Cortical Networks for Visual Self-Recognition

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This paper briefly reviews recent developments regarding the brain mechanisms of visual self-recognition. A special cognitive mechanism for visual self-recognition has been postulated based on behavioral and neuropsychological evidence, but its neural substrate remains controversial. Recent functional imaging studies suggest that multiple cortical mechanisms play self-specific roles during visual self-recognition, reconciling the existing controversy. Respective roles for the left occipitotemporal, right parietal, and frontal cortices in symbolic, visuospatial, and conceptual aspects of self-representation have been proposed.

Keywords: visual self-recognition, fMRI, occipitotemporal cortex, parietal cortex, frontal cortex

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1. Special Mechanisms for Visual Self-Recognition

The ability to recognize oneself visually has been studied with particular interest in its relationship with the concept of self. Evidence for the special cognitive mechanisms underlying this ability has been obtained by observing the behavior of nonhuman animals and human infants in front of a mirror. While animals exposed to a self-image in a mirror first behave as though they are being confronted by conspecifics, chimpanzees [1] and orangutans [2], but not other animals, begin to behave as though they know that the animal in the mirror is their own reflection. A human infant usually starts to show evidence of self-recognition in a mirror at around 20 months of age, which is preceded by recognition of the parents [3]. This evidence suggests that visual self-recognition depends on a special cognitive mechanism attributable to higher cognitive development than the mechanisms for recognizing conspecifics.

Neuropsychological evidence suggests that this special mechanism for visual self-recognition is accommodated in a specific brain network. A patient with an infarction of the left ventral occipital region showed selective impairment in the recognition of her own face [4]. Two recent studies have demonstrated the hemispheric dominance of visual self-recognition [5, 6].

Interestingly, however, the two studies showing hemispheric dominance gave opposite results. Both studies used a morphing technique to “mix” the subject’s own face and the face of a familiar person, and the recognition bias in each hemisphere was examined. Keenan *et al.* [5] presented a morphed face to presurgical patients undergoing an intracarotid amobarbital (Wada) test, and showed that the right and left hemispheres selectively process one’s own face and a well-known face, respectively. By measuring the motor-evoked potential induced by transcranial magnetic stimulation of the motor cortex during face presentation, they confirmed the right-hemisphere dominance of self-recognition in normal subjects by showing higher activity in the right hemisphere than in the left hemisphere during self-recognition. In contrast, Turk *et al.* [6] presented morphed faces to each visual field of a split-brain patient, who showed a recognition bias toward his own face in the left hemisphere and a bias toward a familiar face in the right hemisphere, suggesting an advantage of the left hemisphere in self-recognition.

2. Multiple Brain Networks for Visual Self-Recognition

The controversy over the hemispheric dominance of visual self-recognition would be reconciled if distinct networks in the two hemispheres have different sensitivities to self-images depending on the experimental design. In fact, evidence from recent cognitive neuroscience research suggests that the self-specific process during visual self-recognition is not unitary, but involves multiple independent processes sustained by discrete brain mechanisms [7].

Noninvasive functional brain imaging techniques, such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), have contributed to clarifying the brain mechanisms involved in the cognitive processes related to self-recognition. For example, the lateral parietal and frontal cortices have been implicated in the processing of coincidence between the proprioception of one’s own action and the visual perception of motion (motion–action contingency) [8, 9], which plays a key role in the infantile development of self-recognition in a mirror [3]. Conversely, functional imaging studies have often reported the activation of medial cortical structures, such as the cingulate cortex and medial prefrontal

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cortex, during the processing of self-related (-relevant or -referential) stimuli [10, 11].

In addition, it is interesting to consider cases of demented patients who combed or shaved in front of a mirror, which is regarded as a sign of visual self-recognition in infant and animal studies, but nevertheless did not explicitly recognize their own mirror images [12, 13]. This observation may show a conceptual limitation of assuming a single self-specific process in visual self-recognition.

3. Functional Brain Imaging Studies of Visual Self-Recognition

The assumption of multiple brain networks for self-recognition is congruent with the results of recent functional imaging studies that directly addressed visual self-recognition in which multiple cortical areas were activated for recognition of the subject's own face [14–19]. The results of these studies, however, were not very consistent, which questions the reliability of the results and their validity as evidence of multiple self-recognition networks. This inconsistency in the results may at least in part stem from technical difficulties specific to the functional imaging study of visual self-recognition. Three factors affecting this issue are summarized: neural adaptation, individual differences, and self-specificity.

