



Split-brain reveals separate but equal self-recognition in the two cerebral hemispheres

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Abstract

To assess the ability of the disconnected cerebral hemispheres to recognize images of the self, a split-brain patient (an individual who underwent complete cerebral commissurotomy to relieve intractable epilepsy) was tested using morphed self-face images presented to one visual hemifield (projecting to one hemisphere) at a time while making “self/other” judgments. The performance of the right and left hemispheres of this patient as assessed by a signal detection method was not significantly different, though a measure of bias did reveal hemispheric differences. The right and left hemispheres of this patient independently and equally possessed the ability to self-recognize, but only the right hemisphere could successfully recognize familiar others. This supports a modular concept of self-recognition and other-recognition, separately present in each cerebral hemisphere.

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1. Introduction

Hemispheric specialization of self-recognition has become critical evidence for the self as a distinct cognitive construct. The ability to recognize one’s own face has often been used as an opera-

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tional definition of higher-order self-awareness (Keenan, Wheeler, Gallup, & Pascual-Leone, 2000). Phylogenetic (Gallup, 1970) and ontogenetic (Amsterdam, 1972) trends suggest that the capacity for visual facial self-recognition develops along with a variety of other cognitive functions that are unique to adult humans and to certain non-human primates. The neuroanatomical substrates and possible lateralization of this ability have only recently been explored. Some studies found a right hemisphere (RH) bias or selective activation for self-recognition (Keenan, Nelson, O’Conner, & Pascual-Leone, 2001; Keenan, Wheeler, Platek, Lardi, & Lasonde, 2003; Preilowski, 1977; Uddin, Kaplan, Molnar-Szakacs, Zaidel, & Iacoboni, 2005), others reported a left hemisphere (LH) bias (Turk et al., 2002), and yet others report significant bilateral contributions to the task (Kircher et al., 2001). However, not all of these studies used lateralized stimuli to restrict visual input to one hemifield (Keenan, Freund, Hamilton, Ganis, & Pascual-Leone, 2000; Keenan et al., 2001; Kircher et al., 2001). Further, some of these reports have presumed that responses with the right or left hand are sufficient to reflect contralateral hemispheric performance (Keenan et al., 2000), though data to the contrary exist (Weems, 2003; Zaidel, 1998). Finally, some studies failed to distinguish decision bias and sensitivity in self-recognition (Turk et al., 2002). Some inconsistencies in the literature are due to conceptual issues. For example, one can use split-brain patients to test theories of positive hemispheric competence, while functional imaging studies in normal subjects can shed light on which hemisphere is more involved during a given task. Together, these kinds of studies can address the issue of whether a hemisphere is necessary and/or sufficient for a particular task.

Here we redress these methodological concerns to more rigorously investigate the claim that the ability to self-recognize is lateralized to one hemisphere. The present study investigated the positive competence of the two hemispheres on a task of visual self-recognition by assessing the sensitivity and bias of NG, a split-brain patient.

2. Materials and methods

2.1. Participant

NG is a 70-year-old woman who underwent complete forebrain commissurotomy (single stage midline section of the anterior commissure, corpus callosum, hippocampal commissure, and massa intermedia) in 1963 to minimize the spread of epileptic seizures. The patient’s case history is documented elsewhere (Bogen & Vogel, 1976). The experimental protocol was approved by the UCLA general campus IRB. Consent from the patient was secured prior to the study, and she was compensated for her participation.

2.2. Stimuli and procedure

Pictures of both the subject and a highly familiar gender-matched associate known by the subject for over 30 years were taken with a Kodak 3400C digital camera. Morphed face images were generated using software called Morph Editor (SoftKey, Cambridge, MA), which allows the experimenter to define the percent of image 1 (based on luminance) to overlay onto image 2. Alignment between faces is achieved by using at least 40 reference points placed on common landmarks such as the eyes, nose, and mouth, as well as tracing the overall head shape. These points

guide the shape of both internal facial features and external head size. Morphed images were created in 5% increments, such that there were 21 self-to-unknown morphs and 21 familiar-to-unknown morphs. These were then converted to a different format using Graphic Converter (Lemke Software, Germany) and given a uniform gray background with photo retouching software (Adobe Photoshop 5.0).

