

# Attributing awareness to oneself and to others

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**This study tested the possible relationship between reported visual awareness (“I see a visual stimulus in front of me”) and the social attribution of awareness to someone else (“That person is aware of an object next to him”). Subjects were tested in two steps. First, in an fMRI experiment, subjects were asked to attribute states of awareness to a cartoon face. Activity associated with this task was found bilaterally within the temporoparietal junction (TPJ) among other areas. Second, the TPJ was transiently disrupted using single-pulse transcranial magnetic stimulation (TMS). When the TMS was targeted to the same cortical sites that had become active during the social attribution task, the subjects showed symptoms of visual neglect in that their detection of visual stimuli was significantly affected. In control trials, when TMS was targeted to nearby cortical sites that had not become active during the social attribution task, no significant effect on visual detection was found. These results suggest that there may be at least some partial overlap in brain mechanisms that participate in the social attribution of sensory awareness to other people and in attributing sensory awareness to oneself.**

social cognition | consciousness | attention

It has been proposed that awareness is the brain’s sometimes inaccurate representation of attentional state (1, 2). In this proposal, which was termed the “attention schema” theory, the relationship between awareness and attention is similar to the relationship between color and wavelength. Color is a construct of the brain that is attributed to a surface, whereas the spectrum of wavelengths reflecting from the surface is the physically real item being represented. Color can be dissociated from wavelength, as demonstrated in a variety of visual illusions. This dissociation occurs because the brain’s representations are simplifications and sometimes inaccurate. In a similar manner, in the attention schema theory, the awareness that the brain attributes to itself is a simplified, sometimes inaccurate model of something. The item being modeled is attention, a real physical process, a mechanistic process of signal enhancement as described, for example, in the biased competition model (3).

Although attention and awareness may seem similar, two aspects of them are consistent with the hypothesis that one is a schematic representation of the other. First, attention is a physical process in the brain, whereas awareness is in the form of knowledge that the brain can potentially report. Second, although the content of awareness and the content of attention overlap most of the time (4–7), it is sometimes possible to attend to a stimulus without being aware of it (8–19). In that case, the brain’s reportable knowledge about what is currently “in mind” becomes dissociated from what it is actually attending to, suggesting that like all representations constructed by the brain awareness is an imperfect model.

One implication of the proposed theory is that the construct of awareness might be used to model other people’s attentional state as well as one’s own (1, 2). In that hypothesis, one’s own awareness, even simple sensory awareness, depends on the same mechanisms used during social cognition to attribute a state of awareness to someone else. A relationship between socially attributed awareness and one’s own awareness has been proposed

before (20–23). The present experiment was intended to test this part of the theory.

The study involved two steps. First, subjects were asked to look at a cartoon face and answer the question, “How aware is Kevin of the object next to him?” Brain activity was measured with functional magnetic resonance imaging (fMRI) to determine whether any brain regions were active in association with this social attribution task. Among other brain regions, the temporoparietal junction (TPJ) was found to be significantly active. Second, in the same subjects, in a later experimental session, the same sites in the TPJ that were significantly active in the social attribution experiment were temporarily disrupted using transcranial magnetic stimulation (TMS). As a result, the subjects showed an impairment in their own reported ability to “see” briefly presented visual stimuli. When nearby sites, sites that were in the TPJ but that had not become significantly active in the social attribution experiment, were disrupted using TMS, no significant impairment in visual awareness occurred. It is of course not surprising to find that disruption of a brain area can disrupt visual detection. It is also not surprising that a region of cortex can become active during social attribution. The purpose of the present experiment, however, was to determine whether those two properties overlapped, thereby testing one key prediction of the theory.

## Results

**Social Attribution Experiment.** We know of no previous studies to test specifically for brain activity caused by attributing the property of awareness to others. We therefore designed an fMRI study for that purpose. In the first part of the study, in the scanner bore, subjects viewed a picture of a cartoon face next to an object. The subjects judged, “How aware is Kevin of the object?”, using a button box to respond either 1 (not aware), 2 (somewhat aware), or 3 (very aware). As shown in Fig. 1, two cues were manipulated: the direction of gaze of the face (toward or away from the object) and the emotional expression of the face (matching or mismatching the valence of the object, e.g., a smile paired with a cupcake or a burning house). The subjects therefore viewed visual cues normally informative about the attentional state of another person and used those cues to judge awareness.

