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An fMRI study of the social competition in healthy subjects

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ABSTRACT

Social interaction requires the ability to infer another person's mental state (Theory of Mind, ToM) and also executive functions. This fMRI study aimed to identify the cerebral correlates activated by ToM during a specific social interaction, the human–human competition. In this framework, we tested a conflict resolution task (Stroop) adapted to a virtual situation of competition. The participants were instructed to play in order to win either against a human-like competitor (human–human competition) or against a non-human competitor (human–machine competition). Only the human–human competition requires ToM as this type of competition is performed under social interaction. We identified first the classical network of executive regions activated by Stroop. Secondly, we identified the social (human–human) competition regions, represented by the bilateral superior and inferior frontal gyri, the anterior cingulate, the insula, the superior and anterior temporal, the hippocampus, the fusiform gyrus, the cuneus and the precuneus. Finally, we identified the executive regions that were modulated by the human–human competition, i.e., the executive control regions additionally activated when mentalizing in the context of social competition. They constituted a network predominant to the right and composed of the superior and middle frontal, anterior cingulate, insula and fusiform gyrus. We suggest that our experimental paradigm may be useful in exploration of the cerebral correlates of social adjustments in several situations such as psychiatric disorders presenting executive and social dysfunctions.

1. Introduction

Human interactions are based on various cognitive and emotional abilities unified within the concept of social cognition. Social interactions include various processes such as social perception (facial expressions, gaze processing), social cognition (ToM, empathy) and executive functions (Hari & Kujala, 2009). The executive functions are specifically involved in the adaptation to new situations that require the overcoming of a habitual response by shifting mental sets, reasoning and planning or maintaining goals. Overall, all these processes are required during social interactions (Suchy, 2009). Moreover, the executive functions modulate the social interactions because people have to constantly integrate feedbacks from the social environmental and elaborate adapted responses. The concept of social cognition relies mainly on the ability to imagine what others think, feel or intend to do in social situations and interactions (Adolphs, 2001). In other words, this concept defines the ability to make inferences about the mental state of other people, a function called Theory of Mind (ToM) (Premack & Woodruff, 1978). Although many neuroimaging studies have explored the cerebral substrate of ToM in various social situations, very few approached this ability during specific social interactions such as competition and cooperation. The social behavior in between -human interactions requires executive control functions but also ToM ability – crucial for the interaction between people.

According to the evolutionary theory, the social competition would be essential to natural selection and social organization (Bowles, 2006; Nowak, 2006). Social competition operates in synergy with another essential social interaction mode, which is cooperation, for shaping the human social behavior. Thus, it has been shown that between-group competition increases the within-group cooperation (Puurtinen & Mappes, 2009), while the within-group competition reduces the cooperation between non-relatives (West et al., 2006).

The competition interactions imply different executive and control mental processes, such as the following: *mental flexibility*, which is the rapid mental adaptation to environmental changes; *decision making* in order to make the appropriate response choice; *inhibition* of pre-potent and non-relevant responses; and *ongoing action monitoring* in order to target the strategies of the opponent competitor (Shallice, 1998). Alongside this executive processing during between-humans competition interaction, each competitor should imagine and anticipate the other's mind state and behavior and thus engage, in other words, the ToM. Moreover, the social competitive behavior includes self-to-other comparison that influences the

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decision making and induces specific social emotions like envy and schadenfreude (gloating) (Dvash, Gilam, Ben-Ze'ev, Hendler, & Shamay-Tsoory, 2010; Fliessbach et al., 2007). These emotions interfere with an evaluation process of people during the social interaction; the evaluation is mostly based on comparison reasoning rather than their intrinsic value (Takahashi et al., 2009).

A large number of studies explored the cerebral substrate of social interactions (Assaf et al., 2009; Baron-Cohen et al., 1994; Baron-Cohen et al., 1999; Brunet, Sarfati, Hardy-Bayle, & Decety, 2000; Castelli, Happe, Frith, & Frith, 2000; Ciaramidaro et al., 2007; Gallagher, Jack, Roepstorff, & Frith, 2002; Gallagher et al., 2000; Goel, Grafman, Sadato, & Hallett, 1995; Hampton, Bossaerts, & O'Doherty, 2008; McCabe, Houser, Ryan, Smith, & Trouard, 2001; Vogeley et al., 2001; Zaki, Hennigan, Weber, & Ochsner, 2010). Nevertheless, only a few studies focused on social competition's neural correlates. For instance, Gallagher et al. (2002) studied social competition by using PET in healthy subjects involved in a competition video game. They highlighted the role of the anterior cingulate gyrus, the medial frontal cortex and the inferior parietal lobule, regions also mentioned by other authors for the same topic and question (Decety, Jackson, Sommerville, Chaminade, & Meltzoff, 2004). During a decision-making task in social competition, Halko, Hlushchuk, Hari, and Schurmann (2009) reported the activation of temporo-parietal junction and the inferior frontal gyrus, both related to the ability to make inferences about the other partner's intentions (Rilling, Sanfey, Aronson, Nystrom, & Cohen, 2004). During social interactions like competition, the medial prefrontal cortex and temporal pole play a more specific role in "on-line" (implicit) ToM process (Assaf et al., 2009). Other areas such as posterior cingulate gyrus, precuneus, superior temporal sulcus, hippocampus, hypothalamus and thalamus have also been reported during social interaction tasks and were particularly related to ToM. Social emotions like envy and schadenfreude related to social comparison may also activate the ToM network (Shamay-Tsoory, Tibi-Elhanany, & Aharon-Peretz, 2007; Takahashi et al., 2009). The number of regions belonging to this large network was often reported as related to executive inhibition control processes (Carter, Botvinick, & Cohen, 1999; Langenecker, Nielson, & Rao, 2004; Mead et al., 2002). Within this framework and given that acting under social competition needs a large panel of executive control abilities, it is difficult to distinguish the regions specifically activated by the executive control functions from those related to the competition situation by itself and to ToM.

