

Stereotype threat engenders neural attentional bias toward negative feedback to undermine performance



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ABSTRACT

Stereotype threat, a situational pressure individuals experience when they fear confirming a negative group stereotype, engenders a cascade of physiological stress responses, negative appraisals, and performance monitoring processes that tax working memory resources necessary for optimal performance. Less is known, however, about how stereotype threat biases attentional processing in response to performance feedback, and how such attentional biases may undermine performance. Women received feedback on math problems in stereotype threatening compared to stereotype-neutral contexts while continuous EEG activity was recorded. Findings revealed that stereotype threatened women elicited larger midline P100 ERPs, increased phase locking between anterior cingulate cortex and dorsolateral prefrontal cortex (two regions integral for attentional processes), and increased power in left fusiform gyrus in response to negative feedback compared to positive feedback and women in stereotype-neutral contexts. Increased power in left fusiform gyrus in response to negative feedback predicted underperformance on the math task among stereotype threatened women only. Women in stereotype-neutral contexts exhibited the opposite trend. Findings suggest that in stereotype threatening contexts, neural networks integral for attention and working memory are biased toward negative, stereotype confirming feedback at very early speeds of information processing. This bias, in turn, plays a role in undermining performance.

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1. Introduction

Stereotype threat, a situational pressure individuals experience when they fear confirming a negative group stereotype, can engender anything from physiological stress responses to meta-cognitive doubt to undermine performance on tests of ability (Schmader, Johns, & Forbes, 2008; Schmader, Forbes, Zhang, & Mendes, 2009; Steele & Aronson, 1995). Less is known, however, about how stereotype threat biases attentional processing in response to performance feedback while individuals perform, and how such attentional biases may ultimately undermine performance. The present study addresses these questions using a social neuroscience approach. Neural indices of attentional processing were utilized to determine whether (a) stereotype threat biases attention toward negative stereotype confirming evidence, and (b) whether such an attentional bias predicts decreased performance under stereotype threat.

1.1. Stereotype threat biases attention toward negative information

Previous work suggests that, stereotype threat initiates a cascade of physiological stress responses, negative appraisals and performance monitoring processes that work either alone or in concert to tax working memory resources that are necessary for optimal performance on difficult tasks (Schmader et al., 2008). These products of threat may bias individuals' attention toward evidence they are confirming a negative group stereotype, and therefore toward more negative information/performance perceptions in general. For instance, stereotype threatened individuals can become more focused on avoiding failure (Seibt & Forster, 2004), and report increased task-related worries (Cadinu, Maass, Rosabianca, & Kiesner, 2005), performance monitoring (Beilock, Rydell, & McConnell, 2007), self-doubt (Steele & Aronson, 1995), anxiety (Spencer, Steele, & Quinn, 1999), and feelings of dejection (Keller & Dauenheimer, 2003).

Shifts in attention toward negative information may be the byproduct of fundamental mechanisms incorporated by the brain to detect threats. When individuals encounter viscerally arousing

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potential threats in their environment, attentional processing is shifted toward identifying the source of the threat (Davis & Whalen, 2001). Thus, the same way a spider phobic can more quickly identify pictures of spiders amongst other information (Wessel & Merckelbach, 1998), stereotype threatened individuals may become quicker to identify cues in the situation that provide evidence for how they are performing. Consistent with this, women can become hypervigilant for sexism-related cues in their environment when anticipating working with a sexist male (Kaiser, Vick, & Major, 2006), cues depicting minority status (Murphy, Steele, & Gross, 2007), and anxiety related words when they anticipate taking a difficult math test (Johns, Inzlicht, & Schmader, 2008).

Attentional shifts toward different contextual cues, be they threat-oriented, task-relevant or task-irrelevant, can undermine performance on more complex, working memory intensive tasks by dividing attentional resources and undermining abilities to inhibit distracting information (Conway, Cowan, & Bunting, 2001; Conway, Tuholski, Shisler, & Engle, 1999). This suggests that stereotype threatening contexts may bias attentional processing toward negative feedback at a fundamental level, and possibly at the expense of working memory resources that contribute to optimal performance on difficult tasks. As perceptual, attentional and working memory processes likely occur in close temporal relation to one another, it can be difficult to capture how these different processes may interact to ultimately undermine performance. A social neuroscience approach addresses this issue, however, by providing a means to assess how stereotype threat alters the dynamic interaction between multiple neural regions integral for distinct cognitive processes on-line, or while individuals perform.