The subject was seated 57.3 cm from a high resolution RGB color monitor of a Macintosh computer, with her chin in a chinrest to ensure consistent viewing. She was instructed to keep her eyes focused on a central fixation cross throughout the experiment.

The experiment was run with the software package MacProbe (Hunt, 1994). Morphed images were presented in a random order either to the left or right side of a fixation point on a computer screen for a duration of 180 ms to prevent involuntary saccades and ensure stimulation of the appropriate hemisphere (Zaidel, 1979). In one condition, the subject was asked to press the top button on a response box if the image presented “looks more like yourself” and the bottom button if the image looked more like “an unknown other face.” This condition included images morphed between the subject and an unknown, gender-matched face. Another condition consisted of viewing morphs between the subject’s familiar associate, DZ, and an unknown, gender-matched face. Here the subject was asked to press the top button if the image presented “looks more like DZ” and the bottom if the image looked more like “an unknown other face.” This condition was used as a control for familiarity and overlearnedness (Fig. 1B).

The subject was tested over six sessions, with each morphed image presented four times/visual field per session. For the first four testing sessions, the subject responded unimanually. Response hand and condition were counterbalanced, such that the subject alternated between starting a session with the right or left hand and doing the “self” or “other” block in alternate sessions. For the last two sessions, the subject was instructed to respond with the left hand if the stimulus appeared in the left visual field (LVF) and the right hand if the stimulus appeared in the right visual field (RVF). As there was no main effect of session, final analyses collapsed data across all sessions, utilizing only responses made in the “pure hemispheric” conditions where stimuli and response hand were congruent (e.g., LVF stimulus, left-hand response; RVF stimulus, right-hand response). The pairing of “crossed” response hand/visual field conditions (e.g., LVF stimulus, right-hand response) introduces noise due to resource limitations resulting from interference between response programming and decision processes (Zaidel, White, Sakurai, & Banks, 1988). Consequently, one routinely excludes “crossed” trials when assessing independent hemispheric contributions. Illustrative examples of the stimuli and task are presented in Figs. 1A and B. Note that the images shown here are example faces, not those actually used in the experiment.

3. Results

Data from “uncrossed” or “pure hemispheric” responses (responses where response hand was congruent to VF of stimulus presentation) were analyzed using a hierarchical χ^2 (Winer, Brown, & Michels, 1991). The hierarchical χ^2 was a four-way, mixed model χ^2 , with response (yes/no) random and all other factors fixed. Additionally, signal detection analysis was used to compute d' as a measure of sensitivity for detecting “self” or “familiar” stimuli, independent of bias (McMichol, 1972).

