tonic background inhibition that normally suppresses unwanted early responses. Nevertheless, the effect of subthalamic nucleus stimulation on basal ganglia output is likely to be more than a 'simple' inhibition [10] and in this respect the effect on saccadic latencies might involve a multifaceted mechanism.

Supplemental data
Supplemental data are available at http://www.current-biology.com/cgi/content/full/18/10/R412/DC1

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[1]Department of Neurosurgery, University Hospital Maastricht, Maastricht, The Netherlands. [2]Department of Neuroscience, Maastricht University, Maastricht, The Netherlands. [3]Department of Physiology, Development and Neuroscience, University of Cambridge, Cambridge CB2 3EG, UK. [4]European Graduate School of Neuroscience (EURON). E-mail: rhsc1@cam.ac.uk

Self-awareness affects vision

Eric L. Smith[1], Marcia Grabowecky[1,2] and Satoru Suzuki[1,2]

What we see can be influenced by attention [1,2] and concurrent sensory inputs from other modalities, such as accompanying sounds [3,4], but can high-level mental factors such as states of self-awareness systematically affect vision? Because associative learning is a fundamental property of the nervous system, we hypothesized that different states of self-awareness might selectively enhance perception of specific visual patterns based on experiential associations. Perception of self-faces provided an ideal test case because of the common experiential associations between perception of mirrored and un-mirrored self-faces and unique states of self-awareness. We found, consistent with the typical experience of looking at a mirrored self-face in privacy and an un-mirrored (for example, photographed) self-face in the company of others, that recognition of mirrored self-faces was superior when self-awareness was internally directed, whereas recognition of un-mirrored self-faces was superior when self-awareness was socially directed. As mirrored and un-mirrored faces are highly similar (as in Figure 1B), our results indicate that states of self-awareness affect visual perception with considerable pattern resolution. This has the intriguing general implication that, when a specific state of self-awareness frequently coincides with visual perception of specific patterns, the mental state and visual processing may become associated so that evoking that state of self-awareness selectively enhances visual perception of associated patterns.

When you look at yourself in a mirror, you are typically alone, privately examining your mirrored (left–right reversed) appearance, and your self-awareness is likely to be internally directed to your immediate percepts, including body sensations. This might result in an association between the visual processing of a mirrored self-face and a state of internally-directed self-awareness. In contrast, when you look at your un-mirrored face in a photograph or video, you are often in the company of other people (to whom you show the photograph or video), and your self-awareness is likely to be socially directed (for example, thinking about how others think of you). This might result in an association between the visual processing of an un-mirrored self-face and a state of socially-directed self-awareness. If visual processing is selectively associated with concurrent states of self-awareness in this way, recognizing your mirrored face should be easier when your self-awareness is internally (compared to socially) directed, whereas recognizing your un-mirrored face should be easier when your self-awareness is socially (compared to internally) directed.

To induce an internally-directed state of self-awareness, we instructed participants to focus on their breathing as a bodily sensation; to induce a socially-directed state of self-awareness, we instructed participants to think about their strengths and weaknesses, as people are typically concerned about how others think of them in social situations (see Supplemental data available on-line for experimental details and control data).

In experiment 1, participants saw mirrored self-faces, un-mirrored self-faces, and other people's faces. The task was to press one button when a self-face was presented and to press another button when someone else's face was presented. Mirrored self-faces were recognized faster when self-awareness was internally (compared to socially) directed, whereas un-mirrored self-faces were recognized faster when self-awareness was socially (compared to internally) directed (Figure 1B; significant interaction, $F_{1,23} = 8.26$, $P < 0.01$).