1.2. Gaining insight in to attentional and working memory processes via cortical interactions

One way to determine whether stereotype threat biases attention toward negative feedback is to assess activity within neural regions integral for perceptual processing, attention and working memory while individuals receive feedback under stereotype threat. Past research indicates that temporal areas such as fusiform gyrus (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Colom et al., 2013), the cerebellum (Ito, 2013), and medial and lateral regions of prefrontal cortex (PFC), including anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex (DLPFC), are all known to play a prominent role in information and performance monitoring processes (e.g., attention and working memory) and may be part of broader error processing networks (Bunge, Klingberg, Jacobsen, & Gabrieli, 2000; Bush, Luu, & Posner, 2000; D'Esposito et al., 1995; Osaka, Komori, Morishita, & Osaka, 2007; Ullsperger & Von Cramon, 2001). For instance, when presented with goal-relevant information, the ACC, DLPFC, and fusiform gyrus all conceivably interact to attend to a stimulus and hold it in working memory (Colom et al., 2013; Osaka et al., 2007).

These cognitive processes can be indexed via the examination of event related potentials (ERPs) elicited in response to stimuli. In relation to feedback, components such as the P100, feedback related negativity (FRN), and P300 can serve as indicators for early attentional processing, more conscious reinforcement learning, and explicit attentional processing, respectively (Holroyd & Coles, 2002; Otten & Donchin, 2000; Rutman, Clapp, Chadick, & Gazzaley, 2009). While an examination of ERPs can provide general assessments of attention, however, they are ultimately (1) global products of fluctuations in power and phase resetting that are influenced by multiple regions in the brain (Buzsaki, 2006) and (2) products of a filtering process that excludes the majority of the EEG signal; signal that could provide additional insight in to multiple cognitive and neural phenomena.

Source localization and time frequency analyses help rectify these issues by identifying the neural phenomena underlying a given ERP. Specifically, while source localization analyses estimate the separable neural generators contributing to a given potential, time–frequency analyses estimate the extent to which collections of neurons oscillate at specific frequencies within a given source. Furthermore, phase locking analyses can estimate the extent to which different neural sources oscillate in synchrony within a given frequency band at specific points in time. That is, in response to a given stimulus, it is possible to assess the extent to which neural ensembles in a given region resonate with one another at a specific frequency, where greater degrees of resonance yields larger increases in power in that specific region, and may potentially propagate that signal to other regions of the brain, which is measured via phase locking or coherence. Sauseng and Klimesch (2008) posit that greater EEG phase synchronization (both phase locking and coherence) ultimately reflects greater information exchange between neural regions comprising functionally related neural networks.

Power and phase locking indices afford a more comprehensive assessment of attentional processing. For instance, power in the theta frequency band (4–8 Hz) in prefrontal sites has been associated with more efficacious attentional and encoding processing (Klimesch, Doppelmayr, Russegger, & Pachinger, 1996; Klimesch, Doppelmayr, Schimke, & Ripper, 1997; Sauseng et al., 2004; Klimesch, 1999). Phase locking between medial and lateral regions, including ACC and DLPFC, within the theta frequency band has also been associated with enhanced attentional/performance monitoring and working memory processing in general (Cavanagh, Cohen, & Allen, 2009; Fell et al., 2001; Hanslmayr et al., 2008; Tallon-Baudry, Mandon, Freiwald, & Kreiter, 2004).

In relation to ERPs, it has been suggested that the P100–N100 complex could reflect phase locking of evoked oscillations within the alpha and theta frequency bands (Klimesch et al., 2004). According to Klimesch et al. (2004), phase locking within the theta frequency band during the temporal window of the N100–P100 complex predicts enhanced attention, encoding and recall of information. Thus Klimesch et al. (2004) argue that this complex and time window could reflect the synchronous activation of the working memory and semantic memory systems.

