBS, at least three additional methods should be considered. While we agree that these are all promising research avenues, likely to shed new light upon the nature of IBS, we contend that not all of them can provide direct evidence of IBS causally facilitating social interaction. We will now briefly discuss each of the proposed approaches.

The first approach proposed to tackle the issue of causality is multibrain neurofeedback (also called crossbrain neurofeedback [6]). This involves feeding back real-time indices of brain activity to interacting individuals, so that these individuals might intentionally modulate their IBS. According to Moreau and Dumas, this approach would be similar to MBS in making IBS an independent variable and social interaction a dependent variable. We cannot agree with this claim. Indeed, the existing implementations of multibrain neurofeedback fail (*a priori*) to distinguish IBS that emerges epiphenomenally as a consequence of two brains processing similar information during a social interaction (see, e.g., [6,7]). This implies that the IBS measured during multibrain neurofeedback is not a genuine independent variable because it might also depend on the measured dependent variable (i.e., the motor or sensory events intrinsic of a social interaction). Thus, multibrain neurofeedback does not allow the experimenters to truly manipulate IBS, but rather it can favor the emergence of IBS in specific conditions.

As a second approach tackling the issue of causality, Moreau and Dumas refer to the human dynamic clamp, an experimental paradigm involving motor coordination between a human and a responsive virtual partner (VP) [8]. Using this elegant paradigm, one can control *ad hoc* parameters of social coordination dynamics, such as the VP's adaptivity. Unlike multibrain neurofeedback, this is a neat and independent manipulation. However, it is not a manipulation of IBS, but rather a manipulation of behavioral coupling between a human and a VP. Indeed, IBS cannot be manipulated through the human dynamic clamp paradigm simply because the VP has no brain activity to be recorded and therefore there cannot be any IBS (and, even if there was, its manipulation would be indirect because it would be entirely mediated by behavior). Alternatively, it could be that Moreau and Dumas are not referring to the causal relationship between IBS and social interaction (the topic of our original piece [2]), but rather to the causal relationship between environmental events and neural oscillatory activity (that may or may not lead to IBS). If the latter, then this issue, albeit important, does not address our original question, (i.e., whether IBS itself directly affects social interaction). Therefore, the human dynamic clamp paradigm does not provide the kind of causal evidence that can resolve the dichotomy between the epiphenomenal and mechanistic perspectives on IBS.

The third proposed approach is mathematical modeling, which is, in our opinion, the most promising among the suggested alternatives to MBS. Indeed, we did acknowledge this possibility in our article (see Box 1 in [2]), although we admit to have been far from elaborating exhaustively on this approach. We therefore thank Moreau and Dumas for their constructive remark. In particular, they highlight evidence indicating that anatomical or functional similarities between two brains might facilitate social interaction, for instance, interpersonal coordination [9]. Thus, one might exploit these similarities to modulate IBS as an independent variable, under the (reasonable) assumption that IBS would be higher in dyads with similar brains. While we agree

that this could and should be considered a causal approach, we advocate that one would also need to control for other covarying factors that, besides anatomical or functional similarities, might impact upon IBS. For instance, consider a dyad formed by two monozygotic twins. As these individuals display remarkable brain anatomical similarities [10], one might assume that they should also display strong IBS and presumably high interpersonal coordination accuracy [9]. However, this would not imply that IBS causes coordination *per se*. Other covarying similarities, such as the fact that monozygotic twins have very similar bodies, could explain the high coordination accuracy. Indeed, the strength of behavioral coupling between two individuals can also depend on similar biomechanical properties (e.g., leg length during side-by-side walking) [11].

In summary, we believe that all of the approaches mentioned by Moreau and Dumas have the potential to yield important discoveries in social neuroscience. Yet, while specifically addressing the issue of causality, and precisely whether IBS might causally facilitate social interaction, we do not believe all approaches can provide direct causal evidence. Or, at least, not as well as MBS does. Most importantly, we all agree on a fundamental point: that social neuroscience needs mechanistic explanations and that we are still far from understanding the significance of IBS for social behavior [12]. We wishfully expect all of the proposed approaches, used in isolation or (better) in combination, to significantly advance this field of research further.

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