Neural basis of stereotype-induced shifts in women's mental rotation performance

Maryjane Wraga,[1] Molly Helt,[1] Emily Jacobs,[2] and Kerry Sullivan[1]

[1]Department of Psychology, Smith College, Northampton, MA 01063, USA and [2]Department of Neuroscience, University of California, Berkeley, Berkeley, CA 94704, USA

Recent negative focus on women's academic abilities has fueled disputes over gender disparities in the sciences. The controversy derives, in part, from women's relatively poorer performance in aptitude tests, many of which require skills of spatial reasoning. We used functional magnetic imaging to examine the neural structure underlying shifts in women's performance of a spatial reasoning task induced by positive and negative stereotypes. Three groups of participants performed a task involving imagined rotations of the self. Prior to scanning, the positive stereotype group was exposed to a false but plausible stereotype of women's superior perspective-taking abilities; the negative stereotype group was exposed to the pervasive stereotype that men outperform women on spatial tasks; and the control group received neutral information. The significantly poorer performance we found in the negative stereotype group corresponded to increased activation in brain regions associated with increased emotional load. In contrast, the significantly improved performance we found in the positive stereotype group was associated with increased activation in visual processing areas and, to a lesser degree, complex working memory processes. These findings suggest that stereotype messages affect the brain selectively, with positive messages producing relatively more efficient neural strategies than negative messages.

Keywords: stereotype threat; fMRI; mental rotation; intellectual performance; spatial cognition

Last year, former Harvard President Lawrence Summers rekindled the debate on the nature of intelligence by suggesting that women may be underrepresented in the sciences because of a lack of "intrinsic aptitude" for science compared to men (Ripley, 2005). Summers' statement reflects the theoretical position that intelligence is an innate ability and, as such, can be measured reliably through academic testing (e.g. Hernnstein and Murray, 1994). An alternate viewpoint is that social rather than biological factors may play a role (e.g. Hermann et al., 1990; Hyde et al., 1990; Singer and Stake, 1986). In particular, academic performance can be influenced by the activation of socio-cultural stereotypes, especially in stigmatized groups such as women (Spencer et al., 1999), African Americans (Steele and Aronson, 1995), Asian Americans (Shih et al., 1999), and the elderly (Levy, 1996). For example, women who are reminded of gender differences in mathematical abilities perform worse on subsequent math tests compared to men (Spencer et al., 1999).

Recent research suggests that academic susceptibility to stereotype messages is not always negative. Activation of *positive* stereotypes also can *improve* intellectual performance (Shih et al., 1999; Wraga et al., in press). The precise

mechanisms underlying such fluctuations in intellectual performance currently are unknown. One hypothesis implicates heightened arousal (Ben-Zeev et al., 2005; O'Brien and Crandall, 2003). High levels of arousal have been shown to both increase performance on easy tasks and decrease performance on difficult tasks (Zajonc, 1965). This hypothesis partially explains the stereotype susceptibility findings, in that negative stereotypes diminish performance on difficult tasks. However, it cannot account for positive shifts in performance associated with positive stereotypes, many of which also have involved difficult tasks. In contrast, a more comprehensive hypothesis posits that performance fluctuations are determined by relative efficiency of processing (Steele and Aronson, 1995). By this account, performance deficits are caused by negative stereotype-induced increases in cognitive or emotional load that interfere with performance (Croizet et al., 2004; Schmader and Johns, 2003). The corollary of this hypothesis is that exposure to positive stereotypes eliminates this additional cognitive or emotional burden, resulting in greater efficiency of processing.

In the current study, we used functional magnetic resonance imaging (fMRI) to test the processing efficiency hypothesis on a spatial reasoning task. Gender differences in spatial abilities often are cited by social scientists as a critical factor for why so few women go into fields such as architecture, engineering, physics, and mathematics (Crawford et al., 1995; Kirkman et al., 2000; Singer and Stake, 1986). Mental rotation tasks, in particular,
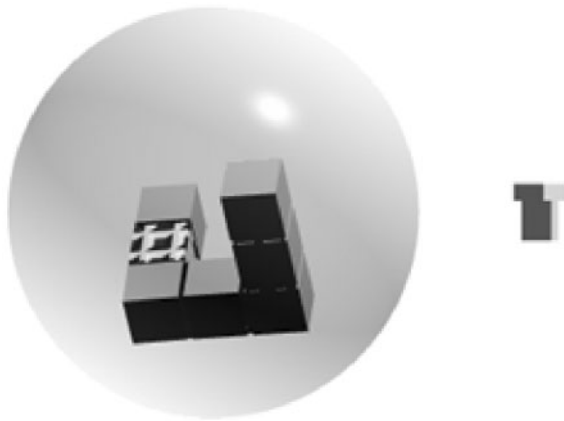
Fig. 1 Sample stimuli used in the self-rotation task. Participants imagined rotating themselves to a location just behind the T-prompt. They then judged whether the object's textured cube was visible from that new perspective. The correct answer for this trial is "yes".