Specific to stereotype threatening contexts, Forbes, Schmader, & Allen (2008) found that when minorities, particularly those that value academics (i.e., those who are most vulnerable; Spencer et al., 1999), were performing on a supposed diagnostic intelligence test under stereotype threat, they exhibited enhanced ACC activity (larger ERNs) in response to recognized mistakes as early as 50 ms post-mistake. This study had several limitations, however, including whether these effects were specific to incorrect responses or stereotype threatening contexts (i.e., all participants performed the task under stereotype threat). Furthermore, distinct psychological processes may contribute to recognizing an erroneous response without feedback, and recognizing an erroneous response on the basis of feedback (Gentsch, Ullsperger, & Ullsperger, 2009). This might be particularly true under stereotype threat, where there could be marked differences between one recognizing error commissions, or just as importantly not recognizing error commissions, and one being told they confirmed a negative group stereotype. Furthermore, providing direct feedback provides a means to assess how attention to feedback unfurls rapidly to potentially bias self and performance perceptions unbeknownst to the stigmatized. Thus, examining attentional processes via ERPs, power within neural regions, and phase locking between neural regions can provide integral insight into the degree to which attentional processes are engaged in response to different types of feedback. This analytic approach also provides a means to examine how stereotype threatening contexts bias these processes toward

negative feedback regardless of whether individuals are cognizant of answering incorrectly.

1.3. Current research

The goal of the current study was to determine whether (a) individuals under stereotype threat exhibit an attentional bias toward negative compared to positive feedback, and (b) whether this attentional bias contributes to impaired performance under stereotype threat. Women received feedback on math problems that were framed as either part of a diagnostic math intelligence test or problem solving task while continuous EEG activity was recorded. Consistent with Forbes et al. (2008), we hypothesized that negative feedback would elicit enhanced attentional processing very early in the information processing stream, i.e., increased midline P100 and possibly FRN amplitudes in response to negative compared to positive feedback. We also expected an increase in power in regions integral for attentional processing including temporal and prefrontal regions, as well as phase locking between ACC and DLPFC sources in response to negative compared to positive feedback, suggesting that negative feedback facilitated interactions between regions integral for attentional and working memory processes. Finally, as divided attention may compromise working memory resources (Conway et al., 2001), and we predict the aforementioned increases in attentional processing is in response to negative feedback, as opposed to say during problem solving intervals (which could be associated with enhanced performance), we predicted that biased attentional processing of negative feedback under stereotype threat in either prefrontal, temporal or cerebellar sources would correspond with decreased performance.

2. Method

2.1. Participants

40 women (21 Diagnostic Math Test: DMT, 19 Problem Solving Task: PST) completed the experiment for course credit. All participants were right handed, raised in the United States, and had no disabilities that would impair task performance. For EEG analyses, an additional four participants were excluded due to technical difficulties leaving a sample of 36 women (18 DMT, 18 PST) for ERP/Time–frequency analyses.

2.2. Procedure

After being prepared for EEG recording, participants were seated in front of a computer screen in a sound-dampened chamber. A pre-recording of the instructions, read by a male experimenter, was presented to participants simultaneously with written instructions. Participants were randomly assigned to either the DMT or PST condition. In the DMT condition, participants were told they would be completing an experimental task that was diagnostic of their math intelligence. In the PST condition, participants were told they would be completing an experimental problem solving task that was diagnostic of the type of problem solving strategies they prefer. To prime stereotype threat, after the instructions participants completed demographic questions and indicated their gender in the DMT condition (e.g., Steele & Aronson, 1995). Participants then completed the math task while continuous EEG activity was recorded.

2.3. Math task

The math task consisted of standard multiplication problems (e.g., $19 \times 46 =$) with three answer choices presented below each problem. The location of the correct answer was randomly presented in the three answer positions. There were two blocks of 25 problems each for a total of 50 trials/problems. Each trial began with the presentation of a crosshair in the middle of the screen, followed by the problem. Participants were instructed to select their answer on a response box. Following each response, participants were presented with feedback on a white background for two seconds that indicated whether they had answered the problem correct (written in blue) or wrong (written in red). Participants were given 16 s to solve each problem. Failure to respond within that time frame prompted wrong feedback. Participants took 10.69 s on average to answer problems. Participants did not have scratch paper. An initial pilot study indicated that this task yielded comparable amounts of wrong and correct feedback.

