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Neuroimaging studies on recognition of personally familiar people

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1. ABSTRACT

From an evolutionary viewpoint, readiness to engage in appropriate behavior toward a recognized person seems to be inherent in the human brain. In support of this hypothesis, functional neuroimaging studies have demonstrated activation in regions relevant to relationship-appropriate behavior during the recognition of personally familiar (PF) people. Recognition of friends and colleagues activates regions involved in real-time communication, including the regions for inference about the other's mental state, autobiographical memory retrieval, and self-referential processes. Recognition of people related by romantic love, maternal love, and lost love induces activation in regions involved in motivational, reward, and affective processes, reflecting behavioral readiness for mating, caretaking, and yearning, respectively. The involvement of motor-associated cortices during recognition of a personal enemy may reflect readiness for attack or defense. Self-recognition in a body-related modality uniquely activates sensory and motor association cortices reflecting the sensorimotor origin of the bodily self-concept, with social cognitive processes being suppressed or context dependent. Issues and future directions are also discussed.

2. INTRODUCTION

As social animals, we interact with many people in daily life. These may be familiar, including friends, loved ones, coworkers, and enemies, or unfamiliar individuals. Appropriate behavior toward an individual depends on relationship involved. It is obviously advantageous for our social survival to be ready for appropriate behavior as soon as a person is recognized. From an evolutionary viewpoint, it seems plausible that such behavioral readiness is one component of the person-recognition mechanism in our brain. This assumption is congruent with our daily experience: when we see a person, we usually adopt an appropriate attitude toward that person without consciously thinking over the relationship. When we see a friend, we are ready for friendly greeting behavior, usually without strategic behavioral planning, to take advantage of that friendship. A person who is in love may automatically become euphoric on recognizing the partner and focus their attention intensely on the partner. On encountering a person whom one strongly dislikes, one may immediately become aggressive or attempt to avoid being seen with that person. The speed and automaticity of behavioral selection and its likely survival advantage suggest that such processes of behavioral readiness are inherent in the person-recognition process in the brain. This review article addresses the

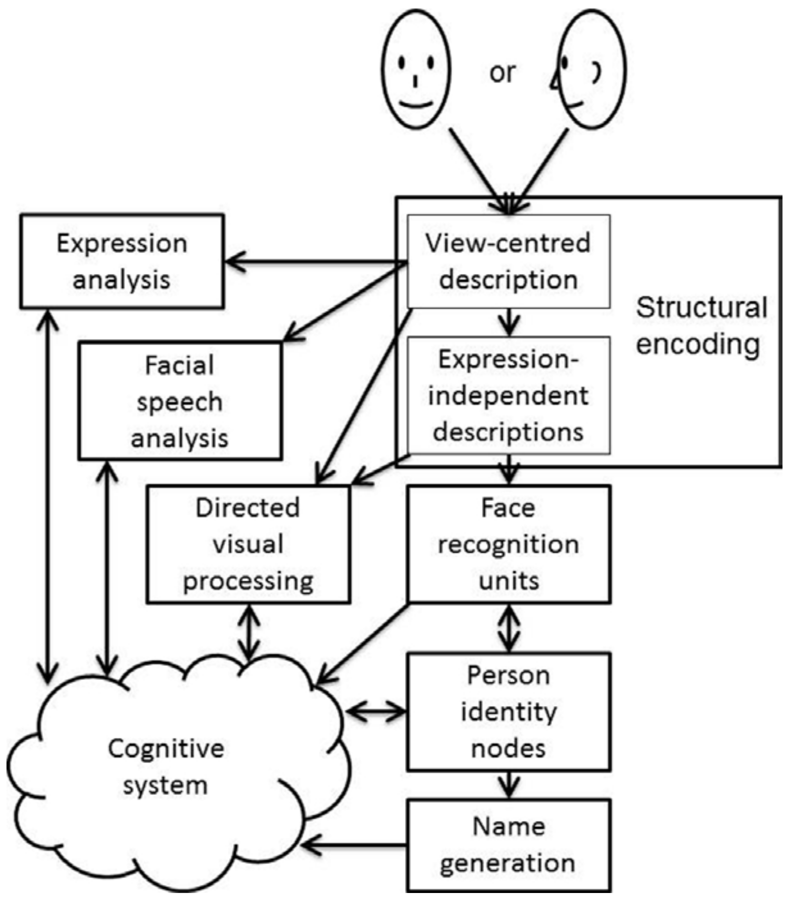

Figure 1. A cognitive model of face recognition. Adapted with permission from ref. (1).

available neuroscientific support for this idea by focusing on findings from functional neuroimaging studies on the recognition of different types of people.

Discussion of the process of behavioral readiness from the viewpoint of a cognitive model of person recognition has been controversial. In a classical model of face or name recognition (1-3), the key process of person recognition is activation of a person identity node (PIN), which is assumed to serve as a gateway from modality-specific perception (e.g., a face or name) to the representation of amodal person-specific information. Furthermore, such information has often been assumed to constitute semantic knowledge of a person, and the role played by behavioral readiness is largely ignored or placed into a black box termed the cognitive system (Figure 1). This neglect of potential behavioral readiness processes is probably because this research field was led by psychologists who were interested in how our brain performs in face or name recognition tests and how this ability is lost in patients with brain damage (1-3). In this type of research, the targets of recognition were typically famous people. However, this is a class of people only very recently added to our recognition repertoire with the development of mass media. With famous people, we are usually exposed to rich information in the media, but we rarely have experiences or prospects of direct social interaction with them in real life. Famous people, therefore, typically activate rich semantic knowledge but are unlikely to induce behavioral readiness.