In experiment 2, we determined whether states of self-awareness influenced the strength (in addition to the speed) of self perception. To vary the strength of 'selfness' of the faces, we created intermediate morphs between the participant's self-face and a celebrity's face. The task was to press one button when the participant detected his or her self-face and press another button when he or she detected the celebrity's face. Stronger self perception would result in increased self responses

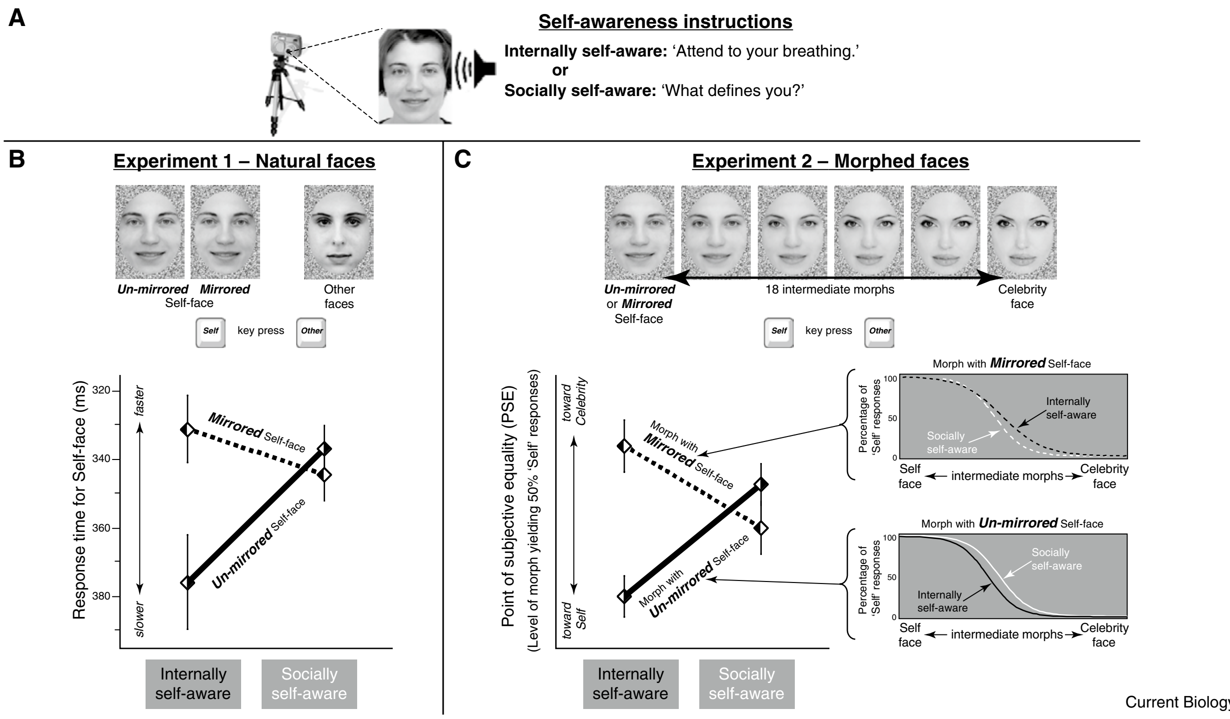

Figure 1. Experimental design and results.

(A) The face of each participant was photographed. Participants were given verbal instructions (provided in the Supplemental data) to induce an internally-directed or socially-directed state of self-awareness. (B) Response times for recognizing mirrored (dashed line) or un-mirrored (solid line) self-faces when self-awareness was internally or socially directed. (C) Left: points of subjective equality (PSEs) corresponding to the perceptually neutral morph levels yielding 50% self responses, plotted for the morphs made with mirrored (dashed line) or un-mirrored (solid line) self-faces when self-awareness was internally or socially directed. Stronger self perception is indicated by the PSEs shifted more toward the celebrity's face (reflecting rightward shifts in the sigmoidal response functions shown in the right panels). Right: the sigmoidal response functions, showing percentage of self responses as a function of the level of morph, for the morphs made with mirrored (upper panel) or un-mirrored (lower panel) self-faces when self-awareness was internally (black curves) or socially (white curves) directed. The response-time axis in B has been inverted so that stronger self perception (faster response times in B and PSEs shifted more toward the celebrity's face in C) corresponds to higher points in both B and C. Note that the patterns of data presented in B and C show the same interaction. Error bars represent ±1 SEM with the baseline individual variability removed.