2.4. EEG recording and data reduction

Continuous EEG activity was recorded using an ActiveTwo head cap and the ActiveTwo BioSemi system (BioSemi, Amsterdam, The Netherlands). Recordings were collected from 64 Ag–AgCl scalp electrodes. Two electrodes placed below the left eye and to the left of the left eye recorded vertical and horizontal ocular movements respectively. During acquisition the ground electrode was formed by the Common Mode Sense active electrode and the Driven Right Leg passive electrode, as per BioSemi's proprietary design. EEG activity was digitized on a computer using ActiView software and sampled at 2048 Hz.

Off-line analyses were conducted with Brain Electromagnetic Source Analysis (BESA) 5.3 software (MEGIS Software GmbH, Grafelfing, Germany). EEG data was average referenced off-line. For ERP analyses, EEG signals were filtered with a high-pass cutoff of 3 and a low-pass cutoff of 15 Hz (24 dB/octave). EEG signals were epoched and stimulus locked to correct and wrong feedback from 500 ms pre-feedback to 1000 ms post-feedback. Epochs containing artifacts (amplitude $>120 \mu\text{V}$, gradients $>75 \mu\text{V}$, low signal $<.01$) were rejected using BESA's artifact scanning tool. Ocular artifacts were corrected via BESA's adaptive algorithm. Epochs were baseline corrected by subtracting the average value of EEG 100 ms pre-feedback from the entire epoch. All participants had at least 10 wrong and correct feedback epochs. Consistent with past FRN studies (e.g., Wu, Leliveld, & Zhou, 2011), average waveforms were generated for wrong and correct feedback along midline channels of the scalp (FPz, AFz, Fz, FCz, Cz, CPz and Pz). Based on visual inspection, peak effects were maximal at CPz; thus peak detection was time locked to maximal amplitudes at CPz. Midline ERPs were operationalized as follows: midline P100 equaled the most positive deflection 75–125 ms post feedback, the FRN equaled the most negative deflection 150–300 ms post feedback, and the P300 equaled the most positive deflection 300–600 ms post feedback.

2.5. Source localization analyses

Source localization and source-based time–frequency analyses were performed in BESA. With BESA, dipole sources are fitted in both orientation and location in the brain to explain the most variance of the ERP scalp topography. Importantly, BESA does not produce an inverse solution. Rather, it transforms electrode space in to source space. This allows for the ongoing EEG activity represented by these sources to be analyzed, which is necessary when conducting induced time–frequency analyses. To avoid distortion of source localization and time–frequency measures, EEG activity was only high-pass filtered at .30 Hz (24 dB/octave). To avoid biasing the results toward any one condition, source localization analyses were conducted on a grand average waveform comprised of wrong and correct feedback epochs from both the DMT and PST conditions. In light of results described below, source models were fitted around the post-stimulus interval of 75–125 ms (the time interval around the midline P100 potential).

The source model was constructed largely on the basis of a sequential fitting strategy (Hoechstetter et al., 2004). This process resulted in sources in the left and right eye (to account for residual eye movement activities), ACC (Talairach coordinates: $x = -3.5$, $y = 46.1$, $z = 2.7$), fusiform gyrus ($x = -60.5$, $y = -31.6$, $z = -21.8$), cerebellum ($x = -21.2$, $y = -81.0$, $z = -24.5$) and occipital lobe ($x = 11.7$, $y = -83.4$, $z = -11.3$). In light of studies implicating the interaction between ACC and DLPFC as integral for attentional processing (Cavanagh et al., 2009; Hanslmayr et al., 2008), an additional source was placed in the right DLPFC ($x = 31.0$, $y = 45.0$, $z = 32.0$). This model accounted for over 99% of the variance for all conditions and types of feedback. To best capture time–frequency effects and account for individual variability, the three orientations comprising each regional source were analyzed as separate single dipoles and uniquely oriented for each participant with respect to their wrong and correct grand average wave forms.