have produced large and enduring gender differences favoring men (Linn and Petersen, 1985; Masters and Sanders, 1993; Voyer *et al.*, 1995). Moreover, there is evidence that gender differences specifically in mental rotation contribute to men's superior performance in the math sections of the SAT and GRE (Casey, 1996). We examined the neural substrate underlying effects of positive and negative stereotype messages on women's performance of imagined rotations of the self (Figure 1), which are thought to play a major role in tasks of human spatial reasoning (e.g. Zacks *et al.*, 2003). Like their imagined object-rotation counterparts, imagined self-rotations produce sizeable gender differences favoring men (Wraga *et al.*, in press). However, a unique feature of imagined self-rotation tasks is that they can have a social implication when described in the context of perspective taking, which involves adopting and/or empathizing with another's viewpoint. Thus, we were able to manipulate the social connotations of the task, construing it either as reflecting performance of perspective taking (associated with female ability) or of spatial reasoning (associated with male ability). Our behavioral version of this paradigm has produced significant shifts in task performance in both men and women (Wraga *et al.*, in press).

We conducted whole-brain fMRI on three groups of women, each of which received a different stereotype message prior to testing. The positive-stereotype group was informed that women perform better on imagined self-rotation tasks than men because of greater ease at perspective taking. The negative-stereotype group was informed that men perform better on imagined self-rotation tasks than women because of greater spatial reasoning skills. The control group received neutral information. All three groups then performed the imagined self-rotation task in an fMRI scanner. We predicted that performance in

the positive-message group would be improved compared to that of controls, and that performance in the negative-message group would be degraded compared to controls. In line with the processing efficiency hypothesis, we also expected brain regions associated with increased cognitive or emotional workload to be activated in the negative-message group but not in the positive-message group.

METHOD

Participants

We tested 54 right-handed women from the Dartmouth College community, aged 18–34 years. Participants were either undergraduate students or graduates with a BA or BS not enrolled in graduate school. Participants were randomly assigned to one of the three experimental conditions (17 control, 18 positive, 19 negative). The behavioral data of eight participants (2 control, 3 positive, 3 negative) were lost due to technical problems; however, the functional data of those participants were included in the analysis. The data of six additional participants were excluded, one due to premature withdrawal from the experiment, one because the participant was aware of the hypothesis being tested, and four due to technical error. Prior to the study, all participants gave written consent to the protocol as approved by Smith College and Dartmouth College. Handedness was determined with the Edinburgh handedness scale (Oldfield, 1971). The participants were paid $20/h for their participation.

Materials

Details of the imagined self-rotation task are described elsewhere (Wraga *et al.*, 2005). The stimuli were three-dimensional (3D) depictions of the multi-cubed objects originally used by Shepard and Metzler (Shepard and Metzler, 1971). Each object appeared within a sphere. One interior cube of each object was textured. Outside of the sphere appeared a 3D T-shaped prompt. Four different objects were created and rotated in increments of 65°, 100°, and 135° along the X (frontal) or Y (transverse) planes, for a total of 24 stimuli. From the 24 stimuli we generated three orders of trials.

Stimuli were presented on a Macintosh PowerBook G3 computer using PsyScope software (Cohen *et al.*, 1993), which also recorded response times (RTs) and response accuracy.

