Neuroscience and Biobehavioral Reviews 44 (2014) 76–93

Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

journal homepage: www.elsevier.com/locate/neubiorev

Review

Social neuroscience and hyperscanning techniques: Past, present and future

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ARTICLE INFO

Article history:
Received 20 January 2012
Received in revised form 20 April 2012
Accepted 26 July 2012
Available online 13 August 2012

Keywords:
Hyperscanning
Social neuroscience
EEG
fMRI
NIRS

ABSTRACT

This paper reviews the published literature on the hyperscanning methodologies using hemodynamic or neuro-electric modalities. In particular, we describe how different brain recording devices have been employed in different experimental paradigms to gain information about the subtle nature of human interactions. This review also included papers based on single-subject recordings in which a correlation was found between the activities of different (non-simultaneously recorded) participants in the experiment. The descriptions begin with the methodological issues related to the simultaneous measurements and the descriptions of the results generated by such approaches will follow. Finally, a discussion of the possible future uses of such new approaches to explore human social interactions will be presented.

Contents

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0149-7634/$ – see front matter
http://dx.doi.org/10.1016/j.neubiorev.2012.07.006

1. Introduction

More than 2300 years ago Aristotle wrote in his work "The Politics" that the human being is a "political animal" (ζῷον πολιτικόν); and that, in particular, humans are "more of a political animal than bees or any other gregarious animals". In fact, "it is a characteristic of man, that he alone has any sense of good and evil, of just and unjust, and the like, and the association of living beings who have this sense makes a family and a state" (Aristotle, 1998). Therefore, the idea that an important trait of being "humans" consists of our relationship with others is deeply rooted in ancient culture. This concept is not limited to classical culture, as shown by the African word *Ubuntu*, which means that "a person becomes a person only through other people" (Hari and Kujala, 2009).

Although the social nature of humans has been evidenced for thousands of years, the field of neuroscience has only started to investigate brain activity during social interactions in the last decades. Social cognition includes all of the cognitive processes necessary to properly understand and store personal information as well as information from other people, including the rules at the basis of interactions with other humans. In recent years, neuroscientists have started to investigate the cerebral structures supporting the processes involved in the social cognition abilities of humans, starting with experimental evidence drawn from brain lesion studies (Wood et al., 2005) and autism (Frith and Frith, 2001; Baron-Cohen, 2006; Williams, 2008). Hundreds of studies performed using normal subjects have elucidated the role of particular brain regions in social cognition tasks. Such studies are reviewed in papers using meta-analysis related to different aspects of social cognition (Hari and Kujala, 2009; Van Overwalle, 2009; Van Overwalle and Baetens, 2009; Van Overwalle, 2011).

From these studies it appears that specific cerebral regions are involved in tasks that require the processing of information relevant for social cognition. In particular, the temporo-parietal junction (TPJ) was described as being consistently activated during tasks involving the short-time estimate of intentions, desires and goals related to other people. Interestingly, the TPJ activation persists also when there is a negative judgment about such goals and intentions (Van Overwalle, 2009). The activity of the TPJ is connected to the consistent activity of the medial prefrontal cortex (mPFC) when the tasks performed need the encoding of more stable and durable information regarding the behavior of people under multiple circumstances, and recognize a common goal in this behavior. In one particular model, proposed after a review of more than 200 fMRI studies, it was hypothesized that the TPJ could be mainly responsible for transient mental inferences about other people, such as their goals or beliefs, while the mPFC supports the processes that enrich such observations with more durable traits and qualities about both others and the self (Van Overwalle, 2009). Thus, it has been suggested that the union of the TPJ and mPFC structures could constitute the "mentalizing" system in humans, which enables the extraction and understanding of the goals of other people by using the capability to properly decode their intentions (Amodio and Frith, 2006; Van Overwalle, 2009). Although the role of the mPFC has been consistently observed in tasks that involve cognitive reasoning, including relational processing of objects (Legrand and Ruby, 2009), a meta-analysis of the literature has shown that it is more likely that cognitive reasoning activates the mPFC because inferences about social agency and the mind are involved in the tasks proposed (Van Overwalle, 2011).

Another cerebral system that has been identified in the last decade and hypothesized to be able to decode actions performed by body parts of other people, such as arms, hands, fingers and limbs, irrespective of the sensory or verbal format of the input, is the so-called mirror neuron system (MNS) (Iacoboni et al., 1999; Rizzolatti et al., 2001; Gallese et al., 2004). The MNS, consisting of cerebral structures located in the anterior intraparietal sulcus and in the premotor cortex, allows other people's goals to be rapidly sensed on the basis of low-level behavioral inputs, although this understanding may be limited to familiar executed actions (Cross et al., 2006; Van Overwalle and Baetens, 2009). Since we often make an estimation of the beliefs and attitude of the others on the basis of their overt actions, it could be hypothesized that the MNS and the mentalizing system work together in the decoding of the other people's mental states (Amodio & Frith, 2006; Frith & Frith, 2006). However, such a statement was not supported by a recent meta-analysis of the literature, which suggested that the MNS and the mentalizing system can be complementary, but that none of the systems are subservient to the other (Van Overwalle and Baetens, 2009). On the other hand, evidence of the cooperation of the two systems has been recently reported (Schippers et al., 2010). A possible synthesis of these debates could lie in the recent suggestion, provided by a meta-analysis of fMRI literature, which suggests that the MNS could extend beyond the cerebral regions typically attributed to it (Molenberghs et al., 2012). This could be consistent with the idea that the vicarious brain activity made possible by mirror neurons extends beyond actions to include the sharing of emotions and the sensations of others as well (Keysers and Gazzola, 2009).

All of these considerations of the existence of different neural systems supporting the recognition in our brains of relevant movements or the behavioral attributes of others mainly arose from experimental paradigms in which one subject was monitored during their interaction with an external partner (either human or computer). However, it is well known that humans behave differently if they are aware that they are interacting with computers instead of with other people (Rilling et al., 2008; Rilling and Sanfey, 2011). Moreover, the reaction to another person's behavior is possibly linked to a kind of relationship arising between the subject and the specific person that they are interacting with, which is not simply described by behavioral data. This requires a direct observation of the "interaction" emerging between the brains of different subjects, which is a possibility that can be only be obtained by measuring the brain activity of the participants simultaneously during the proposed tasks. In addition, the laboratory and technical limitations of brain scanning devices often offer poorly ecological settings for the execution of the experiments, which seriously affects the kind of social behavior that can be analyzed. To reach a deeper comprehension of the mechanisms involved in social interactions during "normal" life situations with our peers it is necessary to generate experimental paradigms that are as "natural" as possible. As noted in a recent review by Hari and Kujala (2009) "much of the fleeting, moment-to-moment information of social interaction remains beyond the reach of studies involving limited stimuli and tasks. The current challenge for brain imaging is to bring every day