## Significance

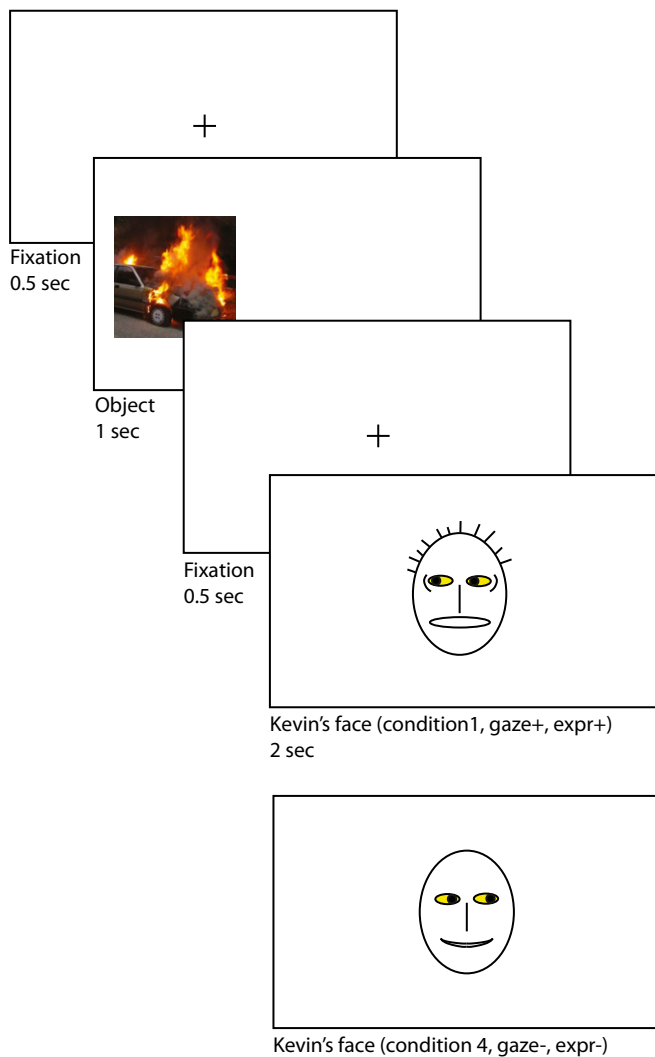
**What is the relationship between your own private awareness of events and the awareness that you intuitively attribute to the people around you? In this study, a region of the human cerebral cortex was active when people attributed sensory awareness to someone else. Furthermore, when that region of cortex was temporarily disrupted, the person’s own sensory awareness was disrupted. The findings suggest a fundamental connection between private awareness and social cognition.**

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**Fig. 1.** Social attribution task. Subjects pressed buttons to rate Kevin's awareness of the object on a scale of 1 (not aware), 2 (somewhat aware), or 3 (very aware). Two versions of the face stimulus are shown corresponding to trial condition 1 (gaze and expression both aligned to the object: gaze+, expr+) and condition 4 (gaze and expression both misaligned with the object: gaze-, expr-). Other conditions included condition 2 (gaze+, expr-) and condition 3 (gaze-, expr+).

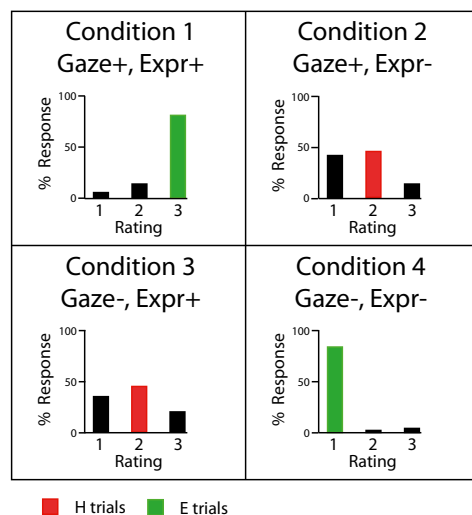
All combinations of cues were tested in a pseudorandomly interleaved manner.