Procedure and design

Participants were tested at Dartmouth College's Brain Imaging Center (DBIC). At the onset of the study, a female experimenter gave instructions offline, which participants read directly from a computer monitor. The first screen differed across conditions, with participants in the control, positive stereotype, and negative stereotype groups receiving unique messages about the purpose of the

experiment (see Supplementary Appendices A, B, and C, herein). All participants then read the instructions for the task, which included one sample trial with a stimulus that did not appear in the test trials. Participants were instructed to summarize each instruction screen. This measure ensured that they had read the manipulation on the first screen, and that they comprehended the task. Participants were asked to imagine rotating themselves to the position of the T and then to make a "yes" or "no" decision as to whether the textured cube would be visible from that position.

Individual rotation trials appeared for 12 s each, regardless of whether a judgment was made. Each set was randomly interspersed with fixation points of 3–24 s (in increments of 3 s), for a total duration of 468 s. An equal number of "yes" and "no" responses appeared in each set of trials.

Participants performed three sets of trials. They responded in the scanner by pressing two button presses, one held in each hand. The buttons were covered with different textures to help participants distinguish them by touch, and were connected to the Macintosh computer via the PsyScope button box. Participants paused briefly between each set of trials.

Trials in each set were presented in a pseudo-random order with the following restrictions: the same response could not occur three times in succession, and the same rotation magnitude could not be repeated until all variations had appeared once. Order of each set of rotations, as well as order of trials within each set was kept constant across participants.

fMRI acquisition

Imaging was performed on a 1.5 T GE Signa CV/NVi LX8.3 MRI scanner (GE Medical Systems, Wakesha, WI). Once participants were inside the scanner, a three-axis scout series was acquired for positioning the subsequent functional slices. 3D high-resolution saggital and 2D transverse coplanar T2-weighted images were acquired for anatomical localization of the subsequent functional images. We obtained three functional sets of trials (156 scans each) in a single session for each participant. Four additional scans at the beginning of each set were discarded to ensure steady-state conditions. A standard head coil with foam padding was used for head stabilization. Functional images were acquired with a single-shot gradient echo EPI sequence, with parameters $TR = 3000$ ms, $TE = 35$ ms, flip angle $= 90°$, 27 contiguous 4.5 mm thick axial slices with 1 mm gap and an in-plane resolution of 64×64 in a FOV of 240 mm. T1-weighted structural images were acquired at the same slice locations to aid in registration ($TR = 650$ ms, $TE = 6.6$ ms). Immediately following the functional scans, high-resolution, 3D T1-weighted structural images were acquired. The trials lasted 24 min, for a total scanning time of 42 min.

Imaging analysis

The data were analyzed using Statistical Parametric Mapping (SPM99) (Friston *et al.*, 1995). Functional data from a participant's event-related fMRI series were first corrected for different slice acquisition time using sync interpolation. Motion artifacts then were corrected to the first functional scan for each participant. The 27-slice structural image was then coregistered to the participant's high-resolution structural image, and the parameters of the resulting transformation were applied to the mean of the motion-corrected images as well as to motion-corrected functional images. The functional images were then directly coregistered to the high-resolution structural image via mutual-information coregistration. The images were spatially normalized to the Montréal Neurological Institute template. They then smoothed with a Gaussian filter of 6 mm full-width half maximum (FWHM) to compensate for anatomical differences among participants.

We analyzed images using a two-stage, random effects analysis. First we conducted within-subject, whole-brain analyses of condition–fixation contrasts using a fixed-effects model under assumptions of the General Linear Model. A regressor was included in the model for each rotation magnitude within the task, convolved with a standard hemodynamic response function (Friston *et al.*, 1995). We then performed a second, group-level analysis of the condition–fixation activations for each between-group contrast, in which subject was treated as a random effect. The group-level analysis was based on one-sample t-tests thresholded at $P = 0.005$ (uncorrected for multiple comparisons) with an extent threshold of five contiguous voxels (Wraga *et al.*, 2005). The resulting clusters of activation were converted from MNI to Talairach–Tournoux space (Brett, 2002).

Behavioral analysis

RTs reported are for correct trials only. Mean RTs >2.5 SD above or below the group mean for a given rotation magnitude were replaced with the group mean for that rotation magnitude. This corresponded to $<2\%$ of data. Mean RTs and percent error for each participant were submitted to a 3 (group) $\times$ 3 (rotation magnitude) mixed design analysis of variance (ANOVA).