Neural adaptation: The detection of faint signals induced by the cortical neural response requires the measurement of repeated (normally tens of times) execution of the same cognitive task in each subject. Since the repeated processing of the same stimulus may cause neural adaptation, which causes the signal to decrease [20], a different stimulus is presented in each trial when studying other cognitive domains. This technique can be only partially applied for visual self-recognition because the identity of the presented person cannot be varied. Therefore, the number of repetitions of stimulus presentation may influence cortical activation.

Individual differences: Functional imaging studies usually generalize the results to a population based on statistical inference over a large number of subjects. The large number of subjects not only increases the statistical sensitivity, but also reduces the risk that the results reflect idiosyncratic effects of a specific subject. Nevertheless, the numbers of subjects tend to be small in studies of visual self-recognition, particularly in early studies in this field. This is presumably due to the larger amount of work involved in stimulus preparation for visual self-recognition experiments compared to other experiments; while one stimulus set is applicable to all of the subjects in experiments examining most other cognitive domains, visual self-recognition studies require preparing pictures of the particular subject, as well as those of a familiar person (see below), for each subject. The small number of subjects is obviously problematic, particularly when examining the sociobehavioral aspects of brain function; considering their large individual differences, this drawback will obviously result in unstable results regarding the intersubject statistical inference due to idiosyncratic effects.

Self-specificity: In functional brain imaging studies, successful assignment of a specific cognitive process to the detected cortical network depends on the appropriate contrasting of task conditions. In studies of visual self-recognition, it is particularly important to control the effect of person-familiarity because the self is likely to be highly familiar, while the familiarity per se is obviously nonspecific to the self. In addition, the effect of person-familiarity on cortical activation is thought to be multifactorial [21]. Accordingly, self-specificity is not assured by comparing a single familiar face because it is impossible to control all of the factors related to person-familiarity.

Regarding these three issues, the fMRI experiment of Sugiura *et al.* [15] was the most carefully designed to date. Relatively few stimulus repetitions (6) and a large number of subjects (i.e., 34) were used to reduce the adverse effects related to neural adaptation and individual differences. To address self-specificity, two personally familiar faces with different degrees of familiarity were presented, in addition to the self face and a control face (a pre-learned face of an unfamiliar person), and the effect of familiarity was eliminated by excluding those areas that showed differential activation between the two personally familiar faces. Two striking results were found (Fig. 1). First, after carefully reducing the possible idiosyncratic and familiarity effects, self-specific activation was still observed in both hemispheres, the left ventral occipitotemporal cortex and the right parietal and frontal cortices, confirming the multiple self-recognition networks. Second, the temporoparietal junction in both hemispheres and the left anterior temporal cortex were activated for familiar faces, but not for the self face, which suggests that visual self-recognition is also special in the sense that it does not rely on familiar-face recognition processes.

These results resolve the controversy in the hemispheric dominance of visual self-recognition [5, 6]. Since the Wada test primarily anesthetizes areas in the middle cerebral artery territory, the procedure used by Keenan *et al.* [5] would have affected the right parietal and frontal cortices, but not the left occipitotemporal cortex, which is in the posterior cerebral artery territory. In addition, it is very likely that the results were affected by the anesthesized left temporoparietal junction and anterior temporal cortex, which are responsible for the recognition of familiar faces. The measurement technique used in their second experiment was sensitive to the excitability of the corticospinal motor system. Therefore, their results should reasonably have reflected the activity of the right parietal and frontal cortices, which partially overlap the motor system. Similarly, it now appears no longer meaningful to conclude that a left-hemisphere advantage exists based on the results of Turk *et al.*'s study [6]. Each stimulus used in their experiment involved competition between one's own