In terms of those with whom we have real-life interactions, *i.e.,* personally familiar (PF) people, the potential relevance of behavioral readiness to the recognition process has previously been suggested. This was largely based on observation of a patient with Capgras delusion, who had intact face recognition ability but who claimed that a specific PF, usually a loved one, was an imposter and showed no autonomic response (*e.g.,* skin conductance response). On the one hand, it has been considered that the Capgras delusion is attributable to impairment of the affective response toward that person or a covert route of face recognition process (4, 5) in a dual-route hypothesis (6). The dual-route hypothesis assumes that face recognition has both overt and covert routes. The former corresponds to the classical conscious recognition process, and the latter is assumed to be an affective process reflected in the autonomic response. On the other hand, a two-factor hypothesis has assumed that delusional phenomena, including the Capgras delusion, require the failure of two serial processes: an anomalous belief caused by the failure of a perceptual process (the first factor) and a failure to correct the false belief thus generated (the second factor) (7). Thus, a supervisory process, such as belief evaluation (the second factor), has been assumed to be critical for correct person recognition. One author has considered the first factor egocentric person representation (*e.g.,* personality, belief, and thoughts) implemented by mind-reading (8).

Early neuroimaging studies of person recognition predominantly addressed the recognition of famous people (9-12). PF people have rarely been used in neuroimaging experiments. The first reports of neuroimaging studies employing PF faces appeared in 2000. The experiments used the faces of colleagues (13), of lovers or friends (14), or of subjects themselves (15, 16).

The increase in the number of neuroimaging studies examining the recognition of PF people over the last decade may reflect three factors. The first is growing interest in social cognitive processes in the human brain, as exemplified by neuroimaging studies on the theory of mind (17, 18) and the mirror neuron system (19, 20). With the heightened interest in the mechanism underlying our sophisticated social interaction, it is natural to address questions regarding how we prepare for different socially adaptive behavior toward different PF people. The second factor is a shift in neuroimaging technique from positron emission tomography (PET), which uses intravenous infusion of radioactive water, to functional magnetic resonance imaging (fMRI). This allowed a wide range of non-medical researchers, including social psychologists, to use neuroimaging techniques for purposes that have little possibility of immediate clinical benefit. Finally, the accumulation of knowledge about the functional anatomy of the human brain, particularly in the social cognitive and affective domains, has made it reasonable to speculate on the cognitive processes that occur during recognition of PF people based on activation. Although confidence in such a 'reverse inference' is undisputedly limited, this is a valuable source of a novel hypothesis on what cognitive processes should be tested, given the appropriateness of the task and the abundance of evidence on functional anatomy (21, 22).

In this paper, we review a decade of functional neuroimaging studies on the recognition of different types of PF people. We focus on activation associated with specific categories of PF people to assess whether such activation can explain behavioral readiness specific to such people. The activation of behavior-relevant cognitive or affective systems during mere exposure in the scanner to stimuli related to these PF people, *i.e.*, without any possibility of actual social interaction, suggests that behavioral readiness is an inherent process in person recognition. Our aim is not to identify behavioural readiness with a person recognition process or a sense of person familiarity but to suggest that automatic recruitment of behavioral readiness during recognition is an inevitable feature of person recognition in terms of behavior or ability.

3. DIFFERENT CATEGORIES OF PERSONALLY FAMILIAR PEOPLE

There are many different types of PF people. Some of these who are in particularly intimate relationships, such as family members and romantic love partners, are often dealt with as unique categories. Several studies have dealt with PF people by excluding or failing to discriminate among unique categories of PF people; here, PF people exemplified by friends, colleagues, and mere acquaintances are termed common PF people. Neuroimaging studies addressing common PF people often deal with their social and affective significance or relevance to autobiographical episodes by comparing activation with that in response to famous people. In contrast, studies that address unique categories of PF people have compared activation with that in response to common PF people to control for unique attributes of this category of PF people. The recognition modality was predominantly a face for all categories of PF people, although a written or spoken name or a voice has sometimes been used.

3.1. Common PF people

Early studies dealt with common PF people as an example of familiar people, comparing activation against that for unfamiliar people. In a few PET studies, activation of the right temporal pole was reported during familiarity judgment tasks among the faces of colleagues and unfamiliar faces relative to that during control tasks with unfamiliar faces only (13, 23). Other studies using fMRI indicated activation of the posterior cingulate cortex (PCC) as subjects passively viewed the faces or heard the voices (24) or simply heard the spoken names (25) of friends or relatives in contrast to those of unfamiliar people.

Later studies addressed the social-cognitive, affective, and autobiographical retrieval processes specifically recruited during recognition of common PF people by comparing activation against that for famous people. Some studies used faces (26, 27), and others used names (28, 29). Another study compared the voices of friends or colleagues with those of subjects (30). Differential activation was commonly identified in several cortical regions, including the PCC or adjacent precuneus, inferior parietal lobule (IPL), posterior part of the superior temporal sulcus (pSTS) or temporoparietal junction (TPJ), and anterior temporal cortex (ATC), including the temporal pole (Figure 2). Studies that used faces also identified differential activation of the medial prefrontal cortex (MPFC) encompassing the anterior cingulate cortex (ACC) and the paracingulate cortex (26, 27).

These cortical regions overlap with regions implicated in real-time social interaction (31-33), or more specifically, in the inference of the mental state of another (*i.e.*, in a theory of mind or mentalizing) (17, 18), in retrieval of autobiographical memory (34), and in self-referential processes (35, 36); these processes have recently been proposed to share common components supported by these regions (37, 38). These observations are consistent with the assumed involvement of social-cognitive or autobiographical retrieval processes in behavioral readiness for PF people during recognition.