Fig. 2 shows behavioral results for 50 subjects. As expected, when the cartoon's gaze was directed toward the object and its emotional expression matched the valence of the object (condition 1, gaze+, expr+), in most trials (81% of trials across all 50 subjects), Kevin was rated as very aware of the object (rating of 3). When the cartoon's gaze was directed away from the object and its emotional expression mismatched the valence of the object (condition 4: gaze-, expr-), in most trials (84%), Kevin was rated as unaware of the object (rating of 1). When the two cues were in conflict with each other, in condition 2 (gaze+, expr-) and condition 3 (gaze-, expr+), in a plurality of trials (45%), subjects responded with the intermediate rating that Kevin was somewhat aware of the object (rating of 2). These results confirm that subjects relied on the two cues, integrating them together to arrive at a judgment of Kevin's state of awareness.

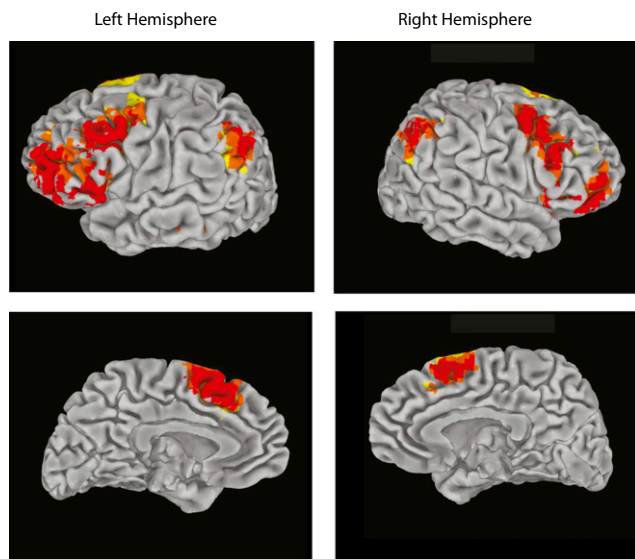
If a brain area is involved in attributing awareness to Kevin, in which task condition should it be more active? If we were looking

for a brain region involved in mathematical computation, it would make little sense to suppose that the area would be least active when a person thinks about the number 0 and more active when the person thinks about 100. Instead, we would suppose that more difficult calculations result in more activity. Just so, if subjects attribute an "awareness of the nearby object" to Kevin, there is no clear reason to suppose that the relevant brain areas are less active when people attribute less awareness or more active when people attribute more awareness. Instead, we should look for brain areas that are more active when the specific computation about Kevin's state of awareness is made more difficult. The present task was designed to manipulate the difficulty of that attribution.

Misaligned social cues can drive greater brain activity than aligned cues (24, 25). Three types of misalignment can be independently tested in the present design. First, the gaze can be misaligned with the object. If any brain regions are sensitive to gaze conflict in the context of this task, they should be revealed by subtracting gaze+ trials from gaze- trials. Second, the emotional expression of the face can be misaligned with the valence of the object. If any brain regions are sensitive to emotional conflict in the context of this task, they should be revealed by subtracting expr+ trials from expr- trials. In the third type of misalignment, the state of awareness implied by one cue can be misaligned with the state of awareness implied by the other cue. We hypothesized that if a system in the brain were responsible for integrating these two cues together to compute a state of awareness for Kevin, then that system should show higher activity when the two cues suggest opposite answers to the particular question of Kevin's awareness (gaze+ expr- trials or gaze- expr+ trials) and should show lower activity when the two cues suggest the same answer to the question of Kevin's awareness (gaze+ expr+ trials or gaze- expr- trials). In effect, a cue



**Fig. 2.** Behavioral results for the social attribution task. Bars show percentages of the three different ratings among all trials by all subjects. Two trial types were defined: "easy integration" (E trials, green bars) and "hard integration" (H trials, red bars). In E trials, behavioral responses suggested that the subjects interpreted the two cues as consistent with each other, both indicating a high degree of awareness or both indicating a low degree of awareness. In H trials, behavioral responses suggested that the subjects had interpreted the two cues as discordant with each other, one cue indicating a high degree and one cue indicating a low degree of awareness, resulting in a judgment that compromised between the two cues. Latencies to respond were similar among all categories (condition 1,  $1.44 \pm 0.49$  s; condition 2,  $1.60 \pm 0.47$  s; condition 3,  $1.52 \pm 0.45$  s; condition 4,  $1.50 \pm 0.46$  s; E trials,  $1.41 \pm 0.46$  s; H trials,  $1.68 \pm 0.52$  s).



