Self-recognition and the right prefrontal cortex

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Although the anatomical and functional substrates subserving face recognition have been subject to extensive investigation, the underpinnings of self-face recognition are not well understood. Given the evidence that own-face recognition has been demonstrated by a select number of species, it is intriguing to speculate whether self-face recognition is accomplished via a 'self-network' or simply a 'face-network' within the brain. Furthermore, the relationship of self-recognition to other self-processes, such as self-evaluation and autobiographical retrieval, are not clearly defined. However, data from fMRI, ERPs and repetitive transcranial magnetic stimulation as well as from split-brain studies and patients with focal lesions, indicate that the prefrontal cortex, with possible right hemisphere lateralization, may be a preferential component in self-recognition. Studies using these methods, as well as PET, have indicated that the self-processes of self-evaluation and autobiographical memory preferentially engage networks within the right fronto-temporal region. Although it is highly improbable that there is a 'self-recognition' or 'self' center, it appears that there may be a bias for the processing of 'self' within the right prefrontal cortex.

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I know that I exist, the question is, What is this 'I' that I know?
Descartes *The Philosophical Writings of Descartes*[1]

Defining the concept of self and understanding the cortical underpinnings of such a concept is a challenge for scientists. Although the psychological and neuroscientific literatures include countless articles, chapters and books that touch upon such ideas as 'self-awareness', 'self-consciousness' and 'self-efficacy', there is no coherent body of knowledge that comprises a cognitive neuroscience of self. Indeed, the relevant evidence comes from sources that have only minimal cross-talk with one another.

The question of the cortical underpinnings of self-recognition is intriguing, as numerous non-human primates with well-developed cognitive abilities, including face recognition, appear unable to distinguish their own face from other faces even after years of training. It has been suggested that recognition of self is an indicator of higher-order self-awareness, such that those individuals that can recognize their own image are capable of other self-related tasks, including rudimentary introspection. It is therefore exciting to pursue the possibility that own-face recognition may not be limited to cortical elements involved in general face recognition and categorization.

After reviewing a number of diverse areas, we have come to a few preliminary conclusions. (1) It appears that involvement of the human prefrontal cortex is critical for a number of sophisticated cognitive acts involving self-recognition. (2) The right prefrontal cortex may play a stronger role than the left in such processes. (3) Self-recognition appears to activate similar networks as other self-processes, including autobiographical retrieval and self-evaluation. (4) More speculatively, it is possible that this self-network is tied to theory of mind abilities and that the two share common neural substrates.

Self-face recognition

General face recognition appears to occupy a specific and distinct region of the brain within the fusiform gyrus[2,3]. This finding appears to be quite robust and is supported not only by recent work using modern imaging techniques[4], but also by the fact that prosopognosia (deficits in face recognition) is reliably observed following damage to this and neighboring regions[5–7]. In normals, it is generally found that subtraction (statistically) of regions involved in face recognition from those in object recognition results in activation within the inferior temporal lobe, often within the fusiform gyrus[2].

However, much less data is available on self-face recognition than on general face recognition. Self-recognition via a variety of stimuli has been studied[8], with the majority of research focused on mirror self-recognition (see Box 1). Because self-recognition may be an avenue to discovering other 'self abilities' in an individual, the question

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Box 1. Self-awareness and the mirror test

Researchers have been using a mirror to examine self-recognition since the late nineteenth century (Refs a,b). However, it was not until 1970 that a series of rigorous experiments was performed to examine species-specific behaviors during mirror exposure. Gallup exposed a group of chimpanzees in front of a mirror for ten days to establish a baseline of behavior (Ref. c). After the tenth day, the chimpanzees were anesthetized and a mark of odorless dye applied in an unobtrusive location above the eyebrow, so that it could not be seen by the animal. When the mirror was re-introduced, all the animals immediately directed touches towards the mark on their foreheads, indicating that they recognized their own image in the mirror (Fig. I). A separate group of chimpanzees without previous mirror exposure was tested concurrently; these controls did not examine the mark after recovering from anesthesia. Although factors such as age and experience with human rearing appear to bear upon performance, numerous chimpanzees and orang-utans examined have 'passed' this test (Refs d,e), whereas both gorillas (Refs f,g) and monkeys (Refs h,i) do not generally make mark-directed responses [although exceptions do exist in the literature (Refs j,k)].