to the morphs that are closer to the celebrity's face, causing a rightward shift (toward the celebrity's face) in the sigmoidal response function (percentage of self responses as a function of the level of morph; see right panels in Figure 1C). The center position of this function within the self–celebrity dimension can be quantified by the point of subjective equality (PSE), which corresponds to the perceptually neutral level of morph (yielding 50% self responses). A PSE closer to the celebrity's face indicates stronger self perception and vice versa. For the morphs made with mirrored self-faces, the PSE was shifted more toward the celebrity's face when self-awareness was internally (compared to socially) directed, whereas for the morphs made with un-mirrored self-faces, the PSE was more shifted toward the celebrity's face when self-awareness was socially (compared to internally) directed (left panel in Figure 1C; significant interaction, $F_{1,8} = 8.72$, $P < 0.02$).

We thus found that perception of mirrored self-faces was enhanced — mirrored self-faces were both more rapidly recognized and more strongly identified — when self-awareness was internally, compared to socially, directed. In contrast, perception of un-mirrored self-faces was enhanced when self-awareness was socially, compared to internally, directed. While extensive prior research has demonstrated stimulus-selective visual effects of attention and crossmodal interactions, we have demonstrated that, based on experiential associations, high-level mental factors such as states of self-awareness can also have surprisingly stimulus-specific effects on visual perception. States of self-awareness might generally provide internal cues to selectively enhance behaviorally relevant perceptual signals.

Supplemental data
Supplemental data are available at http://www.current-biology.com/cgi/content/full/18/10/R414/DC1

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[1]Department of Psychology and [2]Interdepartmental Neuroscience Program, Northwestern University, Evanston, Illinois 60208, USA.
E-mail: satoru@northwestern.edu

Supplemental Data: Self-awareness affects vision
Eric L. Smith, Marcia Grabowecky, and Satoru Suzuki

Supplemental Experimental Procedures

Participants. Northwestern University undergraduates (N = 24 for Experiment 1, and N = 10 for Experiment 2) gave informed consent to participate for partial course credit. They all had normal or corrected-to-normal visual acuity and were tested individually in a dimly lit room.

Experiment 1 (*mirrored* and *un-mirrored* self-faces versus unfamiliar faces). The face of each participant was photographed, converted into a grayscale image and cropped with an elliptical mask to prevent the use of eye color, skin tone, and hair as cues to recognize self-faces. The *mirrored* and *un-mirrored* self-faces were intermixed with 80 Asian and Caucasian, male and female faces, which were matched for size (5.8° x 7.0° visual angle at the viewing distance of 50 cm) and average luminance (80 cd/m^2). Each trial began with a simultaneous flash (100 ms) of two asterisks on the left and right sides of the 17" LCD monitor (11.4° from the center) to induce a distributed state of visual attention to encourage holistic processing of a subsequently presented face. The face was centrally presented for 175 ms and participants responded as to whether it was a self-face or someone else's face.

Following 24 practice trials, these self-recognition trials were run in two self-awareness conditions, (1) when self-awareness was internally directed and (2) when self-awareness was socially directed; the instructions used to induce these self-awareness states are provided as audio files. In each self-awareness condition, 24 self-faces (half *mirrored* and half *un-mirrored*) and 20 other faces (randomly selected from the pool of 80 faces) were presented. Following every 11 trials, refresher instructions were given to maintain the desired state of self-awareness. The order of the two self-awareness conditions was counterbalanced across participants.

Experiment 2 (*mirrored* and *un-mirrored* self-faces morphed with a celebrity's face). The basic procedure was the same as in Experiment 1 with the following exceptions. The strength of "selfness" was varied by digitally interpolating between the participant's face and the face of a celebrity (using Avid's Elastic Reality software with 49 reference nodes). A celebrity face was selected for each participant based on similarity to his or her skin tone and gender, chosen from Brad Pitt, Angelina Jolie, Halle Berry, or Denzel Washington. Celebrity faces were used so that both self-faces and other faces were familiar to the participants. The 20 interpolated faces (including the original faces) varied smoothly from self to celebrity.