BEHAVIORAL RESULTS
Accuracy

Figure 2 shows mean proportion error for the three groups. We found significant fluctuations in performance accuracy for the two stereotype message groups compared to the control (neutral condition) group, $F(2, 43) = 12.80$, $P = 0.0001$. Participants in the negative-stereotype condition made 6% *more* errors ($M = 42\%$; $SE = 0.10$) than controls ($M = 36\%$; $SE = 0.09$), $t(29) = -2.27$, $P = .032$; whereas participants in the positive-stereotype condition made 8% *fewer* errors ($M = 28\%$; $SE = 0.07$) than controls,
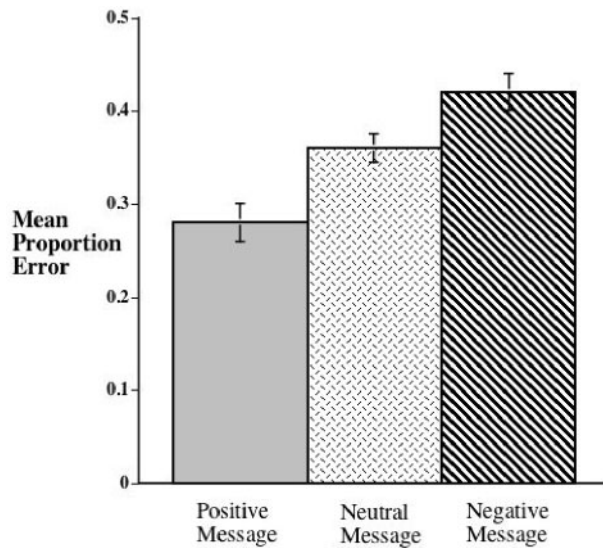
Fig. 2 Mean proportion error and standard errors of the self-rotation trials for the three conditions. Lower values on the y-axis indicate better performance. On average, women in the positive stereotype group made 8% fewer errors than women in the control (neutral message) group, whereas women in the negative stereotype group made 6% more errors than those in the control group.

$t(28) = 3.04$, $P = 0.005$. The ANOVA revealed an additional main effect of rotation magnitude, $F(2, 86) = 21.93$, $P = 0.0001$. *Post hoc* linear comparisons revealed that errors for $100°$ rotations decreased compared to those of both $65°$ ($t(45) = 7.66$, $P = 0.0001$) and $135°$ rotations ($t(45) = -4.58$, $P = 0.0001$). No interactions reached significance.

Response times

Analysis of RTs yielded no difference among groups, $F(2, 43) = 1.21$, $P = 0.309$. The ANOVA yielded a main effect of rotation magnitude, $F(2, 86) = 3.65$, $P = 0.030$, in a pattern similar to that of errors. *Post hoc* linear comparisons revealed that RTs for $100°$ rotations were significantly faster than those of $65°$ rotations ($t(45) = 2.69$, $P = 0.010$) and marginally faster than those of $135°$ rotations ($t(45) = -1.80$, $P = 0.078$). No interactions reached significance.

The V-shaped effect found for both errors and RTs, which was caused by relative decreases at $100°$ rotations compared to $65°$ and $135°$ rotations, is similar to patterns found in other imagined self-rotation studies (Wraga *et al.*, 2004; Wraga *et al.*, 2005). It previously has been attributed to the fact that performance is typically faster and more accurate with self-rotations that are more closely aligned with one of the major axes of the human body (e.g. $100°$) than those that are not (e.g. $65°$, $135°$) (Wraga, 2003).

fMRI RESULTS

The purpose of this study was to explore the neural mechanisms underlying stereotype susceptibility effects on women's imagined self-rotation performance. To achieve

Table 1 Areas of activation in the negative stereotype condition compared to the control condition (top) and the positive stereotype condition compared to the control (bottom). Talairach and Tournoux (1988) coordinates for activation peaks and maxima t-values are provided