Although these data are debated, there is further discussion as to what it means to 'pass' the (mirror self-recognition) MSR test. Gallup has implied that self-recognition indicated via this test is an indicator of self-awareness, that is, the ability cognitively to model one's own mental state (Ref. c). This possibility has been elegantly formulated into a concise theory in which implications for passing the test are encapsulated under the term 'autonoetic consciousness'. Within the realm of non-human primates, it does appear that those individuals that 'pass' the MSR test display a series of individual and social behaviors that may require self-awareness, although the relationship between these displays and MSR performance remains correlative (but see Ref. l).

Fig. I. Chimpanzees and the mirror test. The behaviors chimpanzees display in front of a mirror demonstrate that they understand they are the object in the reflection. Typical patterns of behavior include inspecting areas of the body that are not observable directly without a mirror. Here, a chimpanzee actually uses a towel to wipe off the mark applied prior to mirror exposure.

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of dedicated or preferential cortical structures that are involved in self-face recognition becomes intriguing. Is it possible that, in higher-order primates capable of self-recognition, there is reliable activation of a common cortical substrate that is engaged when the individual 'recognizes' its own image?

Work within the field of psychophysics may provide a first insight as to the possible cortical correlates of self-recognition. Tong and Nakayama[9] recently reported an interesting phenomenon in an experiment using a computerized reaction-time task. In one condition, subjects were required to search for their own face against a backdrop of other faces. This was compared to a search for an unfamiliar face. Tong and Nakayama found that even across hundreds of trials, subjects were quicker at identifying their own face than an unfamiliar face. This advantage remained even for novel, unfamiliar views (45 and 90 degrees), as well as for inverted faces. This 'robust' representation of the self-face was suggested to be view invariant – possibly involving an abstract representation of one's own face. However, there is contradictory evidence, such that 'non-familiar' views of one's own face are in fact more difficult to recognize than familiar views[10].

A follow-up study, with an emphasis on possible hand response differences, has demonstrated that self-faces are recognized significantly earlier than familiar or stranger

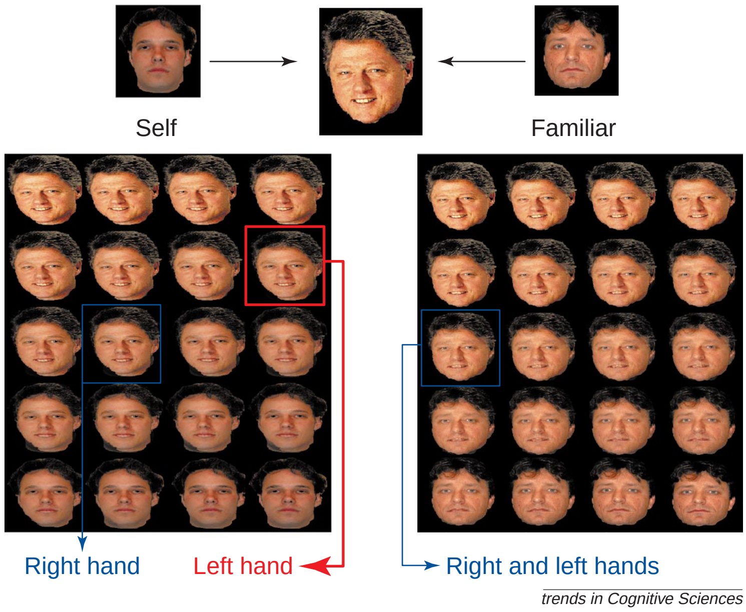

Fig. 1. Combining a series of faces using 'morphing', allows for the novel testing of self-face identification. Here, a series of morphs was created between the sample participant and Bill Clinton. A second series of morphs was created between a person that the participant was familiar with and Bill Clinton. The morphs were displayed as a 'movie' on a computer screen, showing the gradual transition from Bill Clinton to 'self' or Bill Clinton to 'familiar'. Participants were instructed to press a key at the point in the movie when they believed the face had become either 'self' (their own face) or 'familiar' (the face of their co-worker). It was found that when the morphs were composed of 'self', and the participants were responding with their left hand, the average stopping point occurred after 40% of the images had been displayed. However, for all other conditions (self right hand, familiar both hands), the average stopping point was approximately 50%. This may indicate a right hemisphere advantage for self-face processing. (Adapted, with permission, from Ref. 13.)

faces[11]. However, this 'self-advantage' was observed only when subjects were responding with their left hand. Because the left hand is controlled by the right hemisphere, the difference observed between the two hands was interpreted as reflecting brain differences in the processing of self-faces.