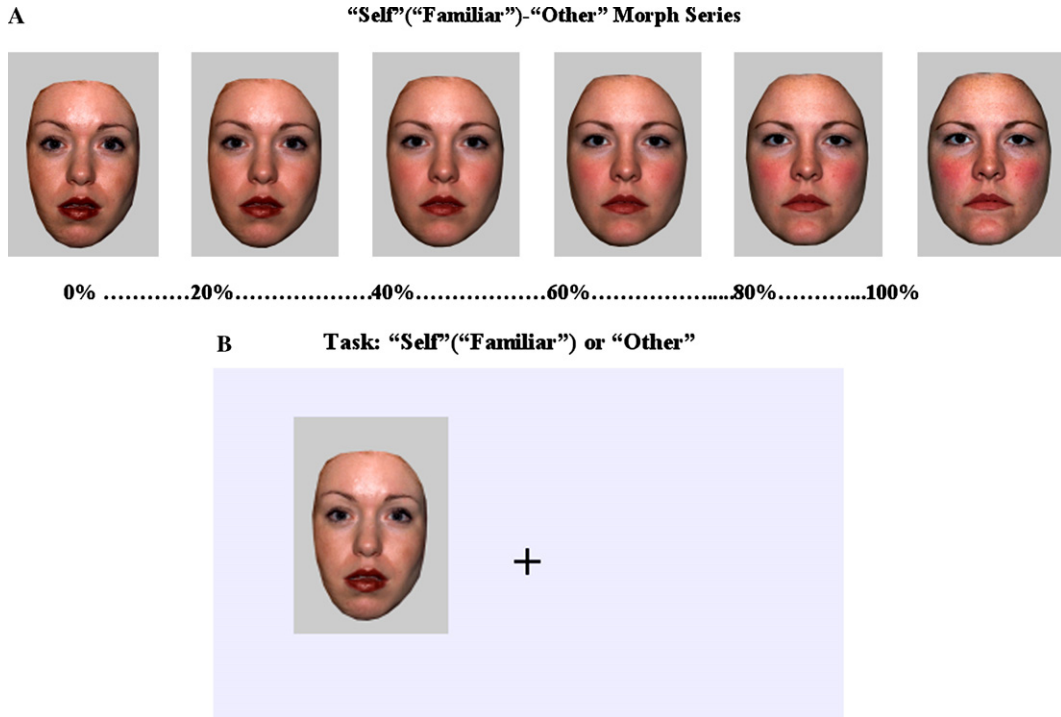


Fig. 1. (A) Morphed images between the subject and an unfamiliar face (“self” condition) and between a highly familiar associate and an unfamiliar face (“familiar” condition) were created in 5% increments. (B) Images were randomly flashed to the right or left of a central fixation cross for 180 ms while the subject made “self”/ (“familiar”) or “other” judgments.

Analysis revealed an overall bias to affirm the presence of the target face, regardless of condition (54.7%, $\chi^2_{(1)} = 11.88$, $p < .001$). Overall, this affirmation bias was stronger in the LH (64.4%, $\chi^2_{(1)} = 51.04$).

As shown in Fig. 2, the subject affirmed the presence of the target face more frequently in the “familiar” condition (64.2%) than in the “self” condition (45.1%, $\chi^2_{(1)} = 49.98$, $p < .001$), but only when the stimulus was in the RVF (82%, $\chi^2_{(1)} = 38.81$, $p < .001$).

The effect of morph interval differed for the two tasks ($\chi^2_{(20)} = 42.78$, $p < .005$). The percentage of affirmative responses to both LVF and RVF trials in the “self” condition followed an orderly descent as the stimuli contained less “self” and more “other” (Fig. 3A). In the “familiar” condition, this orderly progression was present for LVF stimuli, but absent for RVF stimuli, producing a Task, VF, and Morph Interval interaction ($\chi^2_{(20)} = 39.05$, $p < .01$, Fig. 3B).

Signal detection methods were used to obtain d' , a measure of subjects' sensitivity to detecting targets independent of bias. These calculations assume the underlying signal and signal + noise distributions are normal and of equal variance. Here, we used d' as a measure of sensitivity to detection of “self” and “familiar” stimuli. Images morphed towards “other” more than 50% were designated as non-target or target-absent trials. A response was considered a “target-present” response if the subject responded “self” in the self condition or “familiar” in the familiar condition. Hits were defined as “target-present” responses to target-present trials. False alarms were defined

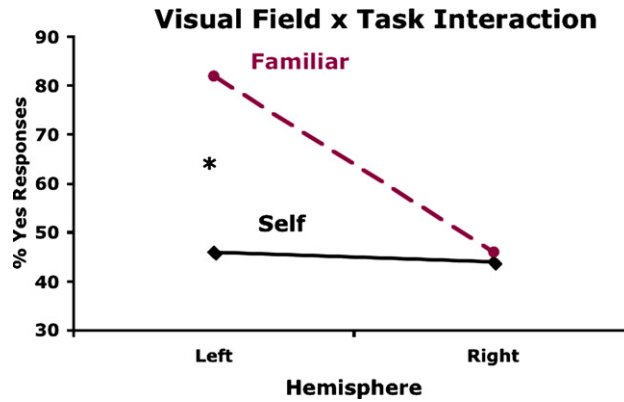


Fig. 2. The target was either a picture of NG’s own face (“self” condition) or of the familiar associate DZ (“familiar” condition). NG responded “yes” to the presence of the target more frequently in the “familiar” task than in the “self” task, but only when responding to stimuli in the left hemisphere.

