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Review

Self-reflection and the brain: A theoretical review and meta-analysis of neuroimaging studies with implications for schizophrenia

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ABSTRACT

Several studies have investigated the neural correlates of self-reflection. In the paradigm most commonly used to address this concept, a subject is presented with trait adjectives or sentences and asked whether they describe him or her. Functional neuroimaging research has revealed a set of regions known as Cortical Midline Structures (CMS) appearing to be critically involved in self-reflection processes. Furthermore, it has been shown that patients suffering damage to the CMS, have difficulties in properly evaluating the problems they encounter and often overestimate their capacities and performance. Building on previous work, a meta-analysis of published fMRI and PET studies on self-reflection was conducted. The results showed that two areas within the medial prefrontal cortex (MPFC) are important in reflective processing, namely the ventral (v) and dorsal (d) MPFC. In this paper a model is proposed in which the vMPFC is responsible for tagging information relevant for 'self', whereas the dMPFC is responsible for evaluation and decision-making processes in self- and other-referential processing. Finally, implications of the model for schizophrenia and lack of insight are noted.

Contents

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1. Introduction

The aim of this paper is to review the literature on self-reflection, and in particular its differentiation from other-reflective processing, by means of a meta-analysis of the fMRI and PET studies published so far on the subject. We will present a model of self-reflection and the brain based on the results of the meta-analysis. The discussion will be expanded to encompass the literature on failure of self-reflection processes, in particular in schizophrenia patients who may be viewed as having important problems in this area (Carter et al., 2001; Baird et al., 2006; Addington et al., 2006; Sprong et al., 2007). Recent neuroimaging evidence (Taylor et al., 2007; Park et al., 2008) suggests that processes relying upon these Cortical Midline Structures (CMS), a set of regions encompassing the posterior cingulate cortex (PCC), the medial prefrontal cortex (MPFC) and the anterior cingulate cortex (Northoff and Bermpohl, 2004), may be affected in this patient group. Finally, the possible role for self-reflection abilities in illness awareness in schizophrenia patients will be discussed.

The study of self has become increasingly popular in cognitive neuroscience over the past decade (Kircher and David, 2003). Several studies have investigated the neural correlates of self-reflection or self-referential processing. In the literature these terms are used interchangably and refer to the evaluation process used to decide whether certain environmental cues apply to one's self or not. Technically, self-referential processing is a broader concept in which all information that somehow refers to oneself is processed and encompasses subconscious as well as conscious processing. Self-reflective processing on the other hand implies a conscious process in which a decision is made regarding oneself.

Having an accurate representation of one's traits, abilities and attitudes is important in evaluating one's own behavior and comparing it with the behavior of other human beings. The most commonly used paradigm to address this concept in experimental and neuroscientific research uses self-reflection in which subjects are presented with trait adjectives or sentences and are asked whether the trait or sentence applies to them. Results have consistently pointed to a role of the CMS in these self-reflection processes, but this has not allayed misgivings regarding the concept of self-reflective processing (Gillihan and Farah, 2005) and whether the processing of self-reflective information is substantially different from the processing of information concerning other people. Finally, it has also been shown that patients who have suffered damage to the CMS have difficulties in properly evaluating their problems and often overestimate their capacities as well as their performance particularly on cognitively demanding operations (Schmitz et al., 2006).