A further study used morphed faces, using self and familiar faces[12]. Both the subject's own face and the face of a familiar person (his or her co-worker) were morphed into the face of a famous person. A series of 20 steps were created for both the self–famous and familiar–famous series. These pictures were then displayed randomly on a computer screen. The subjects were asked to answer 'Yes' or 'No' to the question 'Is this face the face of a famous person?'. When the faces were composed of self, for example 50% self and 50% famous, the subjects tended to respond 'No', indicating that the face was not famous. However, when the morph was 50% familiar and 50% famous, the subjects tended to respond 'Yes', indicating that they thought the face was famous. The twist on these data was that the effect was robust for the left hand and not the right. In other words, when the face was composed of 'self' and the subjects responded with the left hand, there was a tendency to identify the face as being one's own face rather than a famous face. However, when responding with the right hand, the faces were identified as famous. The fact that subjects responding with the left hand, and not the right, over-identified certain morphs as 'self' is remarkable.

Like the initial reaction time study, these results indicated that the right hemisphere (controlling the left hand) may process self-faces preferentially, as reported in a similar study by Keenan *et al.*[13] (Fig. 1).

Studies with split-brain patients indicate a possible preferential role for self-recognition within the right hemisphere. Nobel prize researcher Roger Sperry investigated 'contentions that the minor (right) hemisphere is wholly lacking in conscious awareness'[14]. Basing his study on the original work of Gallup (see Box 1), Sperry and his colleagues presented self-stimuli (e.g. photographs of one's own face) and non-self stimuli (e.g. photographs of family members) to the right hemisphere of patients who had undergone forebrain commissurotomy surgery. They found that the right hemisphere had no difficulty in discerning self-related material. In fact, presentation of the patients' own face resulted in a positive emotional response, including 'a large sheepish grin'.

Although Sperry and colleagues concluded that the right hemisphere responds at least 'equally' to the left in terms of self-recognition, Preilowski[15] provided evidence that the right hemisphere may demonstrate preferential activation. Working with two patients, Preilowski measured skin resistance (SR) response (an indicator of arousal) to the presentation of faces, including the patient's own face, and to other emotional stimuli. In both patients, the SR response was greater for emotional stimuli presented to the left hemisphere than to the right. SR response was the same in both hemispheres for familiar faces. However, for self-faces, the SR was approximately twice as great when the faces were presented to the right hemisphere than when they were presented to the left. Further, within the right hemisphere, the average SR response was about twice as great for self-faces as opposed to familiar faces.

Unfortunately, few studies have examined self-face recognition with modern neuroimaging techniques. An initial ERP study[16] found that when self-faces were presented during a passive task (i.e. the subject is not to attend to his/her own face) there was a general overall cortical response when compared to non-target familiar faces (laterality was not examined). Given this, we recently found not only a greater 'cortical response' to self-faces but a degree of specificity as well[17]. Using ERPs, we found that there was a greater right ventral prefrontal response when subjects were asked to attend to their own face than to another individual's face.

We have used fMRI to determine with greater specificity the degree to which one's own face may activate particular regions of the cortex[17]. In this study, the subjects' own face was contrasted with the face of a famous person (Bill Clinton). Although the data are preliminary, we have found activation within the right inferior frontal gyrus on the border of the medial frontal gyrus (Fig. 2). These results have been extended using repetitive transcranial magnetic stimulation (rTMS) to confirm the findings that the right prefrontal cortex may be involved in self-face identification (J.P. Keenan, PhD thesis, University at Albany, 1998).

Repetitive TMS provides a 'virtual patient', allowing the induction of temporary inhibition of cortical networks that may be responsible for a given behavior. Occasionally, nature has provided a similar opportunity to study self-recognition in patients who have suffered from brain conditions and traumas. Under the classification of Delusional Misidentification Syndromes are a number of cases in which patients suffer from loss of self-recognition without either misidentification of others (i.e. Capgras Syndrome) or concurrent prosopognosia. Furthermore, within this subset of cases are patients in whom neither severe dementia or other delusions appear with the syndrome of self-image misidentification, and in whom neuropsychological/imaging data are available. The first of these case reports[18] described a woman with right temporal–parietal damage who was able to use a mirror to identify others but who insisted that, when the image in the mirror was her own it was 'an exact duplicate of herself'. A second case[19] was of a woman with right parietal and white matter frontal atrophy, as determined by computed assisted tomography (CAT) and MRI imaging. She could also use a mirror to identify other people but insisted that her own reflection was of a girl who resembled her, but was much younger. Even after coaching, the patient insisted that the image was a little girl. A recent report (N. Breen, unpublished data) of a patient with right prefrontal damage, revealed a similar profile: One of the patients who was able to identify others via use of a mirror insisted that his own image was not his own.