**Fig. 3.** Group fMRI data from 50 subjects. Data were aligned to Talairach coordinates and projected onto a standard pial surface. The contrast performed was H trials – E trials. Thresholded at  $P < 0.05$ , corrected for multiple comparisons adjusted for a 15-voxel minimum cluster size.

integration system should work harder when it must integrate two conflicting cues.

One potential pitfall is that the cues might be misinterpreted by the subjects. Suppose Kevin is looking at a car wreck and smiling. The experimenter may have intended those cues to be in conflict with each other (gaze+, expr–), but the subject might think that Kevin is sadistic and that both cues indicate awareness of the wreck. The subjects' own responses were used to try to identify the trials that were interpreted as intended. Trials were categorized into two types. The first was termed “easy integration” (E trials) and the second was termed “hard integration” (H trials). In Fig. 2, green bars show E trials, and red bars show H trials. In E trials, the subjects' behavioral results showed that, as intended, they interpreted the two cues as consonant with each other, both indicating a high degree of awareness (resulting in a rating of 3) or both indicating a low degree of awareness (resulting in a rating of 1). In H trials, the subjects' behavioral results showed that, as intended, they interpreted the two cues as discordant with each other, one cue indicating a high degree of awareness and one cue indicating a low degree of awareness, resulting in a compromise judgment between the two cues (a rating of 2).

E and H trials involved the same social attribution task, the same stimulus materials, the same proportion of positive and negative emotional valence, the same proportion of trials in which the gaze was toward the object or averted from the object, and the same proportion of trials in which the emotional expression matched the object or mismatched the object. E and H trials differed only in that in H trials, the trial-specific behavior of the subjects showed that the two cues were interpreted as discordant with each other on the particular question of Kevin's awareness, and in E trials, the trial-specific behavior showed that the two cues were interpreted as concordant with each other on the particular question of Kevin's awareness. Thus, any areas of the brain that integrate the two cues together to answer the particular question of Kevin's awareness should be more active in H trials than E trials.

No significant fMRI activity was obtained in group analysis when probing the first type of misalignment by subtracting all gaze+ trials from all gaze– trials or when probing the second

type of misalignment by subtracting all expr+ trials from all expr– trials. However, when the third type of misalignment was probed by subtracting E trials from H trials, statistically significant results emerged. Fig. 3 shows the fMRI group results for all 50 subjects. This figure shows the contrast between H trials and E trials thresholded at  $P = 0.05$  corrected for multiple comparisons with a minimum cluster size of 15 voxels. Areas of activation showed a high degree of bilateral symmetry. Coordinates for the peaks and centroids of clusters are provided in Table 1. On each hemisphere, four main areas were found: one in posterior cortex in the TPJ and three in the prefrontal cortex, including a dorsolateral prefrontal region, an anterior ventral prefrontal region, and a region on the medial wall of the hemisphere. Fig. 4 shows the time series data averaged across all subjects for two example areas, the right and left TPJ. The response was significantly larger in H trials than E trials.

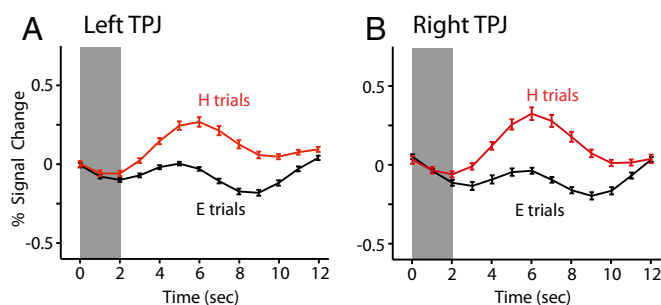
**Visual Detection Experiment.** One to 8 wk after the fMRI experiment, subjects were tested on a visual detection task while single-pulse TMS was applied to the TPJ (Fig. 5). Of 50 subjects tested in the fMRI experiment, 18 returned for the TMS experiment. Subjects were instructed to “press the key as quickly as possible when you see the dot.” The dot was flashed in the left or right visual field or was absent, in equal proportion of trials. The TPJ has been reported to have substantial intersubject variability in its anatomical location (26, 27). Therefore, targeting the TPJ with TMS is ideally done on an individual subject basis rather than on the basis of an average or typical location. In the present study, TMS stimulation was compared between two adjacent sites within the TPJ. For the experimental site, for each subject, the TMS was targeted at the site of peak significant activity that had been found within the TPJ in the social attribution task in the same subject. In a separate block of trials, as a control site, the TMS was shifted 2 cm anterior. (The range of effect of TMS is ~1 cm.) In that way, it was again targeted to the TPJ but at a cortical site where no significant activity had been obtained in the social attribution task in that subject. Because of superficial nerve stimulation, not all subjects could be successfully tested at both sites.

