Neurobiological Correlates of Social Conformity and Independence During Mental Rotation

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Background: *When individual judgment conflicts with a group, the individual will often conform his judgment to that of the group. Conformity might arise at an executive level of decision making, or it might arise because the social setting alters the individual's perception of the world.*

Methods: *We used functional magnetic resonance imaging and a task of mental rotation in the context of peer pressure to investigate the neural basis of individualistic and conforming behavior in the face of wrong information.*

Results: *Conformity was associated with functional changes in an occipital–parietal network, especially when the wrong information originated from other people. Independence was associated with increased amygdala and caudate activity, findings consistent with the assumptions of social norm theory about the behavioral saliency of standing alone.*

Conclusions: *These findings provide the first biological evidence for the involvement of perceptual and emotional processes during social conformity.*

Man is born free; and everywhere he is in chains.

Jean Jacques Rousseau, *The Social Contract* (1762)

Individuals in democratic societies are free to make choices and express their opinions, but the price of such freedom is sometimes the subjugation of individual choice to the general will—Rousseau's social contract. The accepted resolution of the conflict between individual and group decision making is the well-known "rule of the majority." There is a sound basis for this compromise: a group of individuals is statistically more likely to make a better decision than any one person alone (Arrow 1963; Grofman and Feld 1988). But the superiority of the group disappears when individuals influence each other (Ladha 1992). Moreover, individuals might capitulate to a group, not as part of the social contract, but because the unpleasantness of standing alone makes the majority opinion more appealing than one's own beliefs (Cialdini and Goldstein 2004). How and why this happens has been debated contentiously. Here, we bring functional magnetic resonance imaging (fMRI) to bear on the problem of social conformity.

The modification of an individual's judgment under the pressure of a group was first demonstrated in a series of experiments by Solomon Asch (Asch 1951, 1952). In these experiments, participants were presented with line segments and made judgments about their relative lengths. Although these tasks were perceptually simple, participants frequently gave the wrong answers when a group of peers was also giving the wrong answer. These findings raised the fundamental question of whether people capitulate to the group despite knowing that the group is wrong (i.e., an executive decision-making process) or whether they conform because the group has altered their perception. An individual's judgment has been assumed to reflect what that individual perceives (Coren and Enss 1993), but other factors can influence perception, such as categorization (Goldstone 1995) and social class (Stapel and Koomen 1997), indicating that perception is not simply a passive process. Although many exogenous factors can modify judgments, the mechanism by which this modification occurs and the degree to which these modifications are based on perception or decision making remains unknown.

With a modification of the Asch paradigm, we used fMRI to examine the alterations in brain activity associated with social conformity and independence. We hypothesized that if social conformity resulted from conscious decision making, this would be associated with functional changes in prefrontal cortex, whereas if social conformity was more perceptually based, then activity changes would be seen in occipital and parietal regions. In the present study, instead of judging relative line lengths, normal adult volunteers mentally rotated three-dimensional objects and had to judge whether the objects were the "same" or "different" (Shepard and Metzler 1971). This task has been well characterized both behaviorally and with functional brain imaging, and activity in the intraparietal sulcus increases during the process of mental rotation (Alivisatos and Petrides 1997; Cohen et al 1996; Jordan et al 2001; Tagaris 1997). To induce conformity while performing the mental rotation task, participants were presented with the responses of four peers, who, unknown to the participant, were actors giving wrong answers half of the time. To differentiate the effect of social conformity from the conflict engendered by misinformation, each participant performed one round of trials with the group and another round in which the actors were replaced by computers.

Methods and Materials

Participants

Participants were 33 normal, right-handed volunteers (14 female, 19 male), with a mean (SD) age of 26.0 (5.8) years (range, 19–41 years). An additional two participants were studied but were excluded from the analysis because debriefing indicated that they did not understand the task. One participant had an

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artifact on her functional brain images and was discarded from the analysis, leaving a total of 32 participants. All participants gave written informed consent to a protocol approved by the Emory University Institutional Review Board. In addition to the participants, four actors (two female, two male) were hired to play the role of the group. The actors were selected to be representative of the age, gender, and ethnicity of the people that historically have volunteered for our imaging studies.

Procedure

Each participant was escorted to the MRI waiting room. For each participant, the actors arrived in haphazard fashion, ostensibly as participants in the same experiment. When the participant and all of the actors were present, the group was escorted to the scanner console room, where the task was explained and the consent forms signed by everyone. We used a digital camera to capture images of the participant and actors. The images were then cropped and used in the subsequent task.

To form group cohesiveness, the participant and the actors simultaneously played a practice round of 20 trials on a network of five laptop computers set up in the scanner control room. All of the group actors participated in this practice simultaneously with the participant, and the procedure was repeated for every participant as though the actors were also appearing naively for the experiment. This included taking pictures of the people each time and signing consent forms each time as well. The practice round itself was constructed of trials with no group feedback. There were two reasons for this. First, we wanted to be sure that the participant was able to do the task on their own, without relying on the group. Second, we wanted to avoid biasing the participant in any way regarding the group's intentions before scanning. After the practice round, the participant was placed in the scanner, and the actors were dismissed until the next participant arrived.