3.2. Love

People with whom one is in love are a prominent example of a unique category of PF people. The cortical

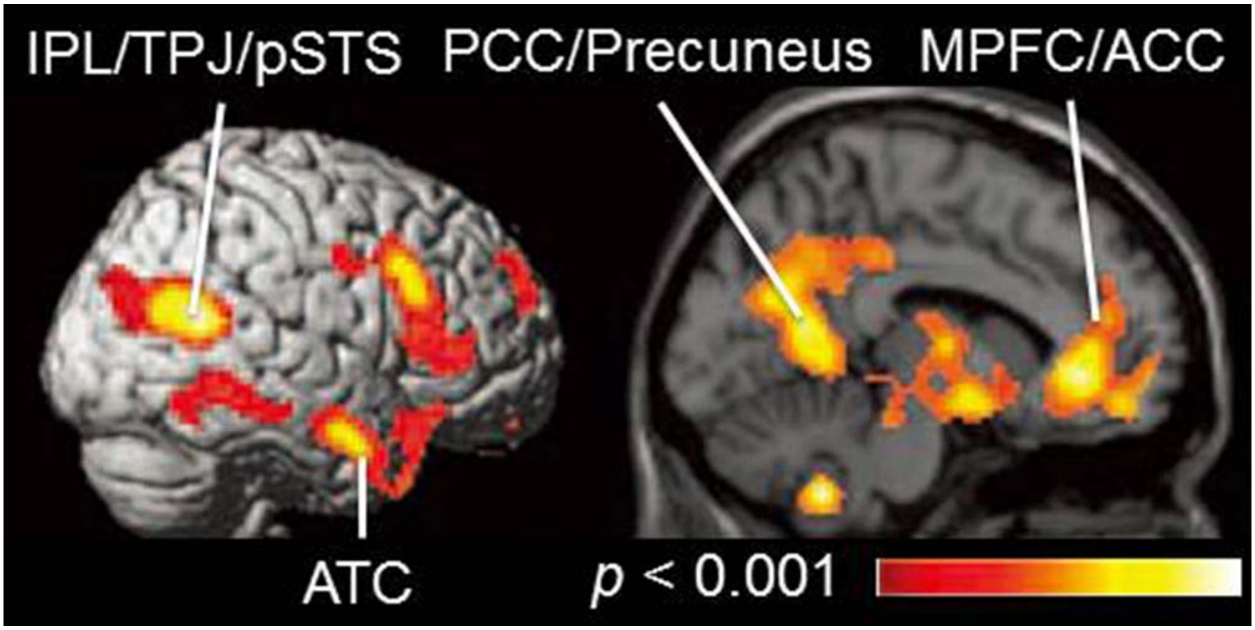

Figure 2. Typical activation pattern specific to common PF people. Activation during face recognition comparing common PF people with famous people. IPL: inferior parietal lobule; TPJ: temporoparietal junction; pSTS: posterior part of the superior temporal sulcus; ATC: anterior temporal cortex; PCC: posterior cingulate cortex; MPFC: medial prefrontal cortex; ACC: anterior cingulate cortex. Adapted with permission from ref. (27).

responses for people in different types of love, including romantic love, maternal love, and lost love, in contrast to that for common PF people has been studied extensively.

3.2.1. Romantic love partner

Among the classes of unique PF people, a romantic love partner was the earliest to be explored for unique neural activation (14). Activation while viewing the face of a romantic love partner was compared with that while viewing a friend of the same gender as the partner (*i.e.*, common PF person) to identify the neural correlates of intense romantic love (14, 39-42). This complex sentiment is characterized by euphoric, erotic, and craving sentiments, as well as focused attention, all of which seem to be relevant to readiness for human mating behavior (43).

Indeed, activation specific to a romantic love partner was observed in the caudate, ventral tegmental area (VTA), and orbito-insular cortex, which are involved in motivational, reward, and affective processes (14, 39-42). Activation has also often been reported in the posterior part of the medial temporal region and cerebellum (Figure 3a) (14, 39-42).

In these studies, a face was presented for more than 10 s to allow subjects to be immersed in romantic love sentiment. This experimental setting was different from the relatively short presentation duration in the setting for other categories of PF people. However, the activated regions were well replicated in a study in which the written name of a romantic love partner or friend was presented subliminally using a backward masking procedure (44). Therefore, the findings seemed to be independent of the recognition modality, presentation duration, and awareness of love sentiment. The findings were also shown to be essentially independent of the phase of love (*i.e.*, early or late) (14, 39, 40), sexual preference (42), and culture (41).

The subjective strength of love sentiment, measured using the Passionate Love Scale (45), has been reported to be correlated with the degree of activation; however, correlations were reported in different cortical regions across studies, such as in the right caudate (39, 40, 46) and the left angular gyrus (44, 47). Correlations with activation have also been reported for many other parameters related to the relationship, such as the duration of romantic love (39, 40), sexual measures (39, 47), and personality traits (41). Furthermore, the findings remain sporadic and must still be replicated.

Deactivation during recognition of a romantic love partner has also been reported in some areas involved in social-cognitive processes, such as the right IPL, pSTS, and medially in the PCC and MPFC (14, 42), and in evaluative processes, such as the amygdala and orbitofrontal cortex (OFC) (14, 40, 41, 46). These findings were not observed for a long-term romantic love partner (39). The observed deactivation of these regions appears to reflect the tendency toward focused attention on a romantic love partner, particularly in the early phase of love.

3.2.2. One's own child

The neural response during recognition of one's own child has been examined with regard to the neural correlate of maternal love, which is characterized by readiness for care-taking behavior.