Although these data appear to indicate that self-face processing may be subserved by right prefrontal processes, numerous other findings suggest that this is not the case. First, damage to the right prefrontal cortex rarely leads to a loss of self-recognition. Although there is evidence that damage to the right frontal region will impair a variety of self-processing behaviors and cognitions, there are few cases in which loss of self-face, but not other-face processing, follows such trauma. Second, some of the results may be accounted for by the effects of familiarity, where lateralized differences in prefrontal cortex processing have been found depending on the degree of familiarity of the face[20,21]. Thus, although the study performed by Tong[9] tried to used 'non-familiar' self-face angle presentations, it is possible that familiarity may have an impact on any self-recognition/identification finding. A similar argument can be made for emotionality and intimacy such that both may influence any study of self-processes[22].

Cortical correlates of self

Given these strong reservations, it appears that right prefrontal–temporal regions may be involved in other self-related phenomena. Although it is true that case studies in this field are quite rare, when there is a loss of 'self' processing, such studies that exist indicate that there may be a correlation between right prefrontal damage and self. Hans Markowitsch has described several patients in whom episodic 'personal–autobiographical' memory is disrupted in the absence of other severe cognitive deficits, including other memory processes[23–26]. In these cases, damage to a network involving the right dorsolateral prefrontal cortex, possibly the right polar prefrontal cortex[25] and the anterior temporal regions[24], may lead to impaired autobiographical

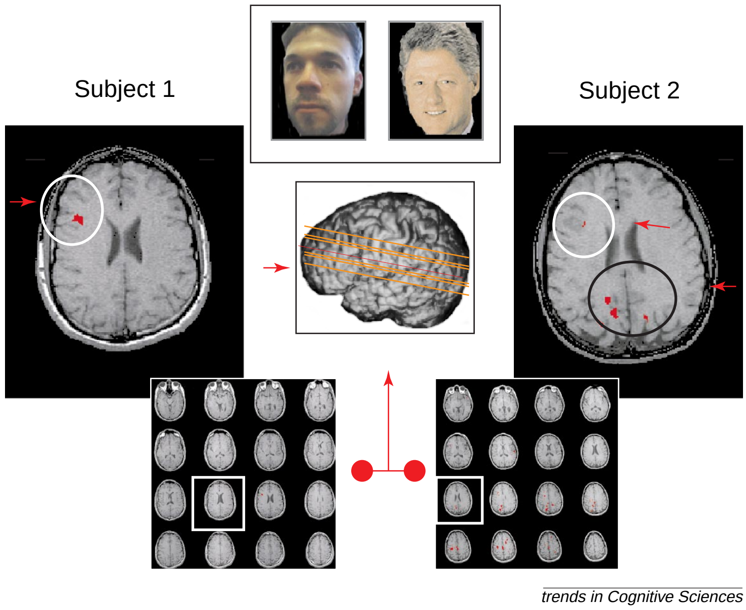

Fig. 2. Cortical activation with self recognition. Neuroimaging using fMRI has indicated that comparing one's own face with other faces may activate regions within the right prefrontal cortex. Presented are the data from two subjects in which viewing of the self-face was contrasted with the viewing of Bill Clinton's face. Activation was found in the right ventral prefrontal region in both subjects, with occipital activation one of the subjects. (Adapted, with permission, from Ref. 17.)

retrograde retrieval. Further, damage to analogous regions on the left side appear to impair knowledge-based memories (e.g. famous events and persons) while sparing retrograde autobiographical memories[26]. Brian Levine has recently reported a similar case in which a patient sustained damage to the right ventral prefrontal region with possible damage to the uncinate fasciculus, a band of fibers leading from the prefrontal cortex to lower limbic regions[27]. This patient exhibited severe autobiographical retrieval deficits. These data map well onto the patients described by Stuss, in whom right prefrontal damage appears to effect personal memories[28].

Neuroimaging in normal populations appears to support these findings. In a PET study, Fink *et al.*[29] compared autobiographical memories with impersonal memories. Personal autobiographical memories, which were presented during scanning, included phrases describing the subject's past such as, 'When you were 15, you took part in a swimming marathon and succeeded to swim 10 miles'. On comparing these sentences with impersonal statements (i.e. autobiographical phrases from another person), it was found that there was significant activation in the right cingulate and prefrontal regions. The regions found active in this study map onto those in patients who have impairment in similar tasks.