Area of activation	Brodmann area(s)	X	Y	Z	t-value	Cluster size (mm³)	R with M% error
Negative–Control							
Medial frontal gyrus	11	4	30	−12	4.09	17	0.32
Orbital gyrus	11	8	26	−28	3.98	7	0.50*
Anterior cingulate	32	−8	38	−9	3.88	10	0.46
Inferior parietal lobule	40	48	−40	64	3.87	5	0.00
Superior parietal lobule	7	−16	−59	62	3.55	5	−0.01
Fusiform gyrus	20/36	−44	−36	−22	3.43	11	−0.00
Inferior temporal gyrus	20	40	2	−37	3.28	14	0.06
Cerebellum		−4	−58	−4	3.22	8	−0.10
Cerebellum		−4	−90	−22	3.14	7	
Inferior temporal gyrus	37	−44	−51	−8	3.05	6	0.21
Positive–Control							
Inferior temporal gyrus	37	59	−58	−4	4.22	15	−0.32
Cuneus	18	−12	−101	2	3.99	13	0.13
Cuneus	18	−4	−100	20	3.85		
Anterior PFC	10	40	62	1	3.76	29	−0.42
Middle temporal gyrus	21	59	3	−20	3.75	5	−0.03
Medial frontal gyrus	11	−8	38	−12	3.58	34	0.16
Middle temporal gyrus	21	−63	−20	−12	3.58	6	0.02
Cingulate gyrus	29/30	4	−50	9	3.53	17	−0.18
Superior occipital gyrus	19	−36	−72	37	3.36	12	−0.53*

*Pearson correlation significant at $P < .05$ (two-tailed).

this, we first compared activation in the two stereotype message groups to that of the control group. We then directly compared activation in negative and positive stereotype groups. Table 1 and Figures 3 and 4 present the results of the comparisons between negative and positive stereotype groups and the control.

The negative stereotype–control contrast (Table 1 and Figure 3) revealed activation in the right medial frontal gyrus (BA 11) extending into left rostral–ventral anterior cingulate (BA 32). The latter region is associated with affective processing, particularly of negative emotions such as anger and sadness (Dougherty *et al.*, 1999; Pardo *et al.*, 1993; Whalen *et al.*, 1998). The negative stereotype–control contrast also yielded activation in the right orbital gyrus (BA 11), a region with several social connotations. It is considered a general storage site in the brain for social knowledge associated with interpersonal relations, including gender stereotypes (Milne and Grafman, 2001). The orbital gyrus also is more specifically implicated in the regulation of
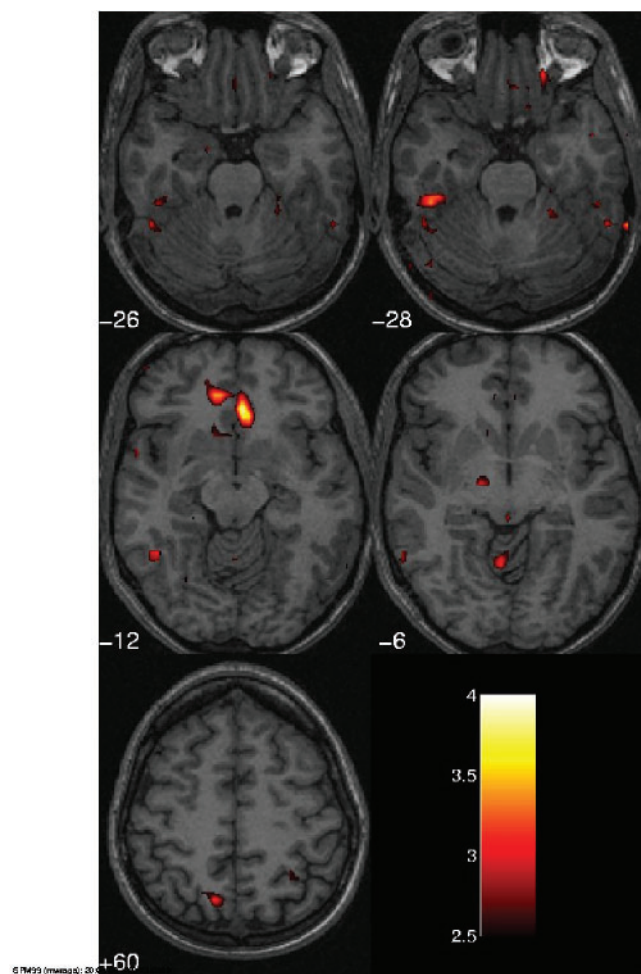
Fig. 3 Axial images ($z = -26$ to $+60$) depicting brain activations resulting from the negative stereotype–control group contrast. Areas depicted include the orbital and medial frontal gyrus, the rostral–ventral anterior cingulate, fusiform gyrus, and superior parietal lobule. Activation is superimposed onto a brain image of a single participant.