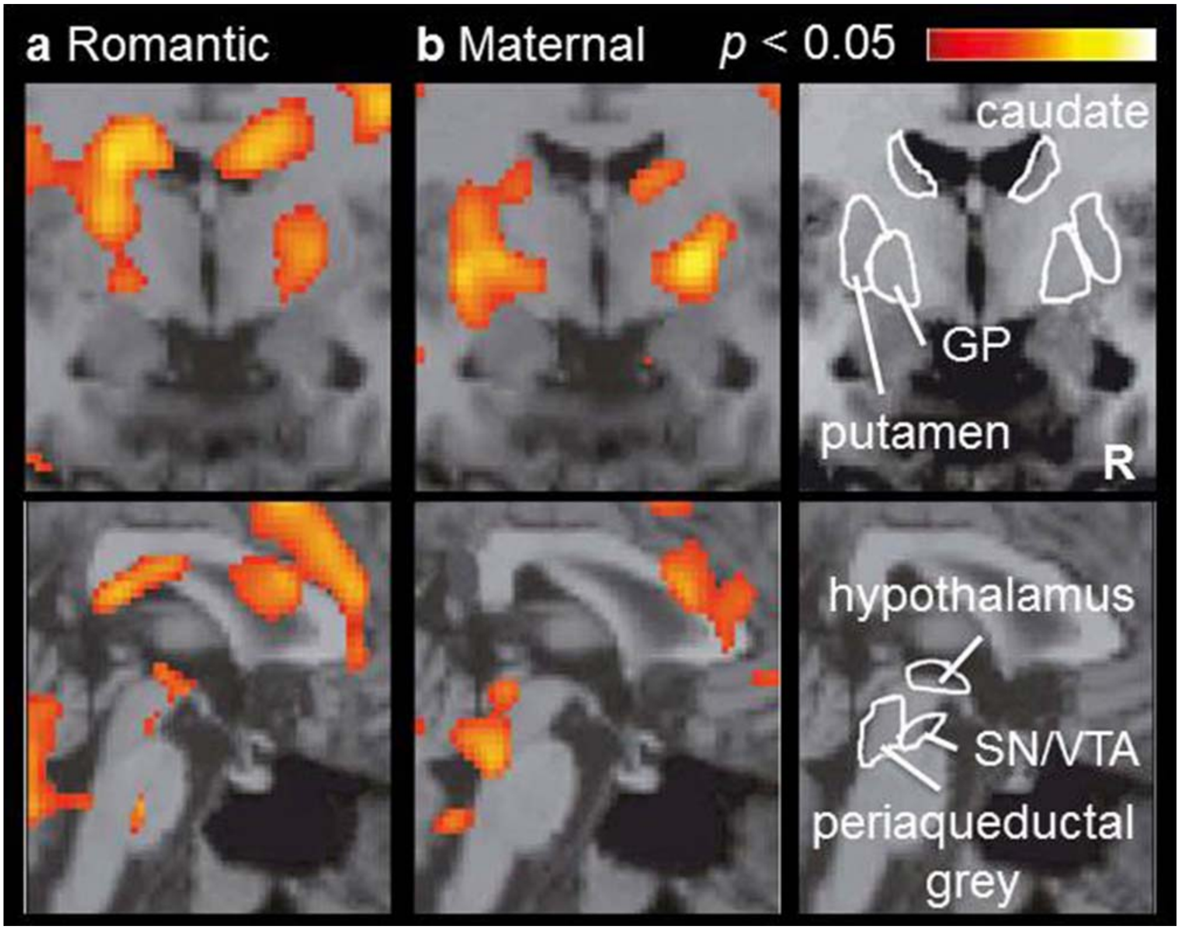

Figure 3. Typical activation patterns specific to romantic love (a) and maternal love (b). Activation during face recognition comparing a romantic love partner and an emotionally neutral friend of the opposite sex (a) and that for a comparison between one's own child and a familiar other child (b). Left panels show structures. GP: globus pallidus; SN: substantia nigra; VTA: ventral tegmental area. R: right. Adapted with permission from ref. (48).

Activation while viewing one's own child's face compared with that of another PF child has been examined in mothers (48, 49) and fathers (50). Several studies have also examined the mother's neural response to her own child relative to that to an unfamiliar face without controlling for the effects related to familiarity (51-53). Activation unique to one's own child's face relative to a common PF child's face has been reported in many cortical and subcortical areas that partially overlap with those for romantic love. Cortical activation was typically observed in the MPFC, bilateral precentral sulcus (PreCS), or posterior part of the middle frontal gyrus (MFG), left inferior frontal gyrus (IFG), bilateral insula, and visual cortex, including the fusiform gyri. Subcortically, the thalamus, lenticular nuclei (sometimes labeled as globus pallidus (GP), putamen, or ventral striatum), cerebellum, and midbrain (labeled as VTA or substantia nigra (SN)) were activated (Figure 3b).

Among these areas, the lenticular nuclei may be characteristically involved in recognition of one's own child, and play an important role in attachment. Activation of a region labeled GP was identified as specific to maternal love in comparison with romantic love (48), and this activation was modulated by administration of oxytocin to fathers (50). A region at a similar location, but labeled as the putamen, showed a higher response to the happy compared to the sad face of one's own child (53). Other activated regions were highlighted in some studies but not supported by others (48-53).

3.2.3. Lost love

Another important aspect of love highly relevant to PF people is loss. Loss of a loved one may cause depression, which can lead to suicide, and emotional regulation is required to cope with this negative affective state.

Subjects who had recently been rejected by a partner with whom they were still in love were scanned while viewing the face of their ex-partners. Relative to viewing the face of an emotionally neutral male friend, activation was observed in the ventral striatum with peaks in the nucleus accumbens (NA), putamen, and ventral GP, as well as in the regions activated for a partner with whom one is happily in love (46).

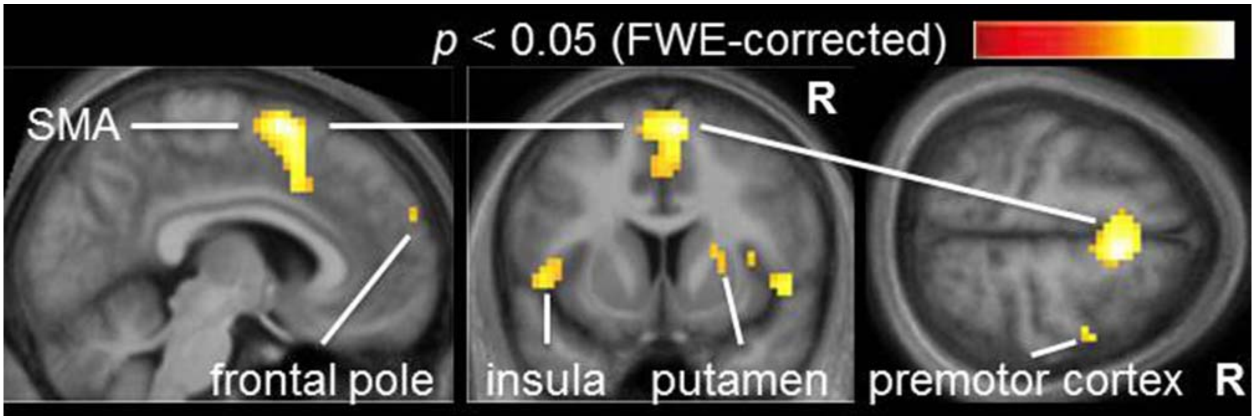

Figure 4. Activation during face recognition comparing a hated person and a neutral person. SMA: supplementary motor area. R: right. Adapted with permission from ref. (60).