Like the evidence presented for self-face recognition and autobiographical memory, seeing one's own name appears to activate frontal regions, as determined in an ERP study[30]. When viewing their own name, rather than names that were not their own, subjects showed a greater degree of activation over frontal cortical regions than more posterior areas (right/left differences were not examined). When laterality is considered, there appears to be a greater right than left activation within the frontal region. Fischler and colleagues[31] used ERPs to examine the possibility that self-referencing may activate different regions of the cortex. They presented subjects with a series of self-referential statements (e.g. their name and their place of birth). Half of the statements, previously provided by the subjects, were true and half were false. It was found that there was greater activation in the right frontal cortex for true statements than for false statements. This difference was not as pronounced in the left frontal cortex.

A recent similar experiment presented subjects with a variety of adjectives during PET scanning.[32] In one phase of the experiment, the subjects had to decide whether the adjective described themselves and respond if it did. In other conditions, the subjects had to decide whether the adjectives described another, famous individual. A series of control conditions were also included. Comparing the 'self' with the 'other' and control conditions, extensive right hemisphere activity was found. Specifically, there was activation in the left and right medial frontal cortex, the right medial frontal gyrus and the right inferior frontal gyrus. The authors concluded that episodic memory retrieval involving the self is signaled by activation in the right prefrontal cortex.

Wheeler and colleagues[33] have attempted to assemble an underlying theory as to the cortical underpinnings of the processing of self-related material. Noting that the term 'episodic' does not specifically describe the cognitive construct of 'self', they proposed the term 'autonoetic consciousness', which may be helpful in describing the 'capacity that allows adult humans to mentally represent and to become aware of their protracted existence across subjective time' (p. 335). This is distinguished from 'noetic consciousness', in which an individual thinks objectively about something they know. Although these terms are quite useful, the authors note that one can be noetically aware about one's self. In other words, one need not be in a state of 'self-awareness' during certain self-related cognitive tasks. The authors speak of a feeling of re-experiencing an event as a critical component for autonoetic consciousness. Given this, which may be viewed as the most precise distinction of 'self' in the cognitive literature, we remain uncertain as to the extent to which subjects in a self-face recognition task are experiencing a state of 'autonoetic consciousness'. The authors note that the capability to 'pass' the Gallup MSR test is a necessary precursor to autonoetic consciousness, although the processes of self-recognition and identification are not identical to autonoetic awareness. Although autonoetic processing appears relevant to autobiographical retrieval and self-evaluation, it is possible that in a rapid self-face identification task, one sees one's own face in a 'noetic', rather than an 'autonoetic' manner. It would appear that this idea needs further investigation before confirmation that self-face processing follows a similar cognitive dimension as other autonoetic experiences.

The possibility that a common neural substrate for self-face recognition or autonoetic consciousness exists is in itself interesting. In terms of self-recognition as indicated by the mirror test, humans and some chimpanzees and orang-utans have made mark-directed responses in front of the mirror (see Box 1). In humans, self-face recognition appears to emerge with a host of other 'higher-order' cognitive processes, at around 18 months of age[34]. It is during this period that, among other processes, the use of self-referential pronouns and self-conscious emotions (e.g. shyness) begin to appear. Although the data are controversial, some have indicated that children with autism[33] and adults with Alzheimer's disease [36] have self-recognition deficits. Further, some have speculated that the possession of autonoetic abilities is a necessary precursor to gaining an understanding of another individual's mental state (see Box 2)[37]. Is it possible that there is a relationship at the cortical level between self-recognition and mental state attribution?

Given these possible directions of research, all of which are being pursued actively, we are excited by the future possibilities. However, it is certainly too early to speculate on the nature of the cortical regions in these (i.e. autism, Asperger's syndrome, Alzheimer's disease) conditions in terms of self. For example, Although some researchers have implied that the deficits within the right hemisphere are related to the symptoms of Asperger's syndrome (a form of autism[38]), it would appear irresponsible to assume that damage to the right hemisphere will result in Asperger's, or that the total of symptoms involved in Asperger's are due to right hemisphere-induced, self-related problems. Deficits of 'self' may play a role in these disorders, which may include abnormalities in right prefrontal function, yet this interplay is probably far from the entire description for any of these diseases.