Fig. 4 Axial images ($z = -16$ to $+36$) depicting brain activations resulting from the positive stereotype–control group contrast. Areas depicted include visual processing areas, middle temporal gyrus, ventral portions of anterior PFC, and cingulate gyrus. Activation is superimposed onto a brain image of a single participant.

self-conscious emotions such as embarrassment and shame (Beer *et al.*, 2003). We found additional activation in several cognitive areas, including the left inferior temporal gyrus (BA 37), a region associated with high-level object processing (e.g. Kanwisher *et al.*, 1997), and the right inferior (BA 40) and left superior (BA 7) parietal lobule spatial processing regions. We also found activation in the left fusiform gyrus (BAs 20/36) and the cerebellum.

To examine whether any of the negative–control brain regions were associated with performance in the negative stereotype condition, we calculated the average adjusted beta estimate (across all voxels) per participant for each major brain region resulting from the negative–control contrast. We then correlated these values with the negative stereotype participants' mean error rates.[1] Resulting *r*-values for each region appear in the farthest right-hand column in Table 1.

Activation in the orbital gyrus (BA 11) was positively correlated with mean error ($r = 50$, $P < 0.05$). We also found the trend for a positive correlation between activation in rostral–ventral anterior cingulate and mean error ($r = 0.46$, $P = 0.08$).[2]

The positive stereotype–control contrast (Table 1 and Figure 4) revealed two areas of activation in common with those of the negative stereotype–control contrast, including the left inferior temporal gyrus (BA 37) and the right medial frontal gyrus (BA 11). However, this contrast also produced many distinct regions of activation. We found activation in left visual association areas (BAs 18/19), as well as the ventral portion of right anterior prefrontal cortex (PFC, BA 10), a component of working memory. The positive stereotype–control contrast also yielded activation bilaterally in the middle temporal gyrus (BA 21), which

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[1] Because of the missing behavioral data in the positive stereotype ($n = 3$) and negative stereotype ($n = 3$) conditions, the behavioral data represent fewer participants than the beta estimate data, which was calculated from the full set of participants in each condition.
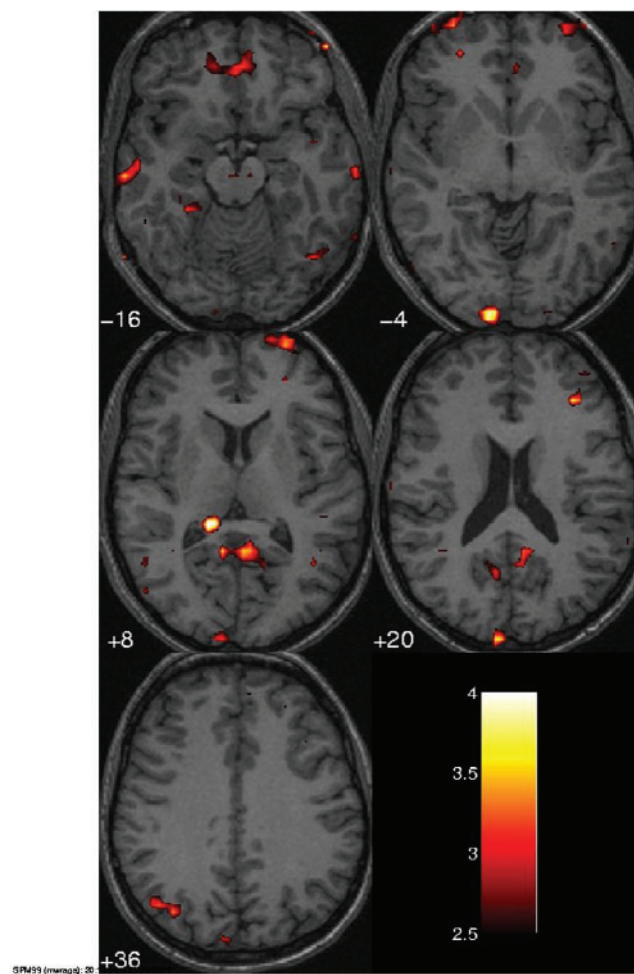
[2] Given the lack of power of our small behavioral data sets, we have included discussion of this trend despite the fact that the correlation did not reach statistical significance.