Activation of the ventral striatum may reflect the characteristic affective or behavioral response to the loss of a loved one. This region showed significantly higher activation for a rejected partner than for a partner happily in love (46). These findings were congruent with higher activation of this region during complicated grief, also known as chronic, pathological, or traumatic grief, compared with that during non-complicated grief while viewing the face of a deceased close relative (54). The degree of activation was positively correlated with subjects' self-reported yearning (54). The finding is in line with the assumed role played by this region in weighing the motivational relevance of upcoming stimuli, irrespective of valence. Recent neuroimaging studies have shown that this region responds during anticipation of monetary loss in a gambling task (55) and during experience of aversive stimuli (56), as well as during those of reward.

The correlation between activation while viewing the rejecting partner and the length of time since the break-up was significantly positive in the left ACC and negative in the bilateral insula and right ventral putamen, probably reflecting successful emotional regulation over time (46).

3.3. Kin

A few studies have addressed activation specific to the faces of family members, such as activation specific to siblings compared with that to a friend or the self (57), comparisons among activations to the father, mother, partner, and self (58), and comparison of activation to the father and to the mother (59). While many regions were reported to show differential activation for many different contrasts, accompanied by interesting interpretations, the findings require future replication considering the weak statistical thresholds and small numbers of subjects included in the studies or the absence of direct comparison among categories of PF people.

3.4. Enemy

An enemy is considered as someone toward whom we hold negative social attitudes and in response to whom we prepare for fight-or-flight behavior. Two recent neuroimaging studies indicated activation in similar areas in response to an enemy.

Subjects who expressed a strong dislike of an individual, such as an ex-lover or a competitor at work, were selected and scanned while viewing the face of this personal enemy (60). Activation was significantly higher in the medial frontal regions likely corresponding to the supplementary motor area (SMA), bilateral premotor cortices, frontal pole, bilateral insula, and the right putamen compared with activation while viewing a control PF face (Figure 4). Activation in the medial frontal, right premotor, and insular regions was positively correlated with self-rating of the degree of dislike. Differential activation in a largely overlapping set of regions was reported when activation while viewing the face of a presidential candidate belonging to an opposing political party was compared with that while viewing the candidate belonging to the party to which the subject was registered (61). Although presidential candidates are "famous," an interaction in terms of voting and policy making may make their relationship "reciprocal" and thus make candidates PF, at least for enthusiastic voters. It has been suggested that the involvement of motor-associated cortices reflects the mobilization of the motor system for possible attack or defense, and that of the insula and putamen reflects negative affective responses such as disgust and fear (60).

3.5. Self

The self may be the most familiar but most atypical class of PF person. Self-recognition is unique in various ways that differ according to modality or context. Viewing one's own face or body is a special experience in that it uniquely belongs physically to oneself, it uniquely lacks direct relevance to social interaction, and yet it has social significance in how it appears in the eyes of others. Hearing one's own name called may signal others' interactive intention. Consistent with such modality- and context-dependent uniqueness, self-specific activation is highly dependent on recognition modality and task context.

3.5.1 Bodily self

Classical neuroimaging studies used the self-face as a probe for neural correlates of self-concept (15, 62-64) or merely as a very conspicuous familiar face (16). The reported self-face-specific activation was inconsistent,