Conclusion

Elaborating and describing a cohesive model for self-face recognition, or self in general, is at present a difficult task. The evidence to date appears to point in the direction of a right fronto-temporal circuit with possible ucinate fasciculus activation. However, a precise description based on the existing data is difficult and different elements of this complex network are implicated across paradigms and neuroimaging methods. For example, in our own work we have found a general ventral region of the right prefrontal cortex activated for self-faces, with the absence of temporal activity. These data, perhaps due to less emphasis on memory retrieval processing, differ from those reported by other researchers in which the right temporal lobes are highly involved. Further, even though a right frontal network is implicated as being critical for self-face processing, split-brain patients can in fact recognize their own face when the left hemisphere is presented with self-photographs. Instead of a single module theory, it would

Outstanding questions

- What is the precise relationship between self-face recognition and self-awareness or autonoetic consciousness?
- What is the function of a lateralized system for self-directed awareness?
- What are the precise anatomical correlates within the right hemisphere that may subserve self-face recognition, as well as other 'self' related phenomena?
- Do anatomical cortical differences between species translate into differences between self-awareness abilities?

Box 2. Theory of mind and self-awareness

Theory of mind (ToM), is a term given to an individual's ability to accurately represent the cognitive domain of another individual (Ref. a). Although self-awareness may encompass the ability to monitor and accurately describe one's own thoughts, ToM is the ability to do the same with a separate individual (i.e. to evaluate the mental state of another). The two phenomena appear to be related, at least in a correlational manner. For example, it has been found that ToM capabilities emerge after the acquisition of self-awareness. Although the timeline for the acquisition of self-mirror recognition capabilities is approximately 18–24 months (Ref. b), ToM abilities arise at about 36–48 months (Ref. c). Further, this relationship appears to be invariant, such that in almost all cases an individual must possess self-recognition before having ToM abilities.

It is possible that there are similarities between self-related tasks and ToM performance. Right hemisphere disruptions can lead to difficulties in comprehending humor, emotion, nonverbal language concepts, facial expression and social judgement (Ref. d). These attributes are possible indicators of mental state attribution. Anosognosia (in which the patient is unaware of his neurological deficits, such as paralysis of a limb) has been associated primarily with lesions to the right hemisphere (Refs e,f). Interestingly, anosognosia may lead to difficulties in comprehending the deficits of another person. Ramachandran and Rogers-Ramachandran (Ref. g) describe three patients with primarily right hemisphere infarcts as having severe deficits not only in comprehending their own left hemiplegias but also in comprehending paralyses in others. Happe and colleagues (Ref. h) recently found that patients with right hemisphere damage performed significantly less well than left hemisphere patients in ToM tasks. Furthermore, right-hemisphere-damaged patients were worse at identifying the point of a joke when the humor was based on understanding the mental state of the characters. These results are replications of previous studies demonstrating a relationship between right hemisphere damage and deficits in ToM performance (Refs i,j).

In normal subjects, there is less clarity in interpretation of the cortical underpinnings of ToM. Baron-Cohen and colleagues (Ref. k) found right orbito-frontal increases using single-emission computerized tomography (SPECT) when subjects were presented with mental state terms, as compared to non-mental state descriptors. However, both Goel *et al.* (Ref. l) and Fletcher *et al.* (Ref. m) have reported studies in which ToM tasks activate left hemispheric structures preferentially, although activity in the right cingulate and prefrontal medial regions was also increased.

Although speculative, it is possible that there is a cortical relationship between ToM and self-awareness. If self-recognition and other self-related cognitive tasks engage elements of the right prefrontal cortex, it is possible that ToM tasks involve both the left and the right prefrontal regions, with overlap between the two regions demonstrating similarity in the tasks of self-reflection and other-reflection.

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appear that a network involving the right hemisphere activates preferentially for self-related stimuli. Interestingly, in some cases it appears that this network is necessary for certain self-processes, such that damage results in the absence of self-processing. However, in other cases where trauma is sustained within the network, patients have the capability to express, understand, and respond to self-related stimuli.

It is a further leap to assume that self-face processing and autobiographical memory subserve similar cortical regions because they both are 'self' phenomena. Although the data appear to support this notion, within our own studies we are unsure as to the relationship. Although it may be true that ideas and investigations of 'self' are better left to philosophers, we hope that our 'cortical deductive' approach will be of some use. As evidence is gathered suggesting that 'self' across memory, perception, recognition and evaluation activates elements of a common network, researchers are aware that the data are far from complete. It is hoped, however, that modern neuroimaging techniques will continue to be used to address and elucidate these phenomena. Given that self-recognition may be a gateway to self-awareness, it will be intriguing to see if such a process can be defined on a specifically cortical level.

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