ToM is a complex cognitive function, incompletely understood and probably related to executive and control operations (Goukon et al., 2006; Perner, Lang, & Kloo, 2002), and thus involved in harmonious social interactions. A significant correlation between ToM and the inhibitory control has been suggested by different studies of an early (preschooler) age (Carlson, Mandell, Williams, & 2004; Carlson, Moses, & Claxton, 2004; Hughes & Ensor, 2005; Rasmussen, Wyper, & Talwar, 2009; Yang, Zhou, Yao, Su, & McWhinnie, 2009). This correlation is robust and independent of the subject's culture (Sabbagh, Xu, Carlson, Moses, & Lee, 2006). At adulthood, the relationship between executive/control functions and ToM is more controversial. Several neuropsychological observations in patients with frontal lobe lesions did not report correlation between executive function and performances of ToM (Rowe, Bullock, Polkey, & Morris, 2001), while other studies found such a correlation (Charlton, Barrick, Markus, & Morris, 2009; Saltzman, Strauss, Hunter, & Archibald, 2000). Nevertheless, as performances decrease with aging for both ToM and executive control functions, it has been accepted that in some way, they should be correlated (Langenecker et al., 2004; Maylor, Moulson, Muncer, & Taylor, 2002).

Social competition is experimentally simulated by using interactive video games such as *Ultimatum Game* (Rilling et al., 2004; Sanfey, Rilling, Aronson, Nystrom, & Cohen, 2003) or *Prisoner's Dilemma game* (Babiloni et al., 2007; Hauert & Stenull, 2002; Kiesler, Sproull, & Waters, 1996). Given that these games simulate cooperation rather than competition interactions, in this study we used a paradigm focused on the competition behavior evaluation. Our experimental paradigm was based on a cognitive color-naming Stroop test (Stroop, 1935) modified by adding a virtual context of social competition. To test the competition, the participants were asked to perform the color-naming interference test by competing against an adversary who was presented either as a human or as a machine adversary. Instructions about the test and the "adversary" were given in order to induce an "on-line" implicit mentalizing process while performing the task. A visual feedback was sent after each response in order to inform participants about their performance relative to the opponent's. ToM was evaluated by comparing human-to-human vs. human-to-machine interactions. The human–human competition under social interaction can be simulated by a human–computer interaction, a paradigm that was already used in other studies (Assaf et al., 2009; Gallagher et al., 2002; McCabe et al., 2001; Rilling et al., 2004).

By using this paradigm, the aim of our fMRI study performed in healthy subjects was to highlight the cerebral correlates of social (human–human) interaction in a situation of competition, while participants performed a modified version of the Stroop test. After the identification of regions activated by the executive functions and by competition, we were interested to know which of the executive regions were specifically recruited by human–human competition, which involved according to the paradigm's construction, a mentalizing (ToM) process.

2. Materials and methods

2.1. Participants

We examined 14 right-handed healthy volunteers (10 females), with mean age of 35.9y (SD = 7.2y). The handedness was determined by means of a modified version of Edinburgh Handedness Inventory (Oldfield, 1971). Participants were recruited from the university and hospital staff and had no history of psychiatric, neurological or other major medical disorder. All of them provided written informed consent, and the study was approved by the local Ethics Committee of Grenoble Hospital.

2.2. Task and stimuli

The participants were instructed to perform a classical Stroop test that was adapted to a virtual situation of competition. Specifically, the subjects were told to perform a classical color-naming task by competing against an adversary, human or machine.

In order to induce a real competition climate, a scenario was played before the participant entered the MRI scanner. The "human" opponent was presented to the participant: a real person who was in front of a computer screen on which the test was ready to start. Another computer connected to the first one was presented as the "machine" opponent. None of the participants realized that was only a "scenario" and not a real situation. Actually, the participant was always playing against a computer. The participants were instructed to play to win by responding as quickly and correctly as possible. Moreover, they were told to be aware of the opponent's intentions and strategies of response. They were informed that the computer's strategy of competition "depend only on some initial parameters of the participant's competition style" (number of errors, reaction time, etc.); they were told that these parameters helped the computer to "guess" the participant's intentions/strategies. In addition, the participants were told that the computer was programmed to further follow a fixed responding