Experimental Task

The participant was presented with pairs of abstract three-dimensional stimuli from the Shepard and Metzler set (Figure 1) (Shepard and Metzler 1971). Participants knew that their responses would be visible to the other people. Half of the stimulus pairs represented the same object (hence called Same) rotated relative to each other, and the other half of the stimulus pairs represented objects that were mirror images of each other (hence called Different) and also rotated relative to each other. The task was to judge whether the objects could be rotated to match each other and hence be judged as being Same, or not, in which case they would be judged as Different. The selection of stimuli was based on the original Shepard and Metzler data showing a linear increase in reaction time (RT) with angle of disparity. We used stimulus pairs with angles of disparity ranging from 100° to 180° (mean 134°), to yield moderately difficult stimuli and to maintain believability around the group's wrong answers. The direction of rotation was randomized and counterbalanced across conditions. Because disparity cannot be defined uniquely for mirror image pairs, we approximated the degree of difficulty in the mirror image set by using a set of stimuli that roughly matched the RTs of the Same stimuli. Importantly, all of the experimental manipulations, namely whether the group or computers were correct or incorrect, were balanced between Same and Different stimuli pairs. Stimulus presentation and response acquisition were coordinated by a laptop computer running the software Presentation 0.55 (Neurobehavioral Sys-

tems, Albany, California). Responses were registered on a fiber optic button box, and the RTs were logged through Presentation.

Each trial began with a group decision phase of variable duration. The participant was told that during this period, the group would see the stimuli, and after all of the group members had made their decision about sameness, their responses would be displayed (hence the variable duration). In one third of the trials, the group's response was hidden from the participant, and this was denoted by an "X" next to each person's icon (baseline condition). By predesign, in one third of the trials the group was unanimously wrong (split 50-50 between Same and Different trials), and in the remaining third, the group was correct (also evenly distributed between Same and Different trials). Sixteen trials of each type (baseline, group correct, group incorrect) were ordered randomly. An additional six "split-decision" trials were randomly interspersed throughout each round. In these trials, the group split either 2-2 or 3-1 on the same–different judgment, and these trials were used solely to maintain believability about the interaction. These trials were not used in the analysis.

After the group decision phase, the participant was presented with the group's response for 3 sec (to guarantee that they saw it), and then the participant was presented with the stimulus pair. The mental rotation period ended when the participant indicated their choice by a button press. There was a 12-sec time limit to respond during the mental rotation period. The percent of trials in which the participant did not answer in time was small (mean 2.0%, SEM 0.5%) across the entire experiment. After the response, the participant's and the group's responses were displayed for 3 sec.

Each participant performed two rounds as described above: once with the group and once with the group replaced by computers. The order was counterbalanced across participants and gender. The instructions for the computer round were purposely vague so as not to bias a particular belief about a computer's validity: "Based on a simple algorithm, the computer will make a determination of whether the objects are the same or different."

Imaging

Imaging was performed on a Siemens 3 Tesla Trio whole-body MRI scanner (Siemens AG, Erlangen, Germany). Head movement was restricted with padding. After performing automatic shimming and acquiring a scout image, we performed two runs of echo-planar imaging (EPI) to maximize the blood oxygenation level–dependent (BOLD) effect associated with neuronal activation (repetition time = 2.345 sec, echo time = 30 msec, 64×64 matrix, 35 slices of 3-mm cubic voxels). The number of scans varied in each run, depending on the speed of the participant, but ranged from 363 to 551.