2.6. Time–frequency analyses

For time–frequency analyses, the source localization model was used as a virtual source montage for raw EEG activity. Raw EEG activity was first converted in to brain source space. Then single-trial source waveforms were transformed into time–frequency space to calculate the instantaneous envelope amplitude and phase of each source as a function of frequency and latency. This was achieved via complex demodulation (Papp & Ktonas, 1977) as implemented in BESA 5.3. Absolute power was calculated by squaring the envelope amplitude (Hoechstetter et al., 2004). The change in power in each source with respect to the baseline was averaged over trials and displayed as a function of frequency and latency in event-related synchronization/desynchronization plots (ERD/ERS, Pfurtscheller & Lopes da Silva, 1999; Fig. 2) to illustrate changes in activity in the time–frequency domain in sources of interest. Frequencies of interest were sampled between 4 and 50 Hz in increments of 2 Hz and in sampling increments of 25 ms latencies between -500 ms and $+1000$ ms relative to feedback presentation onset. Consistent with Sauseng and Klimesch (2008), we operationalized frequency bands as followed: theta = 4–8 Hz, alpha = 8–12 Hz, beta = 13–30 Hz and gamma = 30–50 Hz.

Phase locking values were calculated for the same frequencies described above (4–50 Hz), with a baseline correction window of 100 ms pre-feedback presentation. Due to unequal trial numbers having detrimental effects on time–frequency analyses (Hanslmayr et al., 2008), wrong and correct feedback trials were matched

within ± 1 epoch for all time–frequency analyses. We accomplished this by randomly excluding trials from one condition until the number of trials in that condition matched the number of trials in the comparative condition. This still provided at least 10 epochs of each feedback type for analyses. All phase locking analyses used the ACC source as the source reference (Forbes et al., 2008). Higher phase locking values indicate a given source exhibited greater phase locking with the ACC source.

These analyses yielded many time and frequency samples nested within subjects and condition. To model within-participant variance separately from between-participant variance, and to account for the interdependence of within-participant and between-participant variance, all time–frequency data were analyzed using hierarchical linear modeling (Raudenbush, Bryk, & Congdon, 2004).

2.7. Stereotype knowledge

Participants were asked the following question during a pre-testing session at the beginning of the semester: “Regardless of what you think, what is the stereotype that people have about women and men’s math ability” (1 = Men are better than women; 7 = Women are better than men).

3. Results

3.1. Behavioral analyses

The math task was designed to be only moderately difficult in an effort to avoid discrepant presentations of feedback type in either condition. As stereotype threat effects typically emerge on more difficult math tasks (Spencer et al., 1999), no overt performance differences between the conditions were expected. An independent samples *t*-test conducted on the number of problems participants answered correctly suggested women in the DMT ($M = 21.00$, $SD = 5.08$) condition performed marginally better than women in the PST condition ($M = 18.53$, $SD = 3.39$), $t(38) = 1.79$, $p = .08$. This trend is in fact consistent with past literature indicating that stereotype threatened individuals actually perform better than their non-threatened counterparts on tasks that are less difficult (e.g., Ben-Zeev, Fein, & Inzlicht, 2005).

Providing further evidence that stereotype threat was primed by our manipulation, women under stereotype threat performed worse on the supposed math test to the extent they had knowledge of the negative stereotype about women’s math ability; a finding that is typical in the stereotype threat literature (e.g., McKown & Weinstein, 2003; Schmader, Johns, & Barquissa, 2004; Keifer & Sekaquptewa, 2007). Moderated regression analyses revealed an interaction between condition and stereotype knowledge ($M_{DMT} = 2.52$, $SD_{DMT} = 1.17$; $M_{PST} = 2.84$, $SD_{PST} = 1.21$), $\beta = .44$, $p < .05$, $R^2 = .10$. Simple slope analyses indicated that whereas the slope for stereotype knowledge in the threat condition was significant, $\beta = -.49$, $p < .03$, $R^2 = .02$, the slope in the control condition was not, $\beta = .14$, $p = .52$, $R^2 = .02$. Unfortunately, the smaller sample size and limited variability in our stereotype knowledge measure prevents us from examining more complex interactions (i.e., 4-way interactions) that utilize stereotype knowledge as a moderator for the EEG effects reported below. Nevertheless, this analysis provides evidence that our manipulation was successful in inducing a stereotype threatening environment for women.

