Brain and Cognition 123 (2018) 65–73

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Functional brain connectivity when cooperation fails

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ARTICLE INFO

Keywords:
Hyperscanning
Brain-to-brain coupling
Functional connectivity
Cooperation
Joint action

ABSTRACT

Functional connectivity during cooperative actions is an important topic in social neuroscience that has yet to be answered. Here, we examined the effects of administration of (fictitious) negative social feedback in relation to cooperative capabilities. Cognitive performance and neural activation underlying the execution of joint actions was recorded with functional near-infrared spectroscopy (fNIRS) on prefrontal regions during a task where pairs of participants received negative feedback after their joint action. Performance (error rates (ERs) and response times (RTs)) and intra- and inter-brain connectivity indices were computed, along with the ConIndex (inter-brain/intra-brain connectivity). Finally, correlational measures were considered to assess the relation between these different measures. Results showed that the negative feedback was able to modulate participants' responses for both behavioral and neural components. Cognitive performance was decreased after the feedback. Moreover, decreased inter-brain connectivity and increased intra-brain connectivity was induced by the feedback, whereas the cooperative task pre-feedback condition was able to increase the brain-to-brain coupling, mainly localized within the dorsolateral prefrontal cortex (DLPFC). Finally, the presence of significant correlations between RTs and inter-brain connectivity revealed that ineffective joint action produces the worst cognitive performance and a more 'individual strategy' for brain activity, limiting the inter-brain connectivity. The present study provides a significant contribution to the identification of patterns of intra- and inter-brain functional connectivity when negative social reinforcement is provided in relation to cooperative actions.

1. Introduction

The 'social brain' has become a central focus of interest in neuroscience research in order to define the neurophysiological basis of social behavior and inter-subjective interactions (Toppi et al., 2016). Cooperation, in particular, can be considered as a social interaction between two or more agents who intend to share their performance and produce a common behavioral outcome. In this perspective, their joint actions are directed towards the achievement of specific common interests that provide significant advantage to all participants involved (Balconi & Pagani, 2014, 2015; Vanutelli, Nandrino, & Balconi, 2016; Balconi & Vanutelli 2017). Earlier work investigated how self-representation, perceived self-efficacy in social interactions, and social cognition are modified by cooperative tasks. Findings showed that a cooperative instruction is able to support a sense of ingroup, and may increase self-efficacy representation, interpersonal cohesion, and general social well-being (Knoblich, Butterfill, & Sebanz, 2011; Liu, Saito, & Oi, 2015).

Concerning the neural networks involved during cooperative behaviors, involvement of relevant prefrontal areas has been noted (Hasson, Ghazanfar, Galantucci, Garrod, & Keysers, 2012; Schilbach, 2010; Vanutelli et al., 2016). Specifically, limbic regions and the prefrontal cortex (PFC) support emotional, cognitive, and behavioral components of social interactions during cooperation (Holper, Scholkmann, & Wolf, 2012). It was observed that both the dorsal (DLPFC) and orbital (VLPFC) part of the PFC are generally engaged during social conditions that involve a cooperative task (Liu et al., 2015; Nozawa, Sasaki, Sakaki, Yokoyama, & Kawashima, 2016). It was suggested that these brain mechanisms probably reflect the recruitment of top-down control processes over specific emotional and cognitive responses to social contexts, as a way to regulate appropriate behavior (Balconi & Vanutelli, 2016a).

However, as noted in many previous studies, a critical aspect that is able to mediate these brain circuits and their activity is the perception of the efficacy of shared strategies; that is, the effects when cooperation goes wrong, or when it goes well. In fact, this feedback can be analyzed as a way to reinforce or not reinforce behavior toward a common direction, and is a relevant tool to train the brain to work synergistically or, on the other hand, to reduce the synergy. Previous studies have explored the effects of positive interpersonal feedback on self-

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https://doi.org/10.1016/j.bandc.2018.02.009
Received 25 August 2017; Received in revised form 22 February 2018; Accepted 23 February 2018

representation (Balconi & Pagani, 2014; Balconi & Vanutelli, 2016b), performance (Balconi & Pagani, 2015, 2014; Balconi & Vanutelli, 2016a, 2016b; Monterosso, Ainslie, Mullen, Pamela Toppi Mullen, & Gault, 2002), and brain responsiveness in cooperative or competitive tasks (Balconi & Vanutelli, 2016b). It was found that positive feedback in relation to the outcomes reinforces efficient performance, activates the PFC, and in many cases, elicits a left-lateralized effect, since the generated positive emotions are linked to the experience of a positive and reinforcing condition for cooperation (Balconi, Brambilla, & Falbo, 2009; Balconi, Grippa, & Vanutelli, 2015a). Further, brain-to-brain coupling was considered in this regard, showing that good self-representation related to positive feedback on joint performance reinforces brain effectiveness and neural synchronization between the inter-agents (Baker et al., 2016).

However, no previous studies have simultaneously explored the effects of negative feedback on behavioral performance and brain correlates during interactions. That is, when we perceive that our cooperative actions are not efficient, what kind of brain and behavioral responses are produced?

