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Dissociable prefrontal networks for cognitive and affective theory of mind: A lesion study

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Abstract

The underlying mechanisms and neuroanatomical correlates of theory of mind (ToM), the ability to make inferences on others' mental states, remain largely unknown. While numerous studies have implicated the ventromedial (VM) frontal lobes in ToM, recent findings have questioned the role of the prefrontal cortex. We designed two novel tasks that examined the hypothesis that affective ToM processing is distinct from that related to cognitive ToM and depends in part on separate anatomical substrates.

The performance of patients with localized lesions in the VM was compared to responses of patients with dorsolateral lesions, mixed prefrontal lesions, and posterior lesions and with healthy control subjects. While controls made fewer errors on affective as compared to cognitive ToM conditions in both tasks, patients with VM damage showed a different trend. Furthermore, while affective ToM was mostly impaired by VM damage, cognitive ToM was mostly impaired by extensive prefrontal damage, suggesting that cognitive and affective mentalizing abilities are partly dissociable.

By introducing the concept of 'affective ToM' to the study of social cognition, these results offer new insights into the mediating role of the VM in the affective facets of social behavior that may underlie the behavioral disturbances observed in these patients.
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1. Introduction

Human social behavior is characterized by the unique capability of using 'metarepresentations' (Leslie & Frith, 1987). This emerges as an individual develops a 'theory of mind' (ToM): the capacity to make inferences regarding others' mental states: their knowledge, needs, intentions and feelings (Premack & Woodruff, 1978). Developmental studies indicate that simple ToM capacity first manifests itself during early infancy when children engage in shared attention and protodeclarative pointing (Baron-Cohen, 1995). Preschool children as young as 3–4 can understand that another person may hold a belief that is mistaken (first-order false belief), e.g., to know that person A might think a cookie is in a jar while the same jar was emptied earlier by person B when person A was not looking (Wimmer & Perner, 1983). Between ages 6 and 7, children begin to pass more advanced tests (second-order false belief) that examine "belief about belief"—what someone thinks about what someone else thinks. As an example: the understanding that secretly seeing person B empty the jar, person A would know the jar is empty but person B would still think that person A believes the jar is full (Perner & Wimmer, 1985). Complex social skills first appear between ages 9 and 11, when children develop further ToM abilities. These can be tested with the social 'faux pas' task (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997). To understand that a faux pas ("wrong behavior") has occurred, one has to represent two mental states: that the person saying it does not know that he/she should not say it and that the person hearing it would feel insulted or hurt. Thus, there is both a cognitive component and an empathic affective component in this particular task (Baron-Cohen et al., 1997).

It has been recently suggested that the development of ToM ability is part of a constellation of functions mediated by the ventromedial (VM) prefrontal cortex which include the orbital and medial PFC cortices (Happaney, Zelazo, & Stuss, 2004). Neuroimaging studies have mainly pointed to the role of the

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medial prefrontal cortex (PFC) in ToM. Fletcher et al. (1995) and Goel, Grafman, Sadato, and Hallett (1995) found left medial frontal activation during performance of ToM tasks using PET scanning. Using fMRI, a similar pattern of left medial PFC activation was demonstrated while performing story and cartoon tasks (Gallagher et al., 2000). Baron-Cohen et al. (1994) also observed increased prefrontal activation during recognition of mental state terms, evident particularly in the right orbitofrontal cortex (Baron-Cohen & Goodhart, 1994).

Summarizing the recent neuroimaging literature, Gallagher and Frith (2003) concluded that the network subserving ToM includes the medial PFC, the superior temporal sulci (STS) and the temporal poles bilaterally. These authors point out, however, that while the medial PFC is the distinctive key region for mentalizing, the STS and the temportal pole are not uniquely associated with ToM.

Lesion studies have equally illustrated the role of the PFC in ToM. Rowe, Bullock, Polkey, and Morris (2001) reported that subjects with either left or right PFC lesions are impaired in ToM ability, as assessed by first- and second-order false belief tests. Stone, Baron-Cohen, and Knight (1998) compared the performance of patients with orbitofrontal cortical damage to that of patients with dorsolateral prefrontal damage on different ToM tasks. Unlike subjects with dorsolateral damage who performed flawlessly on all tasks, the performance of patients with orbitofrontal damage resembled that of individuals with Asperger's syndrome, exhibiting good performance on first- and second-order false belief tasks and impairment on the faux pas task (Stone et al., 1998).