Debriefing Procedure

After the scan procedure, participants completed a questionnaire to assess their perceptions about the experiment. Using a visual analogue scale (VAS), participants were asked to rate their own accuracy, the accuracy of the other players, and the accuracy of the computers. Participants also checked a series of Yes/No questions: 1) Did you ever follow the answer of the other players? If yes, because (select all that apply): a) you were sure you had the right answer and that the majority response was right; b) you were sure you had the right answer, but picked the wrong answer to go with the majority response (explain why); c) you were not sure about your answer and decided to go with the majority response (explain why). Similar sets of questions were
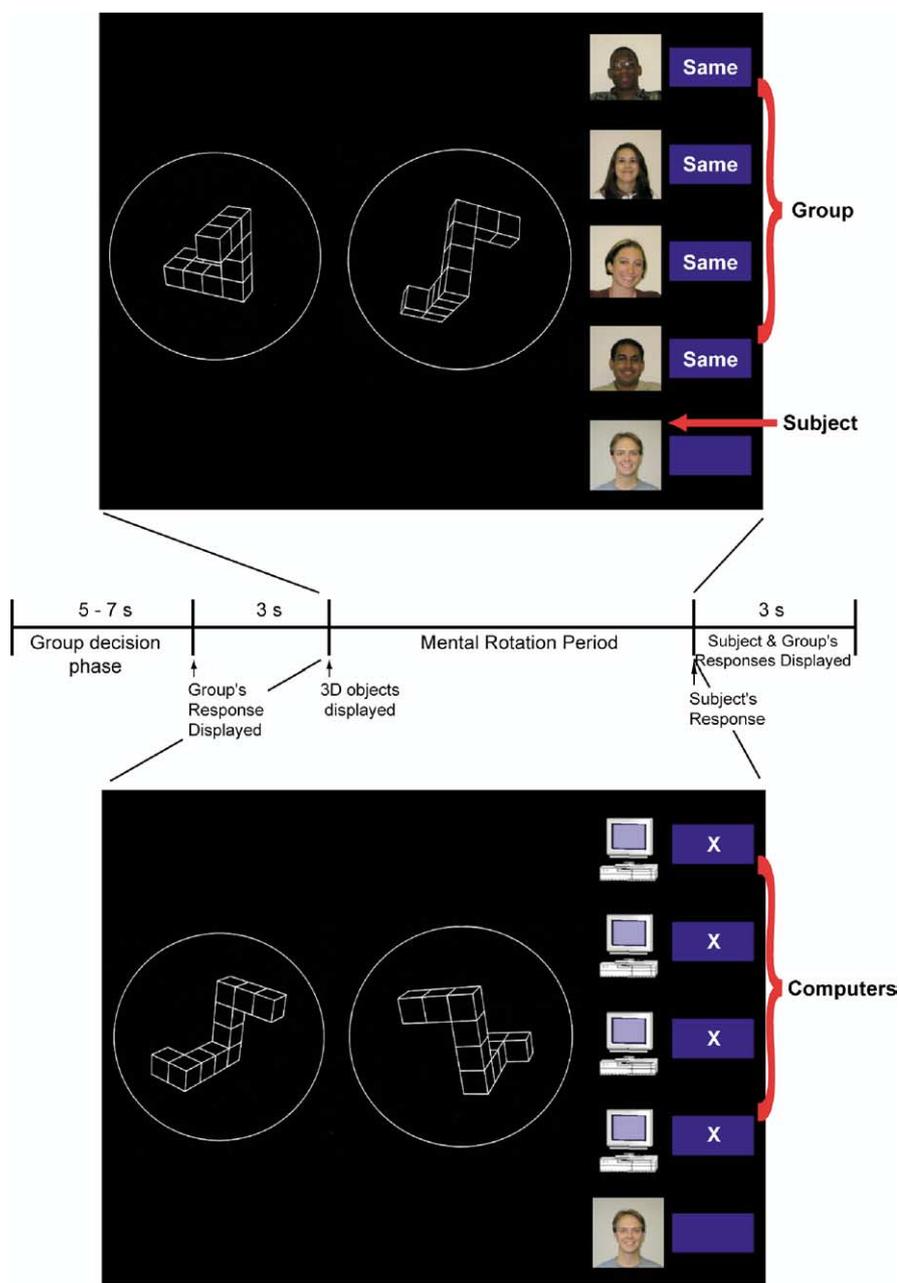
Figure 1. Participants were presented with pairs of three-dimensional objects on a computer screen during a mental rotation period, and they had to decide whether the objects were the "same" (can be rotated to match) or "different" (no rotation can make them match). To induce social conformity, each trial began with the objects being shown first to a group of peers (Group; top panel). In actuality, the group was composed of actors, and their responses were predetermined. After a variable-duration decision phase, the collective response of the group was displayed to the participant. This ensured that the participant would see the group's response. After 3 sec, the same pair of objects was displayed to the participant. In the example shown, the objects are different, but the group has unanimously said they are the same (the participant has not responded yet). The participant responded with a button press, indicating whether the objects were the same or different. Trial types were randomized across three conditions: group correct, group incorrect (as shown), and baseline (responses blinded to participant with an "X"; bottom panel). One run of 48 trials was performed with the group, and another run of the same 48 trials was performed with the group replaced by computers (bottom panel), in which the faces of the group were substituted with computer icons. The order of group and computer runs was counterbalanced across participants and gender.

asked for the cases of going along with the computers, going against the group, and going against the computers. All but three participants filled out the questionnaire.

Image Analysis

All image analysis was performed with SPM2 (Wellcome Department of Imaging Neuroscience, London, United Kingdom). Functional images were first interpolated to correct for slice timing. Functional images were then corrected for motion and then spatially normalized to the SPM2 EPI template reslicing at $3 \times 3 \times 3$-mm resolution and smoothed with an 8-mm isotropic gaussian kernel (Ashburner and Friston 1999; Friston et al 1995).

Statistical analysis was performed with a two-step procedure, first at the individual level and then at the cohort level, providing statistical inference in a random-effects model across participants (Friston et al 1999). Several different first-level models were used,

each aimed at contrasting a specific main effect. This included separate models based on external information (correct, incorrect, or none), stimulus type (same or different), participant's response (correct or incorrect), as well as a model that categorized trials on the basis of a combination of these effects. The more fine-grained categorization of trial types meant a concomitant loss of observations for some participants who did not make many errors, so this model was used only in the analysis of conformity and independence (see Supplement 1 for effects and their durations). Contrasts were generated from the design matrix at the individual participant level and then entered into a second-level analysis for statistical inference. We considered significant activation to have occurred in a cluster of at least 5 voxels (except as noted otherwise) if the peak activation level was significant at $p < .001$ (uncorrected for multiple comparisons).
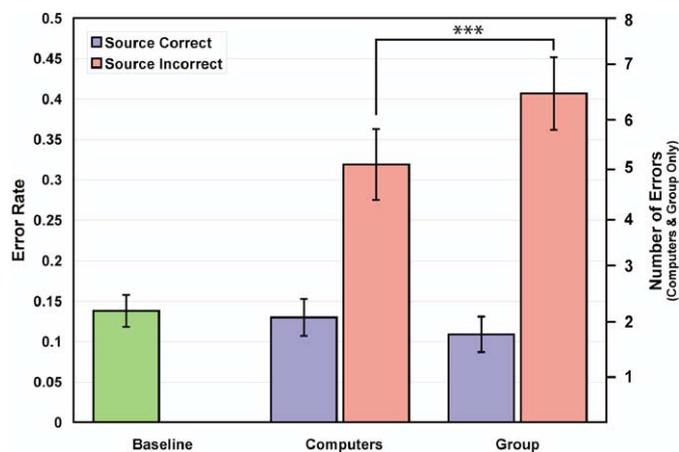
Figure 2. Mean error rates as a function of the source (Computers or Group) and type (Correct or Incorrect) of information. The actual number of errors in the Computers and Group conditions are shown on the right-hand scale (the number of errors in the baseline condition must be multiplied by two, because there were twice as many trials in this condition). Repeated-measures analysis of variance revealed a large main effect of the type of information (Correct, Incorrect, or None) on error rates [$F(2,31)$ = 31.29, $p <$ .0001], and post hoc comparisons indicated that incorrect information resulted in significantly greater error rates ($p <$ .0001) than both baseline (green) and correct information (which were not significantly different from each other, p = .348). The interaction of the source of information (Group or Computers) with the type of information (Correct, Incorrect, or None) was also significant [$F(2,31)$ = 6.53, $p <$ .004], and the post hoc comparison indicated that the error rate when the group gave wrong information (mean 41%, SEM 5%) was significantly greater than when the computers gave wrong information (mean 32%, SEM 4%) [***paired $t(32)$ = 3.55, $p <$ .001].