The set of 20 morphs were presented four times for a total of 80 trials in each self-awareness condition, with a refresher self-awareness instruction given after every 20 trials. Each participant was tested in both self-awareness conditions as in Experiment 1. However, because generating morphs was time consuming and it was desirable to test each participant within less than an hour, each group of participants viewed the morphs based on either *mirrored* or *un-mirrored* self-faces. Participants responded as to whether the presented face was a self-face or a celebrity's face. Interestingly, although 20 levels of interpolated faces were presented, most participants stated in the post-experiment debriefing that they saw only two (either self or celebrity) or at most three distinct faces, indicating the categorical nature of face perception.

For each participant, percentages of self responses were plotted as a function of the level of morph (going from self to celebrity in 19 even steps) for the relevant morph type (made with *mirrored* or *un-mirrored* self-face) for each self-awareness condition (internally or socially directed). Each response function was smoothed by a method of 3-point moving average, so that it could be reasonably fit by a logistic function of the form, $P = \frac{1}{1+e^{-(x-a)/b}} \times 100$, where P is the percentage of self responses, a is the point of subjective equality (PSE, the morph level yielding 50% self responses) and b is the slope of the sigmoidal response function. The fits were all good with r^2 ranging from 0.977 to 0.998. The average response functions shown in the right panels in Figure 1C represent the logistic functions with the average values of a (PSE) and b (slope) obtained from responses to the corresponding morph type (made with *mirrored* or *un-mirrored* self-faces) and self-awareness condition (internally or socially directed). The PSE's (indicating the strength of self perception) for each morph type are plotted in the left panel in Figure 1C as a function of the self-awareness condition. Note that the morph type and self-awareness condition had no statistically significant effects on the slope of the response function.

Supplemental Results

Control Experiment (*mirrored* and *un-mirrored* self-faces versus *mirrored* and *un-mirrored* celebrity faces)

We demonstrated that perception of *mirrored* self-faces was enhanced when self-awareness was internally (compared to socially) directed, whereas perception of *un-mirrored* self-faces was enhanced when self-awareness was socially (compared to internally) directed. We then suggested that this pattern of results was consistent with the typical experience of looking at oneself in a mirror in privacy (when self-awareness is internally directed) and looking at oneself in a photograph in the company of others (when self-awareness is socially directed). One way to strengthen this experiential-association-based account was to show that the differential effects of internally and socially directed states of self-awareness on perception of *mirrored* and *un-mirrored* faces occurred only with self-faces.

Obviously, the aforementioned experiential associations do not apply to perception of celebrity faces, so that the internally and socially directed states of self-awareness should not differentially affect perception of *mirrored* and *un-mirrored* celebrity faces. Alternatively, it could be that the obtained self-awareness effects on perception of *mirrored* and *un-mirrored* self-faces was not due to experiential associations but due to the slight difference in perceptual familiarity between *mirrored* and *un-mirrored* self-faces because most people view their *mirrored* self-faces more frequently than their *un-mirrored* self-faces. Because celebrity faces are typically viewed as *un-mirrored*, *un-mirrored* celebrity faces should appear more familiar than *mirrored* celebrity faces. Thus, if a slight difference in face familiarity was the source of the differential effects of self-awareness on perception of *mirrored* and *un-mirrored* self-faces, recognition of an *un-mirrored* celebrity face (as well as recognition of a *mirrored* self-face) should be faster when self-awareness is internally (compared to socially) directed, whereas recognition of a *mirrored* celebrity face (as well as recognition of an *un-mirrored* self-face) should be faster when self-awareness is socially (compared to internally) directed. We conducted a control experiment to evaluate these alternative hypotheses.