Table 2 Areas of activation in the negative stereotype condition compared to the positive stereotype condition (top) and vice versa (bottom). Talairach and Tournoux (1988) coordinates for activation peaks and maxima *t*-values are provided

	Brodmann area(s)	X	Y	Z	*t*-value	Cluster size (mm^3)
Negative–Positive						
Ventrolateral PFC	45/47	−40	20	3	3.91	14
Cerebellum		28	−29	−32	3.79	9
Amygdala		16	−5	−13	3.58	10
Cerebellum		12	−52	−34	3.01	5
Positive–Negative						
Anterior PFC	10	−8	66	0	4.07	7
Posterior cingulate	31	8	−25	34	3.86	8
PTO junction	39	−63	−61	25	3.61	8
Medial frontal gyrus	11	4	58	−13	3.46	13
Anterior PFC	10	−36	66	−10	3.26	5
Anterior PFC	10	32	66	−7	3.25	12

previously has been implicated in egocentric encoding (Bottini *et al.*, 2001). Additional activations included the right cingulate gyrus (BAs 29/30).

To assess associations between these brain regions and performance of the positive stereotype group, we calculated the average adjusted beta estimate (across all voxels) per participant, for each major brain region resulting from the positive–control contrast and correlated these values with the positive stereotype participants' mean error rates. Resulting *r*-values for each region appear in the farthest right-hand column in Table 1. Activation in the superior occipital gyrus (BA 19) was negatively correlated with mean error ($r = −0.53$, $P < 0.05$). We also found a trend for a negative correlation between activation in anterior PFC (BA 10) and mean error ($r = −0.42$, $P = 0.12$).[2]

Table 2 presents the results of the direct comparisons between the two stereotype message groups. With a performance difference of 14%, this comparison represents the most extreme difference between conditions. In general, the results of these contrasts support those relative to the control group. The negative stereotype–positive stereotype contrast yielded activation in the left ventrolateral PFC component of working memory (BAs 45/47) and the cerebellum. This contrast also yielded activation in the right amygdala, a region associated with fear and other negative emotions (LeDoux, 2000).

The reverse comparison of positive stereotype–negative stereotype groups yielded greater activation in the right posterior cingulate (BA 31), which has been shown to play a role in spatial navigating via cues generated through self-movement (Whishaw *et al.*, 2001). We also found activation in the left parieto–temporal–occipital (PTO) junction (BA 39), an area associated with the processing of

egocentric transformations (Wraga *et al.*, 2005; Zacks *et al.*, 1999, 2003). We also found activation bilaterally in ventral and medial portions of anterior PFC (BA 10).

DISCUSSION
The degraded performance of women in the negative stereotype group is consistent with previous studies examining stereotype susceptibility in women through other behavioral measures (Shih *et al.*, 1999; Spencer *et al.*, 1999); the enhanced performance in the positive stereotype group is in line with our previous work (Wraga *et al.*, in press). These shifts in accuracy induced by explicit stereotype messages provide clear evidence that some of women's underperformance on spatial reasoning tasks may be attributable to social factors. A less obvious but equally significant point is made when one examines the performance of the control group, who received neutral information. The fact that women in the control group showed poorer accuracy compared to the positive stereotype group suggests that women are not necessarily performing at their ability ceiling when performing mental rotation tasks under "neutral" conditions. Interestingly, the stereotype susceptibility effect appears to operate on an unconscious level. In debriefing, when participants in all conditions were asked whether the message they read prior to testing had affected their performance, 90% reported that it had not influenced them at all.

The brain imaging results reveal deeper insights into the mechanisms underlying stereotype susceptibility effects. The contrasts between the two stereotype message groups and the control group yielded patterns of brain activity supporting the hypothesis that stereotype susceptibility works through changes in processing efficiency. Although the negative stereotype–control contrast yielded activation in neural regions that facilitate mental rotation performance, including high-level object processing and spatial processing areas, we also found evidence of increased emotional load. For spatial tasks, increasing load typically is exemplified in performance decreases that correspond to increased neural activity (e.g. Leung *et al.*, 2004). In our negative stereotype–control contrast, two of the largest and strongest areas of activation, the orbital gyrus (BA 11) and rostral–ventral anterior cingulate (BA 32), were found to increase in activation as a function of participant error. These findings suggest that relatively poorer performance in the negative group resulted from participants' increased focus on self-conscious emotion and/or the elicitation of gender stereotypes, in combination with negative emotional processing. This extra mental focus created an undue burden that undermined the negative stereotype group's performance of the imagined self-rotation task.