Fig. 6A shows the mean results for TMS of the experimental site (13 subjects). The graph shows the visual detection performance (percentage of targets detected) in the left and right visual field, during TMS to the left and right side of the brain. The interpretation of these results requires caution. Because single-pulse TMS is a minimal perturbation, a sensitive threshold detection was used to measure performance. Because of the sensitivity of the threshold detection task, a large number of factors

**Table 1.** Talairach coordinates for the seven main areas of activation shown in Fig. 3

Area	Peak			Centroid		
	ML	AP	DV	ML	AP	DV
Left TPJ	44	65	45	41	62	38
Right TPJ	–50	65	36	–43	61	39
Left DLPC	47	8	45	39	–3	47
Right DLPC	–56	–14	6	–44	–12	37
Left APC	41	–33	11	47	–20	–4
Right APC	–50	–20	–4	–41	–34	2
SMA	–2	–20	51	0	–17	53

For each area, the coordinates of the centroid (geometric center of the cluster) and of the peak activity are given. For the area on the midline, although the activation extended into both hemispheres, a single region of significant activity overlapped both hemispheres and therefore a single set of coordinates is given. AP, anterior–posterior; APC, anterior prefrontal cortex; DLPC, dorsal lateral prefrontal cortex; DV, dorsal–ventral; ML, medial–lateral; SMA, supplementary motor area.



**Fig. 4.** Time series data for the left (A) and right (B) TPJ. For each brain area, mean fMRI activity is shown as a function of time through the trial. The activity is averaged over eight adjacent voxels per subject and averaged over all subjects (error bars show SE among subjects). The gray bar shows time of face presentation. The TPJ showed significant activity during the social attribution task and was significantly more active in H trials than in E trials.

can shift baseline performance. It has been reported that visual detection is slightly better in the left visual field (28); hence, the left side of the graph is expected to be shifted up. The noise of the stimulator can distract and reduce detection performance; thus, comparison with nonstimulation controls is not useful. For these reasons, main effects are not informative about the hypothesis. Only the interaction term can test the hypothesis. If TMS induces symptoms of visual neglect, then this dataset should show a significant interaction indicating that TMS to the right or left TPJ differentially affected detection in the left or right visual field. A  $2 \times 2$  repeated-measures ANOVA was applied to this dataset. Crucially, the interaction between the two variables was significant in a direction consistent with TMS reducing visual detection in the contralateral visual field (interaction:  $F = 5.76$ ,  $P = 0.03$ ; main effect of visual field:  $F = 1.06$ ,  $P = 0.32$ ; main effect of TMS hemisphere:  $F = 0.08$ ,  $P = 0.78$ ).

Fig. 6B shows the mean results for the control TMS site (14 subjects). We hypothesized that in these trials, there would be no evidence of an interaction effect—no evidence that TMS in the left or right TPJ would differentially affect visual performance in the right or left visual field. In a  $2 \times 2$  repeated-measures ANOVA, the interaction between the two variables was not significant (interaction:  $F = 0.11$ ,  $P = 0.75$ ; main effect of visual field:  $F = 2.59$ ,  $P = 0.13$ ; main effect of hemisphere:  $F = 0.52$ ,  $P = 0.48$ ).

## Discussion

The TPJ, bilaterally but with an emphasis on the right side, has been implicated in theory of mind and especially in reconstructing the cognitive beliefs of others (29, 30). It has also been suggested that the TPJ might not be solely involved in theory of mind but instead may serve a more general role in attention. It may be part of what has been termed the ventral attention network. The TPJ, posterior superior temporal sulcus, and ventral prefrontal cortex are active in association with changes in one's own attentional state, especially when a novel or unexpected stimulus draws attention (31–34). Moreover, lesions in the TPJ are associated with hemispatial neglect (35–37), and disruption of the TPJ has been found to induce visual extinction (38).