Results

Behavioral Measures of Conformity

Conformity was defined as agreeing with the exogenous source of information, either peers or computers, when the information was wrong. Conformity was measured behaviorally by the change in error rates of the participants between their baseline performance and the conditions in which exogenous information was presented (Figure 2). The baseline error rate was computed for each participant from the trials in which no group (or computer) information was given (mean 13.8%, SEM 2%). The error rate increased to 41% (SEM 5%) when the group gave wrong information, which was significantly greater than when the computers gave wrong information (mean 32%, SEM 4%) [paired $t(32)$ = 3.55, $p <$ .001].

There were significant differences in RTs, and these differences depended on several factors (Figure 3). After adjusting for the effect of Same/Different stimuli, there was a significant lengthening of RT when external information was present [$F(2,579)$ = 20.27, $p <$ .0001]. But restricting the analysis to trials in which incorrect information was provided, there was no significant difference in RT between going with (i.e., Conformity) or against (i.e., Independence) the information [$F(1,190)$ = 2.65, p = .105], indicating that participants did not take longer for one behavior or the other. Notably for the subsequent image analysis, the source of the external information, either Group or Computers, also did not have a significant effect on RT [$F(1,576)$ = .554, p = .457].

Debriefing Questionnaire

Participants were debriefed through a combination of a VAS and specific questions. The reliability of the VAS ratings for accuracy

was assessed by the correlation between self-rated accuracy (Self) and actual overall accuracy (Actual). Linear regression showed a strong correlation between these two measures where Self = .17 + .69 × Actual (R = .67, $p <$ .0001, df = 27). If we assume an intercept at the origin, then Self = .90 × Actual, indicating that participants, on average, slightly underestimated their true accuracy but were within 10% of their true value.