The positive stereotype–control contrast yielded a pattern of brain activation that generally supports a very different trend. We found greater activation of secondary visual processing areas (BAs 18/19), a result that is consistent with

some (Creem *et al.*, 2001; Zacks *et al.*, 1999) but not all (Wraga *et al.*, 2005) neuroimaging studies of imagined self-rotation tasks. However, for the broader range of mental rotation tasks, the recruitment of visual imaging and memory areas is a well-established asset to performance (Kosslyn *et al.*, 1995, 1998). Moreover, in the current study, activation in the superior occipital gyrus (BA 19) was found to increase as a function of improved performance. We also found the trend for increases in anterior PFC (BA 10) activation as a function of improved performance. The role of anterior PFC in working memory is one of the least understood phenomena of the human brain. A recent meta-analysis of 104 studies suggests a functional distinction between ventral and medial portions of the anterior PFC, with the former being involved in more cognitive aspects of working memory and episodic memory retrieval, and the latter involved in tasks of mentalizing, which requires reflecting on one's emotional and mental states (Gilbert *et al.*, 2006). The activation we found in the positive–control contrast was in the ventral portion of anterior PFC, consistent with the cognitive interpretation. Additional studies underscore the highly complex nature of cognitive processing within anterior PFC. For example, greater anterior PFC activation is associated with the integration of multiple cognitive outcomes for a common behavioral goal (Ramnani and Owen, 2004), as well as distinguishing between target and non-target stimuli during the recognition phase of a spatial working memory task (Leung *et al.*, 2005). Either or both of these functions would give a person a performance edge in the mental rotation task used in this study.

Taken together, the enhanced areas of activation we found in the positive stereotype group combined with the absence of evidence for increased mental load reflect a trend of relatively greater neural efficiency for processing imagined self-rotations.

The patterns of brain activation we found when directly contrasting positive and negative stereotype conditions reinforce the results of the comparisons with controls. Participants in the negative stereotype group showed greater activation of the amygdala, which has extensive connections to both the ventral anterior cingulate and orbital frontal cortex, and is associated with fear and other negative emotions (LeDoux, 2000). We also found greater activation in the ventral PFC, a region associated with relatively simple working memory processes, such as encoding and retrieval of information (Petrides, 2000).

In contrast, participants in the positive stereotype group exhibited greater activation bilaterally in the ventral and medial portions of anterior PFC, responsible for relatively complex working memory processing. We also found enhanced activation of the left PTO and right posterior cingulate, regions integral to processing egocentric transformations (Whishaw *et al.*, 2001; Wraga *et al.*, 2005; Zacks *et al.*, 1999, 2003). These regions collectively reflect a network of enhanced efficiency for the skills required to perform the imagined self-rotation task.

Our findings generally support other processing efficiency accounts of stereotype susceptibility with one notable difference. Previous accounts have posited quantitative shifts in working memory as a function of stereotype susceptibility (e.g. Schmader and Johns, 2003). Our results suggest that the mental load induced by negative stereotype messages is not generated in working memory, but rather in regions associated with social and emotional processing. Moreover, the distinction we found within working memory was qualitative (activation of complex *vs* relatively simple processing regions) rather than quantitative. Future research is needed to explore this issue further.

In summary, our results indicate that experiential factors such as stereotype susceptibility can contribute to women's chronic underperformance on mental rotation tasks. Moreover, the patterns of neural activation we found across experimental groups are consistent with the hypothesis that stereotype messages work by altering the neural efficiency of the task at hand. These results demonstrate the remarkable power of context in determining human cognitive processing. They also underscore the import of stereotype messages, which have the potential to both undermine and enhance the academic performance of stigmatized groups. Thus, regardless of the degree to which women are intrinsically disadvantaged when it comes to math and science, negative public emphasis on the issue, particularly by an authority figure, will most likely only widen the gender performance gap in spatial reasoning skills required to succeed in such fields. However, our results suggest that those desiring to narrow the performance gap need not wait for individual and collective attitudes about women and science to change. By simply altering the context of a spatial reasoning task to create a more positive message, women's performance accuracy can be increased substantially through greater neural efficiency.

Conflict of Interest

None declared.

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