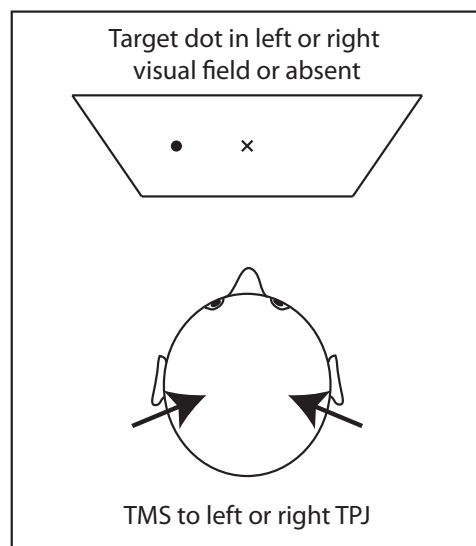
How can two seemingly unrelated functions, social attribution and one's own attention, overlap within the TPJ? Several suggestions have been proposed. One is that the two functions do not entirely overlap in their cortical representations but have some degree of separation (39). Another proposed explanation is that the two functions—social attribution and attention—are opposite and are near each other in cortical space to better suppress each other (40).

We suggest another perspective. We suggest that some aspects of attention, awareness, and social attribution are more closely related than has been previously recognized. In this perspective, the apparent cortical anatomical overlap of attention, neglect, and social attribution results because the three phenomena have significant functional overlap. The proposal can be summarized in the following tentative statements: to monitor and predict attention, it is useful for a brain to construct a representation of attention. The item we report as awareness is a simplified and sometimes inaccurate representation of attention. Awareness can be attributed to oneself or to others, to model one's own or someone else's attention. The TPJ may be a part of the system that attributes awareness to others and to oneself. The present experiment lends support to this theory by showing that specific regions of the TPJ are active during the attribution of awareness to someone else and that disruption of those specific sites can disrupt a subject's reported visual awareness.

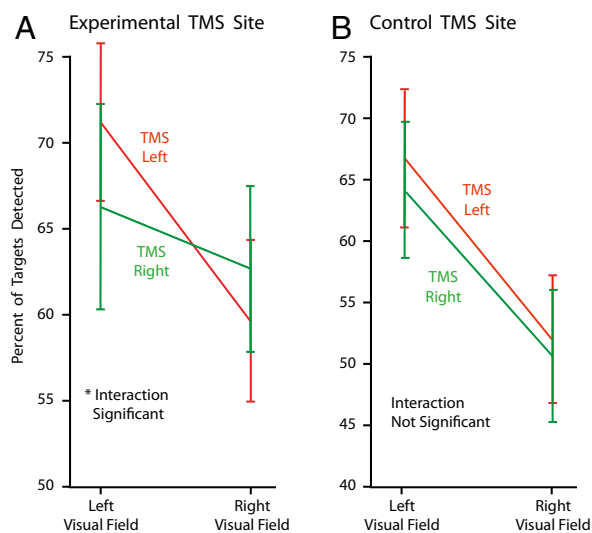
## Materials and Methods

**Subjects.** The study was approved by the Princeton Institutional Review Board. All subjects gave informed written consent, had normal or corrected to normal vision, and had no history of psychiatric or neurological disorders. The fMRI study included 50 subjects (28 females; 45 right-handed; 18–49 y of age). One to 8 wk later, subjects performed the visual detection task while TMS was applied. Because of the high rate of subject dropout between the two studies, a large number of subjects were tested in the MRI phase to result in a useable number of subjects in the TMS phase ( $n = 18$ ; 7 females; 17 right-handed; 18–45 y of age).