On average, the group's accuracy was rated as 65.1% (SEM 2.5%), and the computers' accuracy was rated as 61.2% (SEM 2.7%). These were not significantly different from each other [two-tailed paired $t(28)$ = 1.491, p = .147], indicating that the participants did not view the group or computers as more reliable than one another. When asked why they went along with the group, 82.8% of participants indicated that on some trials they were sure that they were right and that the group was right too (89.7% for the computer), 58.6% indicated that on some trials they were not sure about their answer and decided to go with the majority (44.8% for the computer), and 3.4% indicated that were sure they had the right answer but went with the majority response anyway (3.4% for the computer).
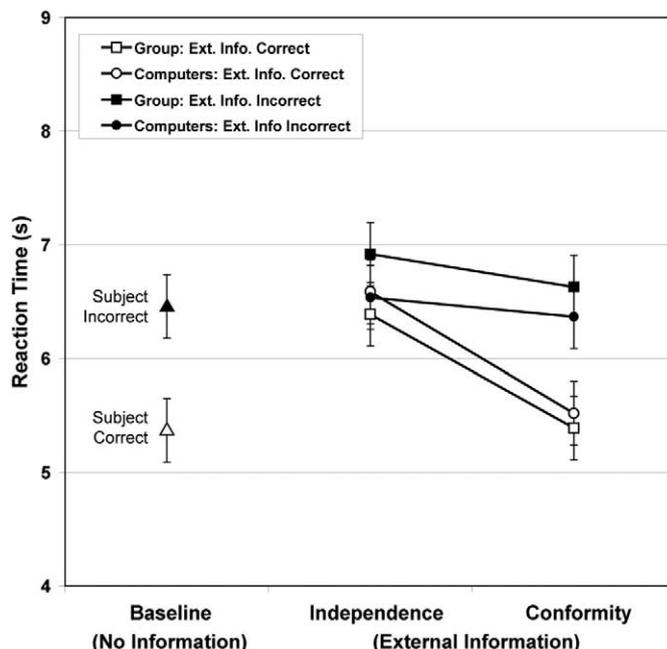
Figure 3. There were significant differences in reaction times (RTs), and these differences depended on several factors. A mixed-model analysis with repeated effects showed that the stimulus pair (Same or Different) had a significant effect on RT [$F(1,579)$ = 66.38, $p <$ .0001], and a post hoc comparison indicated that Different stimuli took .815 sec (SEM .100 sec) longer than Same stimuli. After adjusting for the effect of Same/Different stimuli in this model, there was a significant lengthening of RT when external information was present [$F(2,579)$ = 20.27, $p <$ .0001]. Moreover, participants took, on average, 1.11 sec (SEM .18 sec) longer to give an incorrect response than a correct response [$t(32)$ = 6.2, $p <$ .0001], but this was modulated by an interaction with the nature of the external information presented [$F(2,579)$ = 20.87, $p <$ .0001]. Restricting the analysis to trials in which incorrect information was provided, there was no significant difference in RT between going with (i.e., Conformity) or against (i.e., Independence) the information [$F(1,190)$ = 2.65, p = .105], indicating that participants did not take longer for one behavior or the other. Notably for the subsequent image analysis, the source of the external information, either Group or Computer, also did not have a significant effect on RT [$F(1,576)$ = 0.554, p = .457].
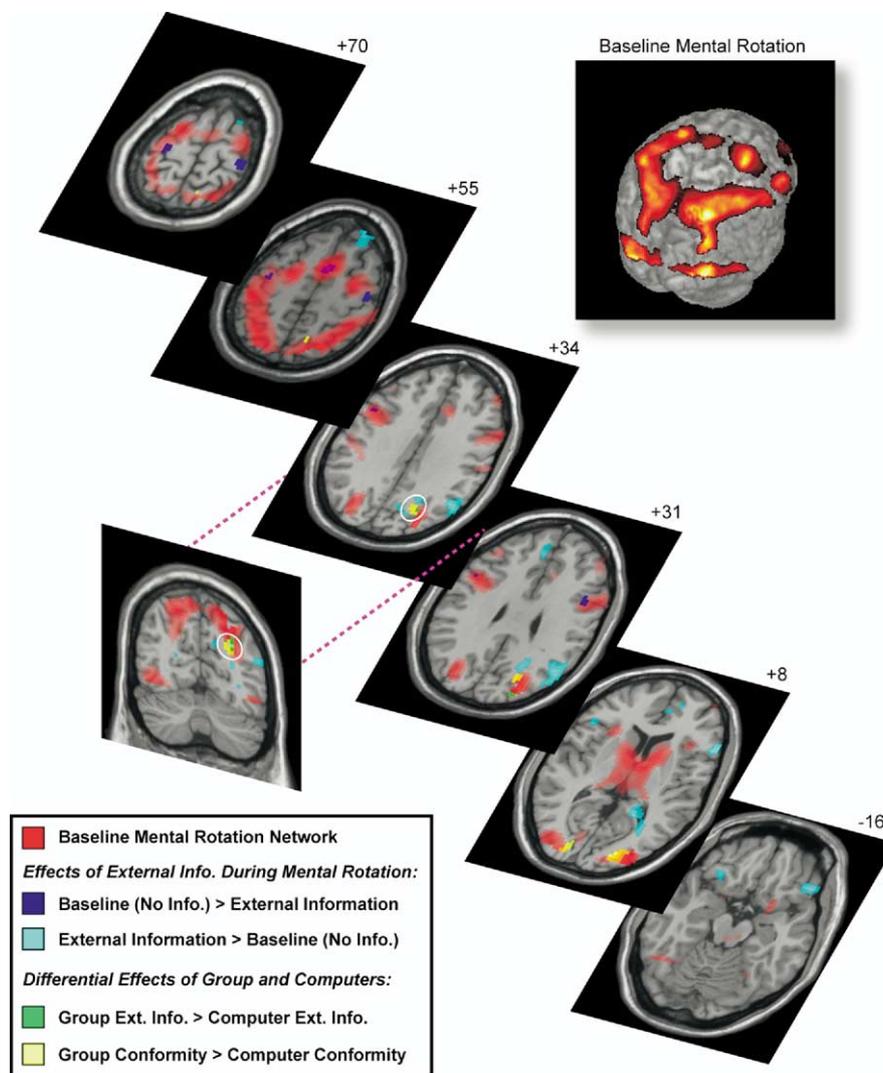
Figure 4. Effects of different forms of external information on brain activation during mental rotation. At baseline (mental rotation with no external information), a wide network of both cortical and subcortical regions was activated (inset and red regions) (all overlays thresholded at $p < .001$, uncorrected for multiple comparisons, and cluster size > 5 voxels). Montreal Neurological Institute coordinates of selected axial slices are indicated adjacent to each slice. External information, regardless of the source, was associated with decreased activation in a small subset of this mental rotation network (dark blue), primarily in frontal regions and the supplementary motor area (slices at +55 and +70 mm). In contrast, external information was associated with increased activation (light blue) in regions largely outside of the mental rotation network, particularly in the right supramarginal gyrus (slices at +31 and 34 mm). When the effects of external information were compared according to the source (Group > Computers), only two small clusters adjacent to the mental rotation network in the right intraparietal sulcus were identified (green). Moreover, the activity in these clusters was largely accounted for by the subset of trials in which the participants conformed to incorrect information from the Group (yellow). An additional two clusters in the occipital cortex were identified as differentiating between conforming to the Group versus the Computers (slice at +8 mm). Thus, the main effect of social conformity (i.e., conforming to the Group relative to conforming to the Computers) was exhibited within the most posterior aspects of the baseline mental rotation network. Because of the anatomic confluence of these different effects within the right intraparietal sulcus, a region-of-interest analysis was performed on this area (circle).

Brain Responses During Mental Rotation

All of the brain imaging results refer to changes in activity during the period of mental rotation, which was defined as the period beginning with the presentation of the stimulus pair and ending with the participant's judgment, excluding the actual response (modeled separately).

We used the trials in which participants received no external information to delineate the baseline mental rotation network. This network provided an anatomic reference against which the effects of external information could be gauged. Mental rotation was associated with increases in BOLD activity in a network of brain regions including occipital cortex, parietal cortex, and parts of the frontal cortex (Figure 4, inset). This network was broadly consistent with previous brain imaging studies of mental rotation (Alivisatos and Petrides 1997; Cohen et al 1996; Jordan et al 2001; Tagaris 1997), and because of the large extent of activations, we do not report specific cluster locations.