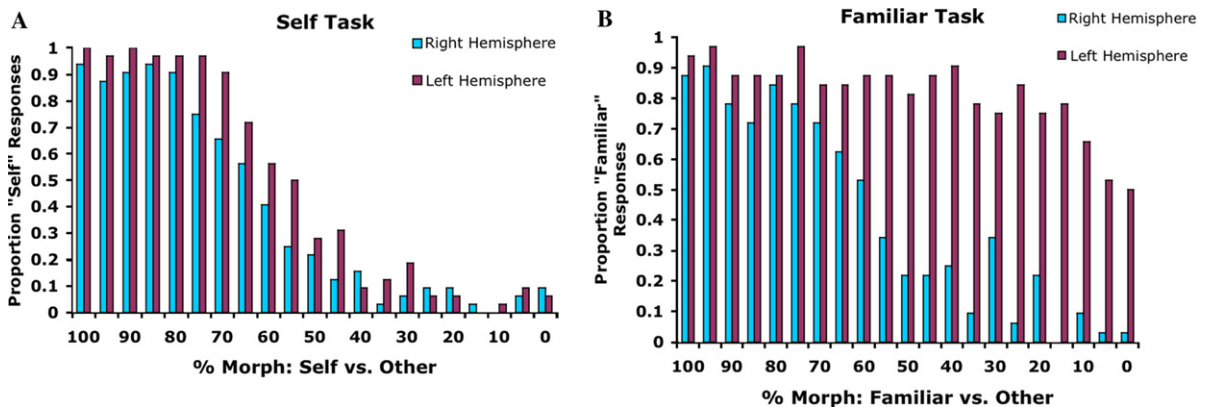


Fig. 3. (A) Proportion of “self” responses as a function of the percentage of NG’s image contained in the stimulus and the cerebral hemisphere that perceived the image and made the response. Both hemispheres were able to perform this task, though the left hemisphere showed more of a “self” bias. (B) Proportion of “familiar” responses as a function of the percentage of a familiar associate’s image contained in the stimulus and the cerebral hemisphere that perceived the image and made the response. Only the right hemisphere of NG could successfully perform this task.

as “target-present” responses to target-absent trials. In other words, a response was considered a hit if the subject identified a <50% morph as “self” in the self condition or as “familiar” in the familiar condition. The responses to the 50% morphed images were excluded from the analysis. Thus, the proportion of hits was defined as the proportion of <50% morph stimuli responded to as “self” in the self condition or as “familiar” in the familiar condition.

This analysis revealed that both hemispheres were significantly above chance ($d' > 2, p < 0.05$) at performing the task of correctly identifying images predominantly containing self-elements (“self-present” targets). However, only the RH ($d' = 1.67, p < 0.05$) was sensitive for detecting “familiar-present” targets; familiar images presented to the LH were not detected above chance (Table 1).

Table 1

Both hemispheres of NG showed sensitivity for detecting “self” images. In contrast, only the right hemisphere of NG was able to detect images of the familiar associate

<i>d'</i>	Self	Familiar
Left hemisphere	2.277 ^a	0.6115
Right hemisphere	2.019 ^a	1.666 ^a

^a Significant as one-tailed *z* scores, $p < 0.05$.