1.1. Neural correlates of self-reflection and the Cortical Midline Structures

Most studies investigating self-reflection processes have found evidence for medial prefrontal cortex (MPFC), posterior cingulate cortex (PCC) and anterior cingulate cortex (ACC) involvement in distinguishing self-related information from non-self-related information. Even though these studies report a similar functional anatomy, the precise involvement of the component structures is debated. One of the first studies looking at the neural correlates of the 'self-reference effect', using PET was done by Craik et al. (1999). The self-reference effect refers to the finding that people tend to remember words when processed in relation to themselves better than words processed more generally (see Symons and Johnson (1997) for a meta-analysis). Craik et al. (1999) found that the retrieval of self-referential information is mediated by right prefrontal areas including the MPFC, whereas the encoding of such information is similar to the encoding of information about others and is mediated mainly by left prefrontal areas. This effect was replicated using fMRI by Kelley et al. (2002), by means of visual presentation of trait adjectives and Johnson et al. (2002) who studied self-reflection by means of a paradigm in which subjects were presented auditorily with short questions, each entailing a trait, attitude or ability (e.g. 'I am a good friend'). As a control condition, they used simple questions entailing general semantic knowledge (e.g. 'You need water to live'). Both studies found anterior MPFC (aMPFC) and PCC activation in the self-reflection condition. The studies by Craik et al. (1999), Kelley et al. (2002) and Johnson et al. (2002) were followed up by a number of other studies using similar paradigms and reporting similar areas of activation. Macrae et al. (2004) demonstrated that activation in MPFC regions corresponded to self-reflective judgments and memory performance related to self-descriptive trait words. Fossati et al. (2003) were specifically interested in the processing of emotionally valenced words in self-reflection. They presented positive and negative trait words and found dorsal MPFC (dMPFC) and PCC activation in a self versus baseline contrast.[4] Interestingly, this dMPFC activation was not specific to either positive or negative stimuli but rather it was present regardless of valence. Gusnard et al. (2001) and Johnson et al. (2005) found only MPFC activation in a similar contrast in which subjects were asked to introspect either in response to pleasant/unpleasant visual stimuli or color preference respectively. Johnson et al. (2006) similarly used an introspection paradigm in which subjects ruminated on hopes and duties in comparison with a condition without self-reference and found MPFC and PCC activation.

Northoff and Bermpohl (2004) reviewed the literature on self-processing and neuroimaging and discussed the role of the CMS in self-processing. They discussed each area separately and came to the conclusion that different areas within the CMS represent different functions, such as representation, monitoring, evaluation and integration. However, their review focused on the processing of self only. Many other recent studies have included an 'other' condition in which the subject is asked to reflect upon another person, either an unfamiliar person, a relative, close friend or someone famous, while presented with trait words (Kelley et al., 2002; Macrae et al., 2004; Schmitz et al., 2004; Ochsner et al., 2005; Heatherton et al., 2006; Schmitz and Johnson, 2006; D'Argembeau et al., 2007; Gutchess et al., 2007; Zhu et al., 2007), trait sentences (Pfeifer et al., 2007; Modinos et al., 2009), or when instructed to introspect upon emotional pictures (Ochsner et al., 2004; Jenkins et al., 2008) or food preference (Seger et al., 2004). The involvement of the MPFC (Macrae et al., 2004; Ochsner et al., 2004; Schmitz et al., 2004; Johnson et al., 2005; Schmitz and Johnson, 2006; Zhu et al., 2007; Modinos et al., 2009) and PCC, precuneus (Ochsner et al., 2004; Seger et al., 2004; Heatherton et al., 2006; Johnson et al., 2006; Schmitz and Johnson, 2006; Modinos et al., 2009) in self-reflective processing is broadly confirmed. However, regarding 'other'-reflective processing and the extent to which this differs from self-reflective processing, the literature does not yield a consensus.

Even though most studies report differences in self-processing versus other-processing, the brain region that is mostly reported to be functionally associated specifically with self-processing is referred to as MPFC (Kelley et al., 2002; Ochsner et al., 2004; Heatherton et al., 2006; D'Argembeau et al., 2007; Gutchess et al., 2007; Pfeifer et al., 2007; Zhu et al., 2007; Jenkins et al., 2008; Modinos et al., 2009), while the same studies report this area to be involved in other-processing as well. Additional areas that are

[4] The terms ventral and dorsal medial frontal cortex are not always well defined in the literature. In this paper, a dividing line will be placed along Talairach *z*-coordinate of 20. The area above will be referred to as dMPFC, whereas the area underneath will be referred to as vMPFC (see Van Overwalle, 2009; Krueger et al., 2009). This roughly corresponds to Brodmann's areas 9 for dMPFC and 10 and 11 for vMPFC (Northoff et al., 2006).