Effects of External Information

Two distinct effects of external information were observed, regardless of the source of information. First, the presence of external information was associated with decreased activation in a subset of the baseline mental rotation network (Figure 4, dark blue). These activations were positive but of a decreased magnitude from baseline mental rotation. With the exception of a single cluster in the left superior parietal lobe, all of these clusters

Table 1. Differential Activations During Mental Rotation, Where Group > Computers, and the External Information Was Incorrect

Brain Region[a]	MNI Coordinates (x, y, z)	Cluster Size	t Statistic
Social Conformity (Participant Incorrect)			
L superior occipital gyrus	−18, −90, 9	21	4.99
R superior occipital gyrus	24, −87, 9	34	4.87
R intraparietal sulcus	24, −69, 36	21	4.83
R intraparietal sulcus	18, −57, 48	20	4.09
Social Independence (Participant Correct)			
R amygdala	15, −3, −18	3[b]	4.30
R caudate head	6, 12, 3	7[b]	3.85

Voxels were selected for $p < .001$ (uncorrected) and extent ≥ 10 voxels (except as noted).
MNI, Montreal Neurological Institute; L, left; R, right.
[a]Brain regions determined from the Duvernoy atlas (Duvernoy 1999).
[b]Because of the small size of these structures, the extent threshold was relaxed.

were located frontally. Second, external information was associated with increased activation (Supplement 1) in regions largely outside, but in close proximity to the mental rotation network (Figure 4, light blue). The right supramarginal gyrus was the largest area exhibiting this increase in activation.

Differential Effects of Group and Computers

To focus on the social component of information during mental rotation, we first contrasted trials with Group Information versus Computer Information, irrespective of whether the information was correct. Because we were interested specifically in the social component, we identified those regions in which the activity was greater for information originating from the Group (i.e. Group Information > Computer Information). At a significance threshold of $p < .001$ (uncorrected) and extent ≥ 10, only one cluster was identified in the right intraparietal sulcus (Montreal Neurological Institute [MNI] coordinates: 24, −69, 39; $t =$ 4.52, cluster size = 12 voxels) (Figure 4, green).

To focus specifically on the social component, we formed contrasts from those trials in which the external information was incorrect and examined the differential effects of Group and Computers. Conformity was defined as those trials in which the participant went along with the external information when the information was incorrect, and independence was defined as those trials in which the participant gave the correct answer when the external information was incorrect. The difference between Group and Computers on these two subsets of trials therefore isolated the social element. Regions in which Group Conformity resulted in greater activation than Computer Conformity are shown in Table 1 and Figure 4 (yellow). Significant clusters were observed bilaterally in the visual cortex that overlapped the baseline mental rotation network. Two other clusters were identified in the right intraparietal sulcus that were at the anatomic confluence of the mental rotation network and the network identified as being more active to external information (Figure 4, circle).

Because the right intraparietal sulcus figured prominently in several contrasts (e.g., baseline mental rotation, Group Info > Computer Info, and Group Conformity > Computer Conformity), and because the specific part of the sulcus implicated in social conformity seemed to lie at the anatomic junction of external information and mental rotation, we performed a region of interest (ROI) analysis on this area. An ROI analysis allowed a more detailed investigation of the effects driving the response in this area, showing that there was a main effect of source (Group vs. Computers) and an interaction between source of information

and whether the participant gave a correct or incorrect response (i.e., social conformity) (Figure 5).

In contrast to social conformity, social independence resulted in only two small clusters of activation: in the right amygdala and head of the right caudate nucleus (Figure 6, Table 1).