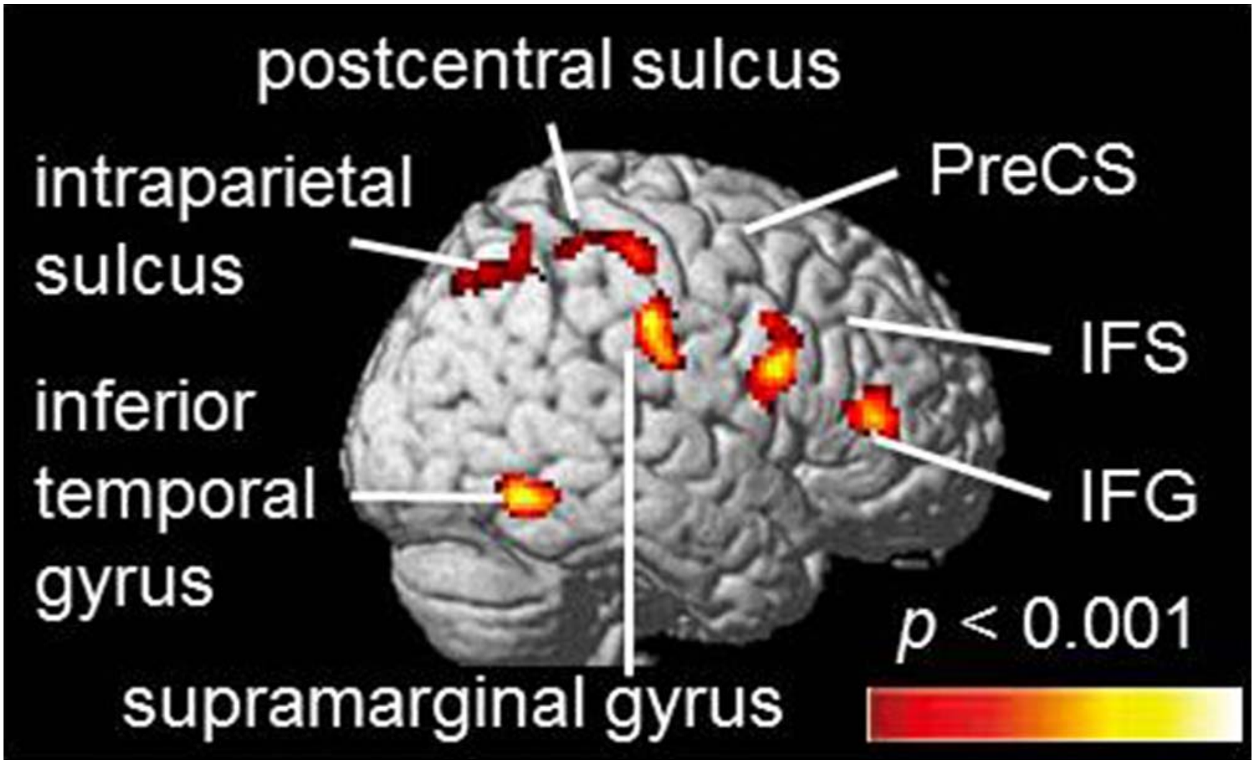

Figure 5. Typical activation pattern specific to the bodily self. Activation during face recognition comparing the self and a friend under conditions without a distracter (Low). PreCS: precentral sulcus; IFS: inferior frontal sulcus; IFG: inferior frontal gyrus. Adapted with permission from ref. (73).

probably due to limitations in the number of subjects, experimental design, and weak statistical thresholds in these studies.

Activations specific to bodily self-recognition (*i.e.*, face, body parts) reported in later studies were largely consistent with one another and congruent with the suggestion that the uniqueness of the bodily self is grounded in sensorimotor experience. That is, activation was largely observed in sensory and motor association cortices, which reasonably accommodate the internal schema of one's own body or the association of one's own action command and expected sensory feedback, as formulated in the forward model (65, 66). When review was limited to studies that used adequate numbers of subjects (>10), an event-related design, comparison with a common PF face, and a moderate statistical threshold ($P < 0.001$, uncorrected), activation for the self-face or self-body presented as photographs or recorded video was consistently identified in the cortex along the entire intraparietal sulcus, in the posterior part of the inferior temporal gyrus, in the supramarginal gyrus (extending into the depth of the postcentral sulcus), in the PreCS, and in the IFG (extending to the inferior frontal sulcus (IFS)), mostly in the right hemisphere (Figure 5) (67-75). Illusory sensation of ownership of an artificial hand induced by synchronized multimodal stimulation (*i.e.*, the rubber hand illusion) is also known to activate overlapping bilateral cortical areas (76, 77). It was suggested that self-face-specific activation in these regions is context dependent in that it was diminished when many different faces were included as distracters (73). With the exception of the anterior part of the IFG/IFS, these activated areas are parts of the sensory and motor association cortices; it is interesting to note that many of these areas coincide with those receiving vestibular input (78, 79).

The role of the right IFG/IFS in self-recognition may be amodal. Activation of this region was also demonstrated for recognition of a recording of one's own voice relative to the voices of other familiar people (30, 68). Activation in part of this region has been shown to be negatively correlated with the degree of embarrassment during viewing of one's own face (80). Activation was, however, missing for the recognition of the written (71, 81) or spoken self-name (82, 83), limiting the amodal nature of the role of this region in self-recognition.

Activation of the insula has often been reported for the sensation of self-agency in action while moving and viewing one's own hand or a manipulable object on a monitor relative to self-agency violated by modulation of visual feedback (84-87). Self-recognition-specific activation of this region was also reported in a few face-recognition studies (15, 62, 67).

3.5.2. Social cognitive process

Many neuroimaging studies of self-recognition have shown that some regions involved in social cognitive processes, specifically the pSTS/TPJ, are deactivated during self-face or self-name recognition (67, 68, 71, 73, 74) relative to PF face or name and unfamiliar face or name; pSTS/TPJ was activated when the presented hand action lost self-agency (86, 87).

Although a few neuroimaging studies have described activation of regions (such as the MPFC, PCC, and pSTS/TPJ) involved in social-cognitive processes during recognition of the self-name called by another person, the comparisons conducted in such studies used unfamiliar names (82, 83). A recent study that compared self and PF names found no significant differences during either visual or auditory recognition (81).

The ventromedial prefrontal cortex (vMPFC) and PCC have often been suggested to be involved in self-referential processes (35, 36). However, these regions were shown to be activated during recognition of the face, written name, and spoken name of both the self and common PF people relative to unfamiliar people (71, 81). Activation of sub-regions of these areas was shown to be self-face specific when distracter faces were manipulated, suggesting the comparative nature of the social value of the self-face (88). Activation in part of the vMPFC known to represent the values of competing options (89-91) and some left PCC sub-region were enhanced in a self-face-specific manner when many different faces were included as distracters (73). In young female subjects, particularly in those with high self-esteem, activation in the right homolog of this PCC sub-region and VTA were enhanced in a self-face-specific manner when the self-face was relatively attractive in contrast to unattractive distracter faces (69).

4. PERSPECTIVES

Several important issues must be addressed to clarify the entire picture of the behavioral readiness process in PF people recognition and to make these findings useful for application in other basic or clinical research fields. Here, we focus on five issues: the potential modality dependency of category-specific activation; several methodological caveats; attempts to experimentally create virtual PF people; relevance of the sense of familiarity; and clinical applications permitting the understanding or diagnosis of mental disorders based on activation during recognition of PF people.