A second critical point is related to the distinction between a one-person and a two-person perspective in explaining cooperative behavior. Indeed, a second perspective emphasizes that a deep understanding of cooperative processes can be obtained by including all interacting actors as a whole system (Hasson et al., 2012; Johnson & Johnson, 2005). Nonetheless, the majority of previous research within social neuroscience has explored this construct by means of single-brain paradigms, in which individual participants interact with a computer, or two people interact one at a time in turn-taking tasks, with off-line measurements (Balconi & Pagani, 2014; Decety, Jackson, Sommerville, Chaminade, & Meltzoff, 2004). Such paradigms cannot explain the complexity of these processes in real-time, and cannot offer a complete understanding of brain-to-brain coupling. More recently, an increased number of researchers have shifted towards a 'wo-person perspective' (Schilbach, 2010) thanks to the creation of the hyperscanning paradigm. This technique permits the simultaneous recording of neural activity from different participants interacting together (Montague, 2002). The underlying idea is that, during joint actions, people become implicitly synchronized (Knoblich et al., 2011), as shown in previous studies that have revealed typical patterns of inter-brain synchronization with correlated cortical responses. For example, Cui and colleagues (2011) recorded the simultaneous brain responses of two people while they performed a computer-based game in which they were required to cooperate or compete; the authors then calculated inter-brain activity coherence. Results showed increased coherence between the two time series in the right superior frontal cortices, during cooperation only, but not during the competitive condition. Similarly, Holper et al. (2012) analyzed between-brain connectivity during an imitation task and found increased coherence with respect to the control condition. Moreover, Nozawa et al. (2016) found increased neural synchronization within the frontopolar cortex between inter-agents performing cooperative verbal communication.

Nevertheless, no previous study has detailed the effect of negative feedback or failing cooperation on functional connectivity, taking into account the hyperscanning perspective.

The effect of negative feedback on goal pursuit has been previously studied with respect to motivational theories, which attest that positive feedback is more effective in supporting goal pursuit than negative feedback, since it can reinforce outcome expectancy of the goal and perceived self-efficacy (Bandura & Cervone, 1983; Zajonc & Brickman, 1969). According to this view, positive feedback increases people's confidence about the possibility of pursuing their goals, thus leading them to expect successful goal achievement. On the contrary, negative feedback undermines people's confidence in their ability to pursue their goals and the opportunity to succeed (Fishbach, Eyal, & Finkelstein, 2010). Based on this evidence, in the present paper we hypothesized that obtaining a negative external evaluation could influence subjects' dyadic strategies, both at a behavioral and neural level. In fact, we hypothesized that receiving negative feedback as a couple could lead to discouragement, and subsequently, to the adoption of dysfunctional goal orientation.

Accordingly, we expected that the brain responses would be similar to those found in a competitive situation, because of the implementation of self-centered, rather than joint, neural strategies. In fact, as already found by Liu and colleagues in a recent paper (Liu, Saito, Lin, & Saito, 2017), although cooperation and competition share the some brain networks due to the interdependent nature of the tasks, competition requires additional mentalizing resources because of its clear self-other distinction.

In the present context, we considered functional connectivity. Functional connectivity is calculated as the simultaneous coupling between two time series (Friston, 2011), and provides a temporal correlation between neurophysiological events that are spatially remote (Zhao, Xi, Wang, Li, & He, 2014). By using functional infrared-spectroscopy (fNIRS) we were able to address the functional connectivity effects and temporal course of brain activation. Indeed, whereas classical imaging (i.e., functional magnetic resonance imaging; fMRI) measures do not seem to completely describe the real nature of social inter-personal processes, fNIRS measurements allow for direct examination of hemodynamic aspects of brain activation in line with social dynamics (Balconi, Grippa, & Vanutelli, 2015b; Biallas, Trajkovic, Haensse, Marcar, & Wolf, 2012). Experimental contexts that imply social interactions are characterized by a fast temporal evolution. For this reason, it is preferable to apply imaging methods that offer good resolution in both temporal and spatial domains, in order to provide an ecological setting to acquire event-related hemodynamic responses, such as fNIRS (Elwell et al., 1993).

Finally, a third critical point is that no previous studies have considered in depth the specific contributions of intra- and inter-brain connectivity during cooperation. That is, the contribution of both individual (intra-brain) and intersubjective (inter-brain) connectivity is unexplored. Earlier work has investigated inter-brain connectivity in romantic partners (Pan, Cheng, Zhang, Li, & Hu, 2017), or when playing a cooperative ecological dyadic game (Liu et al., 2016); however, to the best of our knowledge, no previous study has directly compared inter- and intra-brain connectivity. When analyzing a cooperative task, it is important to explore the activation of specific brain areas, and their connections within each brain alone, as well as the inter-brain connections. Moreover, we propose a new computation, the ConIndex, which allows calculation of inter-brain synchronization. This procedure has already been applied in our recent paper describing positive cooperative social dynamics (Balconi, Pezard, Nandrino, & Vanutelli, 2017). Results showed that the experimental conditions were associated differently with activation of frontal and prefrontal networks, in single and joint brains. Thus, a further objective of the present work was to explicitly compare intra- and inter-brain connectivity when cooperation goes wrong.

Therefore, in the present study we aimed to investigate the relationship between intra- and inter-brain functional connectivity during cooperation, within a hyperscanning paradigm in which participants were required to synchronize their behavioral performance. Halfway through the task, participants received feedback on their performance, manipulated ad hoc by the experimenter, in order to induce a negative perception of self-efficacy that would in turn influence the construction of joint strategies. We hypothesized that, at the cognitive level, increased cognitive effort would result in the post-feedback condition being characterized by poor performance (increased RTs and ERs), when compared to the first part of the task where there was no specific social feedback. At the brain level, we assume that external negative social feedback will increase intra-brain and inter-brain functional connectivity. In fact, improved synchronization could be considered a strategic way to reinforce and restore cooperation that was previously failing. Alternatively, it is also possible that discomfort and a negative