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Original article

From social behaviour to brain synchronization: Review and perspectives in hyperscanning

De la synchronisation comportementale à la synchronisation cérébrale : état de l'art et perspectives en hyperscanning

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Abstract

Recently, the neuroscience field took a particular interest in the use of a neuroimaging technique called 'hyperscanning'. This new technique consists in the simultaneous recording of the hemodynamic or neuroelectric activities of multiple subjects. Behind this small technical step lays a giant methodological leap. Groundbreaking insight in the understanding of social cognition shall be achieved if the right paradigms are implemented. A growing number of studies demonstrate the potential of this recent technique. In this paper, we will focus on current issues and future perspectives of brain studies using hyperscanning. We will also add to this review two studies initiated by Line Garnero. These studies will illustrate the promising possibilities offered by hyperscanning through two different key phenomena pertaining to social interaction: gesture imitation and joint attention.
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Keywords: Hyperscanning; Synchronization; Spontaneous imitation; Joint attention; Gaze; EEG

Résumé

Récemment, un intérêt particulier a été porté à l'utilisation d'une technique de neuro-imagerie appelée *hyperscanning*. Cette nouvelle technique consiste en l'enregistrement simultané de l'activité hémodynamique ou neuroélectrique de plusieurs sujets. Derrière ce petit pas technique se cache un grand pas méthodologique. Il peut nous conduire à une meilleure compréhension de la cognition sociale si toutefois les bons paradigmes expérimentaux sont développés. Le nombre croissant d'études utilisant l'*hyperscanning* démontre le potentiel de cette technique. Dans cet article, nous traiterons à la fois de son récent historique mais surtout des futurs potentiels qu'elle ouvre. Nous illustrerons cela par deux réalisations en *hyperscanning* dont Line Garnero a été l'instigatrice. Ces réalisations serviront d'exemple pour montrer les possibilités prometteuses par l'*hyperscanning* au travers de deux phénomènes clés dans les interactions sociales : l'imitation gestuelle et les comportements de regard en attention conjointe.
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Mots clés : Hyperscanning ; Synchronisation ; Imitation spontanée ; Attention conjointe ; Regard ; EEG

1. From behaviour synchronization...

"The most important things in human life come down to relationships with other people," says Michael Huerta (associate director of Neuroscience and Basic behavioural science at the National Institute of Mental Health). Our actions, feelings,

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and thoughts take place in a social world where communicating with others is an everyday challenge. Wilson and Wilson [1] theorised on a particular type of interindividual interaction: conversation. According to the authors, during conversation, several oscillators in the brain of the listener are led by some oscillators of the speaker's brain. In this oscillatory interplay, the two brains become synchronized. Even though the authors based their model on conversation properties, the idea of inter-brain synchronization can be generalized to any social situation, which generates coordination between partners. This paper especially takes interest in two phenomena that entail behaviour synchronization: gesture imitation and gaze following.

Gesture imitation has been pointed out as a keystone of human social interaction because of the ability it gives us to know others as persons like ourselves [2,3]. Pragmatically, the matching of our own behaviour with that of others allows us to detect contingencies in our social world. This enables us to synchronize with others, copy them, and learn in which context particular behaviours have to be used [4,5]. Growing evidence at the developmental [6], psychological, and neuroscientific levels indicates that perception and action are in fact intertwined processes. The recent discovery of mirror neurons provides a direct demonstration of this overlap between perception and action networks. Furthermore this discovery also puts in light the major role of this overlap in motor imitation. However, imitation is only related to morphological similarities of gestures. Thus it is not the only component of motor social interaction. Behavioural synchrony complements imitation during interindividual interaction by providing a temporal coherence between the interacting partners. Developmental studies have demonstrated a very early ability to detect interactive synchrony in humans: the introduction of a delay in the loop of interaction between a baby and his/her mother leads to a breakdown of the ongoing communication [7,8].

These results suggest an intrinsic human capacity for perceiving and producing events in synchrony with other individuals. Immediate imitation is an almost perfect example of interactive synchrony [6]. It was suggested that the dynamics of neuronal coupling plays a role in the emergence of such synchrony, providing a neural substrate for interpersonal exchanges and synchronizations among individuals at the behavioural level [1]. The modelling approach further suggests that the phenomenon of turn-taking may emerge from the synchrony itself [9,10].

Thus, spontaneous gestural imitation is an ideal case for the study of behavioural synchrony and its neuronal correlates. It possesses all the features of social interaction and leads to phases of behavioural synchronies. Furthermore, it is mainly a motor interaction. In comparison with a verbal interaction, the hypothesized underlying interindividual neural synchronization should be easier to detect.

Other types of interindividual interactions may generate such neural synchronizations. For instance, gaze following is a key example of behavioural synchronization in everyday life. Interestingly, it is easier for humans than other species to follow the eye direction of their conspecifics. Indeed, the human eyes have evolved to allow perceiving clearly the contrast between the (white) sclera and the (darker) iris. This facilitates the detection of someone's eyes and more importantly it makes it easier and faster to identify the direction of the gaze of seen fellows [11,12]. Gaze direction subtends referential communication and synchronisation during interindividual exchanges. For example, during conversation, gaze contributes to speech understanding as well as to the organization of turn-taking with eye contact enabling the converses to be coordinated and synchronized [13].

Furthermore, eye direction perception is a core process of joint attention, which is a fulcrum of social cognition. Joint attention results from the alignment of an observer's attention with that of a seen fellow, enabling both persons to attend to the same external object [14–16]. This behavioural synchronization is crucial to social interaction as it subtends the understanding of others' attentional focus and intention. Joint attention is proposed to be one of the precursors of Theory Of Mind (TOM) [17]. TOM is the skill to attribute mental states to others and to understand that their believes, emotions, intentions, desires might differ from our owns. This ability is essential for understanding others and for adaptive communication and interaction with others. We believe that engaging in joint attention processes prompt coordinated actions between the participants, which might lead to interindividual neural synchronizations.

In sum, both gestural imitation and joint attention involve another partner with whom a non-verbal, interpersonal communication is established. They provide good ecological paradigms for the study of human social interaction. Combined with the use of a new neuroimaging technique called hyperscanning, they also open the way for the investigation of interindividual neural synchronizations that might accompany behavioural synchronies. This brain-to-brain synchronization emerges from the sensorimotor couplings created through the social interactions.

2. . . .to brain synchronization

Almost nothing is known about the brain activities of two individuals while those individuals are engaged in a social interaction. Recently, a new technique made possible for researchers to record at the same time two persons engaging in an interpersonal exchange. This technique is called hyperscanning and has been applied with fMRI and EEG. Hyperscanning is a very powerful method as it makes possible to perform within- as well as between-brain analyses.

The hyperscanning story starts with an uncanny use of the technique. Indeed, this technique was first applied to parapsychology issues [18,19]. The main purpose of these studies was to investigate telepathy, namely the brain information transmission between isolated participants. The conclusions were highly suspicious. In a small number of cases, the brain activity of one person was reported to correlate with that of a partner localised in another room without any communication device linking the two participants. Many commentaries questioned these idiosyncratic results. They pointed out that the positive results obtained were most likely attributable to some dynamical similarity between the two brains engaged in the same perceptual context rather than to an effective transmission of information.

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