4.1. Recognition modality

Neuroimaging studies on the recognition of PF people have usually used faces or names, and occasionally voices, as stimuli. The findings are often assumed to be independent of recognition modality. However, dependence or independence of a modality is important when the aim is to understand how behavioral readiness is linked with perceptual processes, how such links evolved, and how the links might be behaviorally advantageous. A classical cognitive model of person recognition assumed that access to person-specific information is basically multimodal, *i.e.*, it is accessed both from face and name *via* a common entrance node (1-3). Indeed, activated regions for common PF people (26-29) or a romantic love partner (14, 39-42, 44) appear to largely overlap between face and name recognition. In contrast, in self-recognition, activation of the sensory and motor association cortices is unique to body-related stimuli (71).

The modality dependence of activation during PF people recognition has been reported only for self-recognition (71). Furthermore, recognition through modalities other than face, name, or voice has rarely been examined. We may recognize some PF people by their smell, the sound of their gait, or the kinematic characteristics of their actions. Activation during recognition in these "minor" modalities and differences or similarities between those and the "major" modalities may also be worth investigating.

4.2. Methodological caveats

It is possible that some of activations reported to be specific to recognition of PF people were in fact artifacts due to methodological flaws. Four potential sources of such artifacts are discussed below. First, some nonspecific stimulus properties may be carried by stimuli for specific PF people. In preparing facial stimuli for PF people, for example, pictures were sometimes provided by the subjects, whereas pictures for control stimuli were prepared by the experimenter. In studies in which facial stimuli were collected in this way, differences in the physical properties of the stimuli due to source differences or subjects' episodic memory of preparing these pictures may have affected activation. The effect of the latter factor is particularly difficult to disentangle from true PF people-induced activation because these effects share the same qualitative components of episodic-retrieval process (92, 93).

Second, some of the activation specific to recognition of PF people may be dependent on a specific property of the stimuli, *i.e.*, activation is related to a specific stimulus property of the PF people represented. In fact, self-face-specific activation in the parietal sensory-motor association cortices appeared to be prominent in studies in which non-frontal or atypical views were used as facial pictures (71-74, 80); if this is the case, functioning of this area could be attributed to some specific property of the self-face rather than the self-face in general.

Third, differences in the parameters of stimulus presentation, such as the presentation duration, intertrial interval, number of faces, and number of repetitions, may affect activation in a more or less person category-specific way. In fact, it has been demonstrated that repeated presentation (27) and the distracter condition (69, 73) significantly affect person category-specific activation. Although face pictures are usually presented briefly (often less than 2 s duration), many studies on love have adopted relatively long presentation durations, often exceeding 10 s (14, 39-42, 48). Although the findings have largely been replicated in other studies using short presentation durations (49, 50) or other stimulus modalities (44, 47), the effects of the duration of stimulus presentation have yet to be assessed in detail.

Finally, some person category-specific activation may be task-induced artifacts. Different tasks are used across studies under the assumption that the effect of the task is equivalent across person categories. This assumption is, however, worth reconsideration. One commonly used task is familiarity judgment, which can ensure the subject's recognition performance with identical task response across familiar people. During the process of familiarity judgment, subjects have to solve conflicts between task-relevant and irrelevant information carried by target stimuli, such as the person-related information and familiarity due to repeated exposure during the experimental session, respectively. It has been suggested that activation of the inferior frontal cortex may be explained by such a conflict-resolution process (94). Another source of artifact is the difference in difficulty of tasks under various conditions. Several cortical areas (collectively termed the default mode network) including the MPFC and PCC as well as the pSTS/TPJ are known to be deactivated during demanding tasks (95). When a given task is more demanding under the control than under the PF-person condition, the greater extent of deactivation under the control condition may result in pseudo-activation for a PF person in such areas.

4.3. Creating virtual PF people

A promising new approach to gaining further understanding of the cognitive process of PF people recognition is to experimentally create virtual PF people. This approach would solve several limitations of studies using real PF people. For real PF people, cognitive factors, including behavioral readiness, that characterize activation during recognition of each category of PF people are inevitably a matter of speculation. Such cognitive factors are often subject to large intersubject variability, thus affecting the results of between-category comparisons of activation; the variability can be used for analysis when it is measurable, but this is often not the case.

Under the assumption that a person becomes PF through daily interaction, it is possible to create virtual PF people through learning sessions entailing virtual social interactions. For such virtual PF people, cognitive components during recognition are operationally definable and can be expected to have less intersubject variability. Examples of such attempts are the creation of a cooperator and defector in the Prisoner's Dilemma game (96) or a friend and foe constructed via feedback of facial expressions that depend on the outcome of a game (97). Both of these studies compared activation during subsequent face perception sessions between face categories. The former study demonstrated the feasibility of creating virtual PF people by showing that activation was greater for cooperator or defector than for familiarized control face in several cortical areas implicated in the recognition of PF people, including the vMPFC, pSTS, insula, amygdala, and striatum (96). The latter study isolated the neural correlates of specific components of behavioral readiness by showing differential activation in the vMPFC/ACC and bilateral amygdalae directly contrasting foe against friend (97).

4.4. Relevance to the sense of familiarity

The involvement of different behavior-relevant cognitive or affective systems dependent on PF-person categories appears possible given the controversial nature of the relevance of these systems to the sense of person familiarity. In the classical PIN concept (1-3), behavioral readiness is distinct from and subsidiary to the person recognition process. The validity of such a PIN concept in the brain has, however, been recently questioned. Neuropsychological and neuroimaging data seem to implicate the ATC in the process under discussion. The effect of lesions in the right and left ATCs on recognition impairment differed among input modalities and domains of person-specific information, contradicting the unitary gateway concept of PIN (98, 99). The neural basis of the covert route, which is assumed to be impaired in those with Capgras delusion, has been suggested to lie in different networks by various authors. Originally the covert route was assigned to the dorsal visual pathway (5) and then to the amygdala (4). Later, the affective nature of the route *per se* became a matter of debate (100, 101). In this context, a previous review of studies on activation specific to common PF people assigned entire activated areas (*i.e.,* both cognitive and affective) to this route (102). From the perspective of the two-factor hypothesis of delusional misidentification, perceptual (first factor) and belief evaluation (second factor) processes have been suggested to be located in the posterior and prefrontal cortices, respectively (8, 103). Some authors have speculated more specifically. The first factor has been considered to be a mind-reading process located in the right TPJ (8), and the second factor to be an hypothesis-evaluation process located in the right lateral prefrontal cortex (103).