Stuss, Gallup, and Alexander (2001) highlighted the specific importance of the prefrontal cortex, especially the right frontal lobe and the medial PFC, in tasks of 'perspective taking' and deception, tasks that are also considered to require ToM.

Yet Bird, Castelli, Malik, Frith, and Husain (2004) questioned the role of the medial PFC cortex in ToM in a recent case study. The authors describe a patient (GT) who underwent a stroke in the anterior cerebral artery territory, resulting in widespread bilateral damage to the medial PFC. While exhibiting a dysexecutive syndrome, the patient displayed intact performance on various ToM tasks such as the picture sequences, "strange story" and animations tasks. Although GT showed some impairment on the violation of norms and faux pas tasks, the authors concluded that this case demonstrated that the medial PFC is not necessarily involved in ToM.

In agreement, Samson, Apperly, Kathirgamanathan, and Humphreys (2005) recently reported evidence from brain-damaged patients, showing that the left temporoparietal junction is necessary for reasoning about beliefs of others. These authors further suggested that while belief-reasoning errors of patients with PFC damage may arise from a dysexecutive syndrome, belief-reasoning errors of patients with damage to the temporoparietal junction is independent of other cognitive impairments (Apperly, Samson, Chiavarino, & Humphreys, 2004; Samson et al., 2005).

Taken together, it appears that the exact role of the PFC cortex in ToM abilities has yet to be elucidated. We recently suggested that the above-noted conflicting reports may reflect differences between task demands and consequently mentalizing processes utilized in these studies (Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2005). For example, while performance on second-order false belief tasks requires cognitive understanding of the difference between the speaker's knowledge and that of the listener (knowledge about *beliefs*), identification of social 'faux pas' requires, in addition, an empathic appreciation of the listener's emotional state (knowledge about *emotions*).

Using Stone et al's (1998) ToM tasks and a detection of irony task, we previously reported that patients with lesions that involve the right ventral medial and orbital (VM) frontal lobe exhibit impaired performance on tasks that assess '*affective ToM*' (identifying social 'faux pas' and irony) but not on tasks which assess '*cognitive ToM*' (second-order false belief). Furthermore, patients' performance in *affective ToM* tasks was positively related to their empathic ability, indicating that the ability to make affective representations of others' mental states is associated with the ability to empathize (Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003). Additional evidence for the existence of dissociation between the cognitive and affective aspects of ToM was suggested by our study which examined two adolescents diagnosed with Asperger's syndrome (AS) (Shamay-Tsoory, Tomer, Yaniv, & Aharon-Peretz, 2002). This study reports two cases of adolescents with AS who showed extreme deficits on measures of empathy. While both patients could recognize various affects conveyed through prosody or facial expressions, they were unable to represent the emotional state of other people. This was reflected by their responses to empathy questionnaires, and their explanations regarding the faux pas. A qualitative analysis indicated that the errors they made in the faux pas detection task were rather due to an inability to make emotional representations or impaired 'affective ToM' rather than a general ToM impairment (Shamay-Tsoory et al., 2002).

The inferences one makes regarding others' mental states include knowledge regarding their thoughts and beliefs, as well as knowledge and empathic understanding of their emotional states and feelings. For example, it may be speculated that while performance of the second-order false belief task requires cognitive understanding of the difference between the speaker's knowledge and that of the listener (knowledge about *beliefs* – "cognitive ToM"), identification of social 'faux pas' requires in addition an empathic appreciation of the listener's emotional state (knowledge about *emotions* – "affective ToM"). It is possible that the behavioral deficit of individuals with VM-PFC damage is specifically related to impairment in this affective facet of ToM, rather than to a general impairment of ToM. Furthermore, using fMRI, Hynes, Baird, and Grafton (2006) recently demonstrated that the medial orbitofrontal lobe was preferentially involved in emotional as compared to cognitive perspective-taking (Hynes et al., 2006). A similar distinction between "affective" and "cognitive" ToM was made by Brothers and Ring (1992), and is referred to as "cold" (cognitive) and "hot" (emotional) aspects of ToM. These authors further suggest that the "hot" aspects of ToM may be mediated by the medial and orbital PFC (Brothers & Ring, 1992). Thus, it might be speculated that the distinct abilities for cognitive and affective

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