4. Discussion

Previous work has suggested a double dissociation wherein the disconnected LH shows a recognition bias for self, and the RH shows a bias for familiar others (Turk et al., 2002) or vice versa (Keenan et al., 2003). Instead, our results show that the LH exhibits a selective “target-present” bias in the “familiar” recognition task. We interpret this pattern as an inability of the disconnected LH of patient NG to perform the “familiar” recognition task. In fact, the LH of NG demonstrates a high false alarm rate in the “familiar” task. That is a characteristic strategy that this patient has used when unable to perform a cognitively challenging task (Iacoboni, Rayman, & Zaidel, 1996). By contrast, it appears that the RH of NG can perform both the “self” and “familiar” recognition tasks. The previously reported selective hemispheric bias for self is not supported in our data. Our findings do suggest a selective deficit in the LH for detecting familiar face stimuli. Indeed, we see no evidence for hemispheric specialization of the capacity for self-recognition in this patient. Our finding that both cerebral hemispheres of this patient equally possess the capacity for self-recognition is consistent with previous reports of independent and similar self-awareness in the two disconnected hemispheres (Sperry, Zaidel, & Zaidel, 1979). On the basis of the case study of this single subject alone, we hesitate to generalize. However, an identical hemifield presentation study in 40 normal subjects also revealed no difference in sensitivity to detection of “self” faces for LVF (mean $d' = 2.556$) and RVF (mean $d' = 2.574$) presentations ($F = .094$, $p = .761$), suggesting that this finding may apply to a more general population (Uddin, Keenan, Mooshagian, Rayman, & Zaidel, 2002). The remarkable fact that NG’s disconnected LH was able to recognize the (100%) unknown other face in the “self” condition but unable to do so in the “familiar” condition is further evidence that the self is a distinct cognitive construct. We suggest that the representation of the self that allows for self-recognition is not restricted to a particular hemisphere, but is rather available to each cerebral hemisphere independently.

There is an alternative interpretation of these data, which cannot be completely ruled out at present. It is possible that in distinguishing the self from an unknown, mere familiarity is sufficient. Thus the RH, which is able to recognize both the familiar face and the self-face may just be performing the task based on familiarity. The LH, on the other hand, is unable to recognize the familiar face, yet recognizes the self-face, thus it cannot be using familiarity alone. This interpretation suggests that only the LH truly recognizes the self, while the RH may be able to complete the task by other means. It should be acknowledged that previous research has suggested a special role for the RH in novelty detection (Martin, 1999) and that novel stimuli can be regarded as unfamiliar. Thus, novelty detection can be the basis for familiarity detection. However, if only novelty detection were operating during both tasks, with the “familiar” task being just a more

difficult novelty detection task, we would not expect the LH to perform qualitatively differently in the two tasks. We suggest that this familiarity/novelty interpretation is unlikely, based on previous data on this patient. NG has previously shown appropriate emotional reactions when pictures of herself were introduced unexpectedly amongst test items shown to the RH (Sperry et al., 1979). Moreover, running an experiment that requires the subject to directly distinguish the self from the familiar other face may still not adequately resolve this objection. It is likely that the self face is more familiar to the subject than any familiar other, so that the classification could be made by degree of familiarity alone. Further careful studies are required to address the confound of familiarity.

While Sperry et al. (1979) report the presence of a similar and well developed self-concept in both hemispheres, other work with commissurotomy patients further suggests different cognitive and emotional characteristics, with respect to the self, present in the two disconnected hemispheres (Schiffer, Zaidel, Bogen, & Chasan-Taber, 1998). We report here the independent ability of each cerebral hemisphere to distinguish self and other, but make no claims as to the nature of the underlying self-concept which gives rise to self-recognition.

When the abilities of the disconnected cerebral hemispheres are independently assessed, no differences with respect to detection of self-images are seen. Previous reports of hemispheric specialization for self-recognition in both split-brain patients and normals have primarily used measures of bias, questionable means of ascertaining behavioral laterality, and centrally presented visual stimuli. When these methodological concerns are addressed, indeed we find no evidence for hemispheric differences in the ability to self-recognize. Our findings suggest that the cognitive capacity that gives rise to visual facial self-recognition is robustly represented in both cerebral hemispheres.

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