**Social Attribution Task.** Stimuli were projected with the Hyperian MRI Digital Projection System (Psychology Software Tools) at the end of the scanner bore. Each subject lay face-up on the scanner bed with foam surrounding the head to reduce head movements and earplugs to reduce noise. The task is diagrammed in Fig. 1. The screen was blank during the 3-s intertrial interval. A fixation cross appeared at the center of the display for 0.5 s. Then, a picture of an object ( $10^\circ$  height, width variable depending on the object but within  $10^\circ$ ) was presented for 1 s. The object could be presented  $15^\circ$  to the left or the right of center. A unique object was used on each trial. Most images came from the Hemera Photo online collection (Hemera Technologies),



**Fig. 5.** TMS experimental design. Each block of trials consisted of a  $2 \times 3$  design: [TMS to the left versus right hemisphere]  $\times$  [target in the left visual field, right visual field, or absent]. In the experimental block, for each subject, the TMS was targeted to the left and right TPJ specifically to the sites of peak significant activity obtained in that subject in the social attribution experiment. In a separate block of control trials, the TMS was targeted to sites in the TPJ where no significant activity had been obtained in the social attribution experiment.



**Fig. 6.** Effect of TMS on visual detection. (A) Mean and SE for experimental trials. The interaction between TMS left/right and visual field left/right is significant ( $F = 5.76$ ,  $P = 0.03$ ). (B) Mean and SE for control trials. The interaction is not significant ( $F = 0.11$ ,  $P = 0.75$ ).

and other images were collected by searching the web. Care was taken that no object contained a face or other social cue that might inadvertently engage social attention. Half of the objects were preselected by the experimenter on a subjective basis to have a positive emotional valence (e.g., a vase of flowers, a wrapped present, a box of chocolates), and half were selected to have a negative emotional valence (e.g., moldy food, a bloody knife, a house on fire). The object then disappeared and the central fixation cross returned for 0.5 s. The cross was then replaced by a line-drawing face at the center of the screen ( $5^\circ$  width,  $8^\circ$  height) for 2 s. The face's gaze could be averted to the left or right. The face could have a schematized smile or alarm expression. The subject's task was to report whether "Kevin" the cartoon seemed not aware (rating of 1), somewhat aware (rating of 2), or very aware (rating of 3) of the nearby object, using a button box with the right hand. Subjects were asked to respond based on immediate, gut impression as quickly as possible after each face presentation.

All 16 combinations ([object left versus right]  $\times$  [object positive versus negative]  $\times$  [gaze left versus right]  $\times$  [expression smiling versus alarmed]) were presented in equal number in randomized order to each subject. The experiment began with a practice run of 15 trials followed by 10 runs of 32 trials each. For each subject, 320 trials of data (excluding practice trials) were collected. Trials were sorted into a  $2 \times 2$  design: [Kevin's gaze matched or mismatched the object]  $\times$  [Kevin's expression matched or mismatched the object]. Fig. 2 shows these four conditions. For each subject, 80 trials were obtained per condition. Trials were also categorized into E and H trials as shown in Fig. 2 and described in *Results*.

**MRI Methods.** Images were acquired with a 3-Tesla Skyra MRI scanner (Siemens) with a standard birdcage head coil. Ten series of 117 volumes were acquired. All acquisitions used a gradient echo, echoplanar sequence with a 64 square matrix (35 axial slices, 3-mm-thick, interleaved acquisition) leading to an in-plane resolution of  $3 \times 3$  mm [FOV  $192 \times 192$  mm, repetition time (TR), 2s; echo time (TE), 30 ms; flip angle,  $77^\circ$ ;  $64 \times 64$  matrix]. The acquisition volume was positioned to cover most of the cerebral cortex.

Echoplanar images were compared with a coaligned, high-resolution anatomical scan of the whole brain taken at the end of each session (40 subjects; MPRAGE sequence; TR, 2.3 s; TE, 2.98 ms; flip angle,  $9^\circ$ ;  $256 \times 224$  matrix; 1-mm<sup>3</sup> resolution) (9 subjects; MPRAGE sequence; TR, 2.3 s; TE, 3.08 ms; flip angle,  $9^\circ$ ;  $256 \times 224$  matrix; 0.9-mm<sup>3</sup> resolution) (1 subject; MPRAGE sequence; TR, 2300 s; TE, 2.93 ms; flip angle,  $9^\circ$ ;  $256 \times 224$  matrix; 1.1-mm<sup>3</sup> resolution).

MRI data were analyzed using AFNI (41) (<http://afni.nimh.nih.gov/afni>), MATLAB (MathWorks), FreeSurfer (42, 43) (<http://surfer.nmr.mgh.harvard.edu>), and SUMA (<http://afni.nimh.nih.gov/afni/suma>). The functional images were slice time- and motion-corrected (44) to the image acquired closest in time to the anatomical scan. The output of the motion-correction algorithm indicated that head movement was negligible ( $<1$  mm) for all subjects. Data

were spatially smoothed with a Gaussian kernel with a full-width half-maximum of 4 mm.