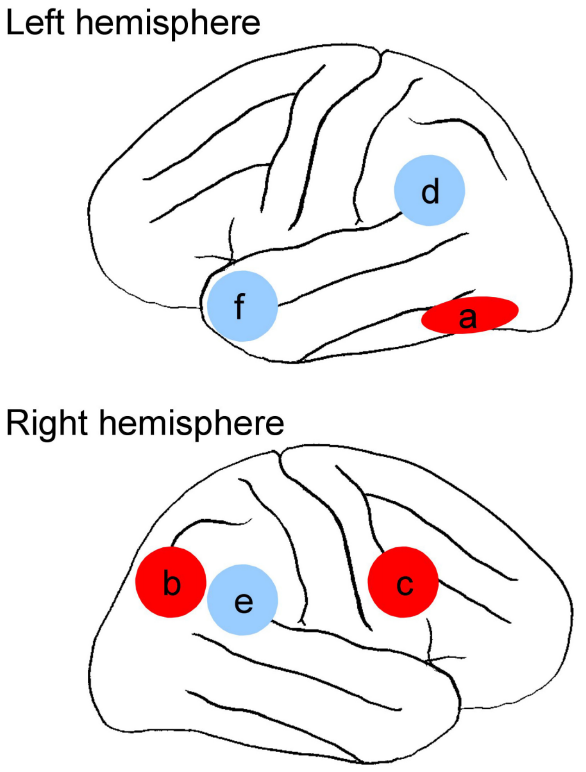

Fig. 1 The results of Sugiura *et al.* [15] are shown schematically. Activation specific to the subject's own face (red) and that specific to familiar faces (blue) occurs on the lateral surface of the left and right hemispheres (top and bottom, respectively). **a** left occipitotemporal cortex, **b** right parietal cortex, **c** right frontal cortex, **d** left temporoparietal junction, **e** right temporoparietal junction, and **f** left anterior temporal cortex.

and a familiar face; thus, they compared the balance of sensitivity between the network for self-recognition and that for recognition of a familiar face between the hemispheres, rather than the sensitivity of the network for self-recognition per se. This fact should now be emphasized considering the marked difference in the organization of face-recognition networks for both one's own face and familiar faces between the hemispheres.

4. Explanations of the Self-Specific Networks

Multiple areas that selectively process a specific category of visual stimulus, such as the face [22, 23], human body [24], or a scene [25], have been identified in the occipitotemporal cortices. Self-specific activation in an occipitotemporal region suggests that one's own face is processed as an independent category from other familiar or unfamiliar faces. The location of the self-specific activation is close to that of the activation that occurs when reading a word or word-like stimulus [26]; this area is sometimes called the visual word form [27] or letter-specific [28] area. Sugiura *et al.* [15] hypothesized that this area processes the self face as a symbol, based on the known role of this region in letter processing and because one's own face shares an attribute with symbols in that it carries a specific sociobehavioral meaning independent of context. This argument was supported in a subsequent fMRI study by Sugiura *et al.* [16] in which self-specific activation was greater for a face picture than for a body picture; this is because one's own face as a symbol is usually presented as a single image, such as in an identification card, rather than as a part of the whole body.

In contrast, the self-specific activation in the right parietal and frontal cortices reminds us of the involvement of this cortical network in processing motion–action contingency [8, 9]. While the importance of this process in developing the ability to recognize oneself in a mirror is demonstrated by the observation that children recognize themselves in a mirror or on live video (motion and self action are contingent) before they recognize themselves in a photograph or a recorded video (motion and self action are not contingent) [3], the "regression" of visual self-recognition in the opposite sequence has been observed in dementia [29], suggesting that this mechanism continues to play a role in visual self-recognition throughout one's life.

In a subsequent fMRI study, Sugiura *et al.* [16] obtained evidence that the right parietal and frontal cortices are functionally independent. An analysis of functional connectivity in the intersubject variability in activation [30] suggested that the right parietal cortex is functionally connected to other posterior cortical areas and that the interaction of the motion in the image and the subject was observed in the self-specific activation. Furthermore, the right frontal cortex is connected with medial frontal regions functionally and individual differences in self-specific activation are observed during the recognition of faces. The results led the authors to postulate that the parietal and frontal cortices play roles in visuospatial and conceptual self-representations, respectively.

5. Face-Recognition Mechanisms Irrelevant to Self-Recognition

It is important to note not only the processes on which visual self-recognition depends, but also those on which visual self-recognition does not depend. The anterior temporal cortex and temporoparietal junction are activated during the recognition of familiar faces, but not during recognition of one's own face [15]. These areas play critical roles in the multimodal processes of person identification [21] and the inference of the intention and belief of others (mentalization) [31]. These facts suggest that face recognition involves not merely access to the memory trace of a face or person, but that the perception of person-related information may automatically prepare one for social interaction with that person. This interpretation is feasible, since on encountering a familiar person, we can determine the attitude toward this person simultaneously with the identification. This account is plausible evolutionally, considering the importance of successful social interaction in survival for humans.

In this sense, one of the most important characters of the self may be the lack of a need for social interaction. Then, how is visual self-recognition advantageous for our physical or social survival? It would be promising to address adaptive accounts for the self-specific mechanism in future studies.

6. Conclusion

While a unitary mechanism for the self has been assumed based on behavioral and neuropsychological observations, evidence from functional imaging studies suggests the involvement of multiple self-specific mechanisms. Although our understanding of these self-specific mechanisms is far from complete, recent fMRI studies of visual self-recognition have suggested roles of the left occipitotemporal, right parietal, and frontal cortices in the symbolic, visuospatial, and conceptual aspects of self-representation, respectively. Future research should examine the socially adaptive aspects of these mechanisms.

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