This control experiment (N = 24) was similar to Experiment 1 except that we replaced unfamiliar faces with *mirrored* and *un-mirrored* celebrity faces. Female participants were shown their *mirrored* and *un-mirrored* faces intermixed with *mirrored* and *un-mirrored* faces of Angelina Jolie. The task was to determine whether a presented face was the participant's own face or Angelina Jolie's face. Male participants determined whether a presented face was their own face or Brad Pitt's face. To confirm that the results of Experiment 1 were not idiosyncratically specific to experimental details, we made the faces slightly larger (8.3° by 9.5°) and we also did not use the initially flashed peripheral asterisks (used in Experiment 1 to cue global attention). We presented 48 faces in each of the two self-awareness conditions (internally or socially directed); presentations of *mirrored* self-faces, *un-mirrored* self-faces, *mirrored* celebrity faces, and *un-mirrored* celebrity faces were randomly intermixed and equal in number.

We replicated Experiment 1 for responses to self-faces. *Mirrored* self-faces were recognized faster when self-awareness was internally (compared to socially) directed, whereas *un-mirrored* self-faces were recognized faster when self-awareness was socially (compared to internally) directed (Figure S1A) (significant interaction, $F_{1,23} = 5.44$, $P < 0.03$). In contrast, the self-awareness manipulation had no differential effects on recognition of *mirrored* and *un-mirrored* celebrity faces (Figure S1B) (non-significant interaction, $F_{1,23} = 0.067$, $P > 0.8$). The overall response times (averaged across *mirrored* and *un-mirrored* faces) appeared to be slower in the internal-self-awareness condition than in the social-self-awareness condition for responses to both self and celebrity faces (Figures S1A and B), suggesting that the internal-self-awareness manipulation might have been more cognitively demanding than the social-self-awareness manipulation. These response time differences, however, were not statistically significant. Overall, the result is consistent with the experiential-association hypothesis and inconsistent with the differential-familiarity hypothesis.

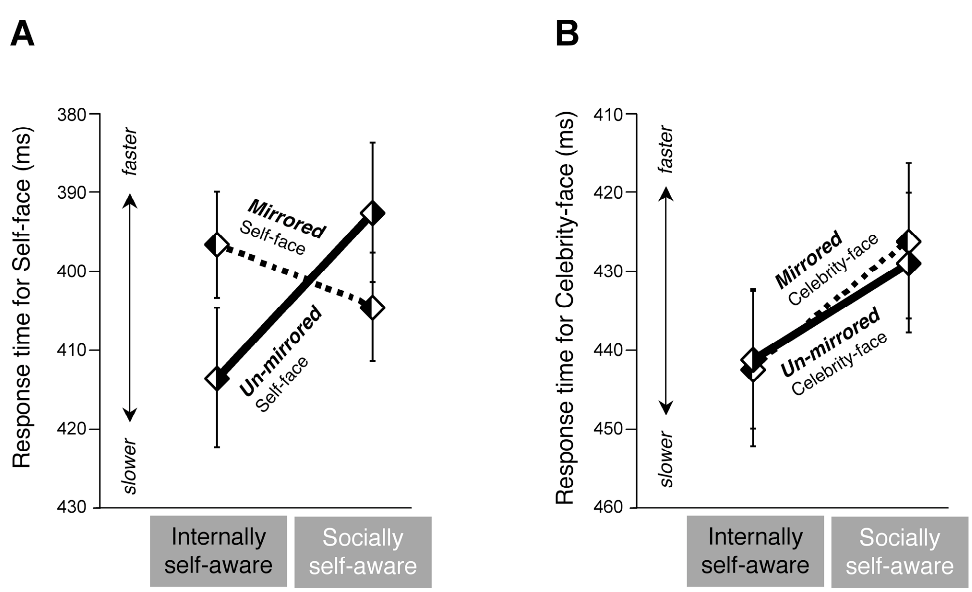

Figure S1. A. Response times for recognizing *mirrored* (dashed line) or *un-mirrored* (solid line) self-faces when self-awareness was internally or socially directed. **B.** Response times for recognizing *mirrored* or *un-mirrored* celebrity-faces when self-awareness was internally or socially directed. The response-time axes are inverted as in Figure 1 so that faster face recognition times correspond to higher points in the graphs. Error bars represent ±1 *SEM* with the baseline individual variability removed.