Statistical analyses were performed using multiple regression within the framework of the general linear model (45) with AFNI. The 2-s presentation of the face stimulus was used as a box-car style regressor that was convolved with a standard model of the hemodynamic response. Regressors of non-interest were included to account for head motion and linear drift in scanner signal. For each subject, three contrasts were performed: [H trials] – [E trials]; [gaze– trials] – [gaze+ trials]; and [expr– trials] – [expr+ trials]. Cortical surface reconstructions of each subject were created with FreeSurfer using high-resolution anatomical scans. Functional data were projected onto the surfaces using AFNI/SUMA and thresholded using a Monte Carlo simulation to achieve a corrected significance of  $P < 0.05$  adjusted for a cluster size of 15 adjacent voxels.

Results were also combined among all 50 subjects. The nine-parameter landmark method (46) available through AFNI was used to align the functional activation maps of all subjects to a single reference. A mixed-effects metaanalysis (47) was used to find regions of significant activation thresholded using a Monte Carlo simulation to achieve a corrected significance of  $P < 0.05$  adjusted for a cluster size of 15 adjacent voxels. The analysis was also performed at cluster sizes ranging from 1 to 100 adjacent voxels with similar results.

**TMS Procedures.** Subjects sat with head position stabilized by a chin rest. Single-pulse TMS was applied using two independently triggered figure-of-eight Magstim 200 Mono Pulse TMS coils. The coils were targeted to specific cortical loci by means of theBrainsight 2.2.7 targeting software, using a Polaris camera to track the 3D position and orientation of the coils and the subject's head. After confirmation that a muscle twitch could be evoked from the hand region of the motor cortex, the TMS coils were clamped into position on either side of the subject's head to target the left and right TPJ with a signal strength set at 70% of the maximum for the coil drivers.

For the "experimental" site, coils were aimed toward the peak of significant fMRI activity that had been found in the subject in the social attribution experiment in the left and right TPJ. For the "control" site, coils were again targeted to the left and right TPJ but shifted 2 cm anterior to be aimed at cortical sites that had shown no significant fMRI activity in the subject in the social attribution experiment. Subjects were tested with an experimental block of trials and a control block of trials, the order randomized between subjects. This blocked design was necessary because of the mechanical difficulty of repositioning the coils to target the new cortical site. For four subjects, TMS-induced nerve pain or twitch prevented us from testing both sites. Of 18 subjects, the experimental site was tested in 13 and the control site was tested in 14.

**Visual Detection Task.** Each block of trials (experimental block or control block) had a  $2 \times 3$  design: [TMS to left or right hemisphere]  $\times$  [target dot presented on left visual field, presented on right visual field, or absent]. Trials when the dot was absent were used to measure false alarm rate. Within a block, each of the six trial types was repeated 20 times for a total of 120 trials, and trial types were randomly interleaved.

Visual stimuli were presented on a monitor 100 cm away. On each trial, a central fixation cross was presented for 1.5 s. Then, on a third of trials, a dark dot (one pixel) was presented  $5^\circ$  to the left of fixation for 0.2 s; on a third of trials, the dot was presented  $5^\circ$  to the right of fixation; and on a third of trials, no dot was presented during the same 0.2-s interval. Then a black and white random-dot mask covered the screen for a variable intertrial interval of 4–6 s. The subject was instructed to press a response key as quickly as possible after seeing the dot.

Initial thresholding runs were performed in which the contrast of the target stimulus against the gray background was varied until the subject could detect the target with a hit rate between 40% and 60%. False alarm rates were computed from the no-dot trials, and most subjects performed below a 10% false alarm rate. When false alarm rates rise, it can be an indication that subjects are not motivated and that the performance is a result of guessing. When subjects performed with a false alarm rate greater than 30%, close to the target hit rate of 40%, those blocks were excluded from further analysis. Once the behavioral threshold was obtained, TMS testing began. The TMS pulse was presented to the right or left TPJ on interleaved trials, 0.2 s after the onset of the target dot. This asynchrony was successful in the past for disrupting parietal visual areas (48).

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