Discussion

We are interested here in the potency of social pressure in inducing conformity and how information that originates from humans, versus inanimate sources, alters either perception or decision making and the neural basis for such changes. When
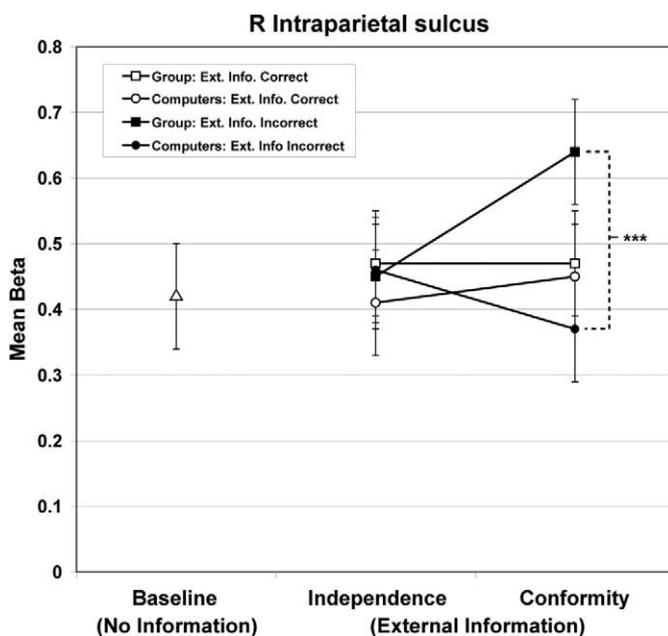
Figure 5. Region-of-interest (ROI) analysis of the right intraparietal sulcus. A 12-mm diameter sphere was centered on the anatomic confluence of effects shown in Figure 4 (Montreal Neurological Institute coordinates: 25, −66, 32). The best-fitting model by Akaike's Information Criterion (Akaike 1974) showed that there was a main effect of source (Group vs. Computers) [$F(1,631) = 6.56$, $p = .01$] and that there was a significant interaction between the source of information and whether the participant gave a correct or incorrect response (i.e., Social Conformity) [$F(1,631) = 5.80, p = .016$]. Post hoc comparisons indicated that conforming to incorrect information from the Group was associated with significantly greater activity than conforming to incorrect information from the Computers [***mean difference .271 (SEM .078), $F(1,71) = 11.98, p < .001$].
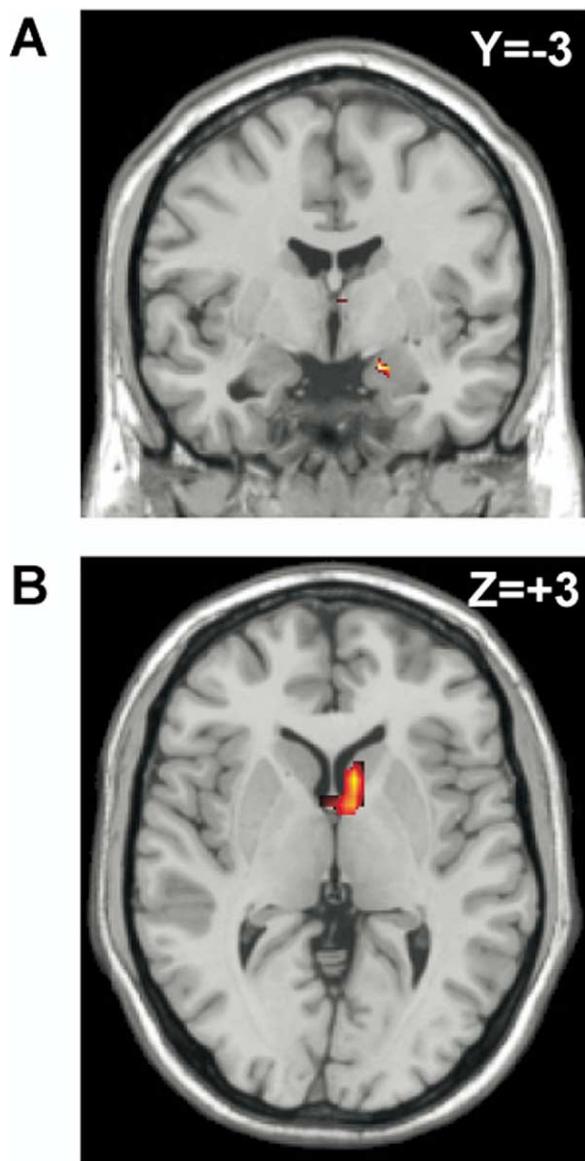
Figure 6. Brain regions associated with greater activity during mental rotation when participants went against the Group, relative to going against the Computers. In the subset of trials in which the external information was incorrect, only the right amygdala (A) and the right caudate (B) showed greater activity when Group Independence was compared with Computers Independence. Peak activations in these two regions were significant at $p <$ .001, uncorrected, but the extent of activation is shown thresholded at $p <$ .01. See Table 1.

participants conformed to the judgments of a group of peers, relative to nonhuman sources, activity within the brain network that normally accomplishes the task of mental rotation was altered. These findings indicate that with mental rotation, the effects of social conformity are exerted on the very same brain regions that perform the task. Although an extensive network of regions was involved in mental rotation, it was striking that the effects of social conformity were detected only in the most posterior aspects—the occipital and parietal lobes.

Perception Versus Decision Making

Asch himself raised the possibility that social pressure could alter perception (Asch 1952). The posterior distribution of the

conformity effect adds further evidence to the possibility that conformity was effected through a change in perception. Previous studies have shown that activity in visual cortical neurons correlates with perception (Britten et al 1992), and in humans, visual cortex activity correlates more closely with perception than actual stimulus properties (Ress and Heeger 2003), a finding consistent with the results reported here. We found evidence for modulation of the same visual cortical regions when participants were about to conform to the group. The lack of concomitant activity changes in more frontal areas was highly suggestive of a process based, at least partially, in perception. Of course, changes in frontal activity could have occurred below our detection threshold, but with 32 participants, we think this unlikely.

It is well known that attention can exert a "top-down" modulation of visuospatial processing (Pessoa et al 2003), and this might underlie the activity changes that we observed. When confronted with a situation in which the group was giving wrong information about a stimulus pair, it was possible that the wrong information evoked extra visual attention. If participants attended more strongly to humans than computers, then one would expect to see greater activation in attentional networks upon presentation of human information, even before the period of mental rotation. But when we compared the activation to Group and Computers before the appearance of the shapes, no differences in activity were observed in either the occipital or parietal cortex, even after dropping the threshold to $p <$ .01. Although human information was more potent in inducing conformity and more strongly associated with changes in perceptual processing in parietal cortex, we cannot conclude that these effects were mediated simply because the participants attended more strongly to human faces.

Another possibility is that the Group evoked a "virtual percept" that competed with that of the participant. Competing visual stimuli generally decrease visual cortex activation, but internally generated attention increases visual and parietal cortex activity (Kastner et al 1999). Trials in which a participant was about to conform represented precisely those trials in which the participant relied on the Group (or Computers). We can assume this information was both represented and processed in a manner substantially different from the shapes themselves, because of the increase in activity outside the baseline mental rotation network (Figure 4, light blue). Even so, the processing of this external information seemed to overlap the mental rotation network in both the intraparietal sulcus and visual cortex (Figure 4, yellow). When the Group (or Computers) gave the wrong answer, a "virtual" percept was created, and although participants were always presented with one stimulus pair, the stimulus could have represented two judgments. Visual cortex activity has been found to correlate with the degree of competition between different percepts (Rees and Frith 1998), and here, we interpret the level of visual cortex activity to indicate the amount of competition between the individual's percept and the external percept provided by the Group (or Computers). The increase in activity within the intraparietal sulcus suggested that the Group's percept was stronger than that of the Computers. The intraparietal sulcus has been implicated in decision making (Shadlen and Newsome 2001), but the right intraparietal sulcus also orients attention to extrapersonal space (Nobre et al 2004). The confluence we found of external information with mental rotation in this area suggests that this region might serve as a mixing ground for internal and external percepts. When activity increased beyond a critical threshold in the intraparietal sulcus, this might

have represented the "winning" of the external percept over the participant's own percept, and conformity became imminent.