Although validation of such hypotheses would require extensive neuropsychological testing to evaluate the effects of lesions in each region on the experience of patients, a neuroimaging approach may also contribute to resolution of the issue. Repetition suppression in activation, the existence of which would indicate critical involvement of the region in task execution, was examined during recognition of common PF people. Repetition suppression was observed in many, but not all, behavior-relevant cognitive or affective systems (23, 27).

4.5. Clinical application

Several neuroimaging studies have used PF faces as stimuli for patients with mental disorders such as autism, depression, and social anxiety disorder to facilitate an understanding of the disorder or to explore potential diagnostic measures.

Several studies have compared activation during recognition of a common PF face (104, 105) and the self-face (106-108) between patients with autism and healthy controls, given that autism is characterized by impairment of sociality. The observed differences between groups were mostly consistent with this notion. Although all of these studies used the face of a stranger as a control, abnormal neural responses in autism have been identified in regions where PF people-specific activation has been reported previously. Activation specific to common PF people (*e.g.*, mother, relatives, friends, colleagues) in the PCC/precuneus and ACC/MPFC was weaker in patients than in controls. Although the adopted statistical threshold was weak, the findings were replicated (104, 105). For self-face-specific activation, no differences between groups were identified in the ordinary face-recognition setting (106, 108). When facial picture sets included embarrassing (non-photogenic) photographs, a within-group difference was apparent in controls but not in patients. Both self-face-specific activation of the PCC and a positive correlation between the extent of embarrassment and activation of the right OFC were observed (107).

Studies in patients with other mental disorders have just begun. One study investigated the possibility of using neural response to the mother's face as an index of depression under the assumption that depression stems from a failure of early attachment experience. The degree of activation in the dorsomedial prefrontal cortex during recognition of the mother's face was predictive of the degree of depression (109). Another study examined the neural response for the self-face in patients with social anxiety disorder considering that distorted images of the observable self are crucial in the development and maintenance of this disorder. In an experimental setting where the self-face was exposed to scrutiny and evaluation by others, self-face-specific responses were smaller in patients than in controls in cortical areas involved in the cognitive control of negative emotion, such as the dorsal frontoparietal cortices and ACC (110).

Clinical application of neuroimaging on PF person recognition is still in its infancy. Interpretation of the clinical data indicates the insufficiency of our knowledge; we do not yet know the exact meaning of each person-specific activation or the potential effects of specific experimental settings. The development of clinical studies is critical for basic research. Clinical and basic research would mutually facilitate an understanding of the PF people recognition process in the brains of patients and healthy subjects.

5. SUMMARY

The readiness to exhibit appropriate behavior toward a person appears as soon as he or she is recognized. Considering its speed and automaticity as well as its likely evolutionary origin, such behavioral readiness may be inherent in person recognition mechanisms in the human brain. A decade of functional neuroimaging studies yielded evidence for this hypothesis; mere recognition of PF people in the scanner induces activation of specific brain regions whose functions are reasonably explained as constituting readiness for behavior upon actually encountering that person. Recognition of common PF people, such as friends and colleagues, was contrasted against that of famous people by amodal activation of the paralimbic cortices involved in real-time communication, including the regions for inferring the mental state of others, autobiographical memory retrieval, and self-referential processes. Recognition of a person in love uniquely induces activation of several cortical and subcortical structures involved in motivational, reward, and affective processes, whereas these activation patterns vary across romantic love, maternal love, and lost love, likely reflecting the characteristics of relationships involving mating, caretaking, and yearning, respectively. The involvement of motor-associated cortices during recognition of a personal enemy may reflect mobilization of the motor system for possible attack or defense. Finally, self-recognition in a body-related modality uniquely activates sensory-motor association cortices, arguably reflecting the sensorimotor origin of the development of bodily self-concept; in contrast, activation of the regions for social-cognitive processes is in part context dependent.

Several issues remain to be addressed in future studies. One insufficiently explored issue is the effect of recognition modality; cross-modal comparisons, particularly including "minor" modalities, are crucial to gain a full understanding of the mechanism. It will also be necessary to reexamine the extant knowledge or to design future experiments keeping in mind the possibility that the identified person category-specific activation may be dependent on specific properties of the experimental setting, such as the stimulus properties, presentation parameters, and the task instruction or context, and may therefore be a technical artifact. Exploitation of virtual PF people, created through learning sessions entailing virtual social interaction, is a promising new direction to overcome several limitations of studies using real PF people, such as the speculative nature of the interpretation of results and intersubject variability in cognitive or neural responses to different PF people. The relevance of behavioral readiness to the sense of familiarity is controversial. A neuroimaging approach, such as exploiting repetition suppression, may help to resolve issues. Application of neuroimaging to PF person recognition in patients has been performed for a few mental disorders. The development of clinical applications would facilitate basic research clarifying our currently inadequate knowledge.

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Abbreviations: PF: personally familiar; PET: positron emission tomography; fMRI: functional magnetic resonance imaging; PCC: posterior cingulate cortex; IPL: inferior parietal lobule; pSTS: posterior part of the superior temporal sulcus; TPJ: temporoparietal junction; ATC: anterior temporal cortex; MPFC: medial prefrontal cortex; ACC: anterior cingulate cortex; VTA: ventral tegmental area; OFC: orbitofrontal cortex; PreCS: precentral sulcus; MFG: middle frontal gyrus; IFG: inferior frontal gyrus; GP: globus pallidus; SN: substantia nigra; NA: nucleus accumbens; SMA: supplementary motor area; IFS: inferior frontal sulcus; vMPFC: ventromedial prefrontal cortex

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