Of course, this does not rule out an executive decision-making process. The debriefing questionnaire partially addressed the degree to which participants were consciously aware of their judgments. Participants were surprisingly accurate in gauging their own performance as well as that of the Group and the Computers. They tended to underestimate their own performance slightly and overestimate that of the Group and the Computers, but there was no evidence that participants found either the Group or Computers more reliable than each other. The vast majority of participants indicated that, at least on some trials, they went along with the external information because they thought that they had arrived serendipitously at the same correct answer.

One possibility is that the external information created confusion in the participants' minds where none existed before. Undoubtedly this contributed to some of the effect, but because social conformity was defined as the difference between conforming to a group and conforming to computers, an added attribute of information originating from humans must have been involved. Another possibility is that external information relieved some of the load on the participants' mental rotation network. In fact, we did find evidence for this. We observed decreased activations during mental rotation in frontal regions when external information was present, regardless of the source (Figure 4, dark blue). Although these regions tended to be restricted spatially, their distribution was markedly different than the aforementioned conformity changes. With the exception of one cluster in the superior parietal gyrus, all of these regions of decreased activation were anterior to the central sulcus. This suggests that participants were still mentally rotating the objects, but the external information relieved the processing load at the output stage. Moreover, this "off-loading" effect did not depend on the source of information.

The Pain of Independence

Compared with behavioral research of conformity, comparatively little is known about the mechanisms of nonconformity, or independence. In one psychological framework, the group provides a normative influence on the individual. Depending on the particular situation, the group's influence might be purely informational—providing information to an individual who is unsure of what to do. More interesting is the case in which the individual has definite opinions of what to do but conforms owing to a normative influence of the group due to social reasons. In this model, normative influences are presumed to act through the aversiveness of being in a minority position (Hornsey et al 2003).

The amygdala activation in our experiment was perhaps the clearest marker of the emotional load associated with standing up for one's belief. This activation occurred during the period of mental rotation, indicating that the emotional engagement was intertwined with the perceptual judgment process. Amygdala activation has been associated frequently with negative emotional states (LeDoux 2000), but the amygdala is also known to modulate social behavior and to be activated by human faces, particularly when the faces have emotional significance (Aharon et al 2001; Amaral et al 2003; Singer et al 2004; Whalen et al 1998). Because we observed amygdala activation only when participants went against the group and not the computers, the amygdala activation might have represented the interaction of negative affect with the social salience of information originating from one's peers—a finding consistent with social norm theory

(Cialdini and Goldstein 2004). Although the peak activation difference was highly significant, the spatial extent was small, and so we must view this as a tentative finding. Nevertheless, several fMRI studies of amygdala activation have reported small spatial extents (Phan et al 2004; Phelps et al 2001; Whalen et al 1998).

Another key component of social norm theory is that the information provided by the group must be salient to the individual. Besides the amygdala, the only other brain structure differentially activated by social independence was the right caudate nucleus (Figure 6). Several studies in both nonprimates and humans have recently implicated this region of the striatum as critically involved in the processing of stimulus saliency (Horvitz 2000; Zink et al 2003, 2004). The striatum seems to be particularly involved in the selection of behaviors based on stimulus salience (Redgrave et al 1999). It is therefore not surprising that the caudate should be most active when the participant behaved independently of the group, for this is the condition of most salience: conflicting information and social isolation.

Limitations

Although we attempted to control for as many aspects of conformity as possible, there are limitations to our study. First, we had to modify Asch's original experiment. Asch used a perceptually unambiguous task of judging relative line lengths, and so any errors participants made would have been caused by social conformity. But even the most conformist of participants in Asch's experiments only went along with the group a few times. In a neuroimaging study, this would not provide a sufficient number of trials to examine. Even with the mental rotation paradigm, there was a relatively low number of conformity trials, averaging five to six per person. This necessitated scanning a large number of participants, which, although partially compensating for the low statistical power, might have led to type II statistical errors, especially with regard to the lack of frontal changes. Second, our experimental setup with a group of peers might have created a "demand" effect on the participants, in effect inducing them to conform more than they would have under other circumstances. Finally, because of the visual nature of the task, the conformity-associated changes in visual and parietal cortex might be specific to visual tasks. These limitations, however, point the way toward future experiments—for example, the role of automaticity versus volition in the perceptual change, or the appeal of belonging to a particular group, or even developmental effects, such as the susceptibility of adolescents to peer pressure.

To our knowledge, this is the first study of brain activity associated with social conformity and independence. Here, we present brain imaging findings that provide key biological evidence for the major psychological theory of conformity and might help resolve some of the controversy surrounding Asch's conformity effect. Asch's results have been replicated inconsistently (Bond and Smith 1996). The two main questions surrounding this inconsistency are whether conformity is culturally determined and whether conformity has changed over time as sociopolitical forces have shaped the relative acceptance of individualism or collectivism (Larsen 1982; Perrin and Spencer 1980). Until now, the only measurements of conformity came from experimental observation of individuals capitulating to a group and the participants' self-report. Our results affirm the hypothesis that brain regions classically associated with perception can be altered by social influences, although the exact

mechanism of this modulation has yet to be determined. The flip-side of conformity, independence, was found to be associated with subcortical activity changes indicative of emotional salience, a finding that lends support to social norm theory (Cialdini and Goldstein 2004).

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