3.2. ERP analyses

To examine whether stereotype threat altered processing of negative feedback at different points in the information processing stream, a 2 (condition: DMT, PST) \times 2 (Feedback: wrong, correct) \times 7 (Channel: FPz, AFz, Fz, FCz, Cz, CPz, Pz) mixed factors ANOVA was conducted on subjects’ midline/posterior P100, FRN and P300 amplitudes (Fig. 1), with repeated measures on the second and third factors. Initial analyses on midline/posterior P100 amplitudes revealed a main effect for channel, $F(1,29) = 14.31$, $p < .001$, $\eta^2 = .30$, a two-way interaction between feedback type and channel, $F(1,29) = 5.47$, $p < .001$, $\eta^2 = .14$, and a three-way interaction between feedback type, channel and condition, $F(1,29) = 2.15$,

$p < .05$, $\eta^2 = .06$. No other effects were significant ($p > .21$). Simple effect analyses within the DMT condition indicated that midline/posterior P100 amplitudes were greater for wrong compared to correct feedback more posteriorly along the midline at Pz ($p < .05$) and marginally at CPz ($p = .08$). No other differences were evident ($p > .17$). Within the PST condition midline/posterior P100 amplitudes were actually greater for correct compared to wrong feedback at sites AFz, Fz and FCz ($p < .02$). No other effects were significant ($p > .08$).

Importantly, differences in midline/posterior P100 amplitudes also existed between the DMT and PST conditions to wrong feedback only. Women in the DMT condition exhibited larger P100 amplitudes in response to wrong feedback compared to women in the PST condition at both anterior and posterior sites along the midline: AFz, Fz, FCz, Cz and CPz ($p < .05$). Women in the PST condition did not elicit larger P100 amplitudes in response to wrong feedback at any site compared to women in the DMT condition ($p > .12$), and there were no differences between the two conditions with respect to P100 amplitudes elicited to correct feedback ($p > .18$).

An identical mixed factors ANOVA conducted on FRN amplitudes yielded a main effect for channel, $F(1,29) = 24.58$, $p < .001$, $\eta^2 = .42$, providing evidence for the typical FRN depolarization effect at fronto-central regions. There was also the expected main effect for feedback type, $F(1,29) = 5.15$, $p < .05$, $\eta^2 = .13$, indicating more negative amplitudes in response to wrong compared to correct feedback. No other effects were significant ($p > .15$). A final mixed factors ANOVA conducted on P300 amplitudes revealed only a main effect for channel, $F(1,29) = 15.45$, $p < .001$, $\eta^2 = .31$, highlighting the expected central-parietal distribution of the typical P300 response. No other effects reached significance ($p > .09$).

Together, these findings suggest that stereotype threat enhanced basic perceptual processing of only wrong feedback very early in the information processing stream. We then conducted time frequency analyses to identify the underlying neural contributions to these global effects.

3.3. Time–frequency analyses

Source localization analyses suggested that midline/posterior P100 potentials likely resulted from activity in ACC, fusiform gyrus, cerebellum and occipital lobe regions (the DLPFC source was added post hoc). To examine whether oscillatory activity within and between these regions was affected by stereotype threatening contexts, and whether oscillatory activity can provide evidence of altered attention and performance, we conducted HLM analyses on power, coherence and phase locking values derived in the five sources.

Illustrating the importance of an HLM approach, the intraclass correlation coefficient of ACC theta power ($ICC = .67$) indicated that between-participant variance accounted for 67% of the total variance in theta power, whereas within-participant variance accounted for 33% of the total variance in theta power. All reported analyses entered centered feedback ($-.5 = \text{Wrong}$, $.5 = \text{Correct}$) and centered threat condition ($-.5 = \text{PST}$, $.5 = \text{DMT}$) as level-2 predictors. The DMT condition was permitted to interact with feedback to examine whether the effect of feedback depended on the DMT condition. Slopes and intercepts of each variable were random, which further modeled within- and between-participant variance that was not explained by our predictors.

3.4. Power analyses

Table 1 shows significant relationships between our predictors and oscillatory brain activity. Consistent with previous research

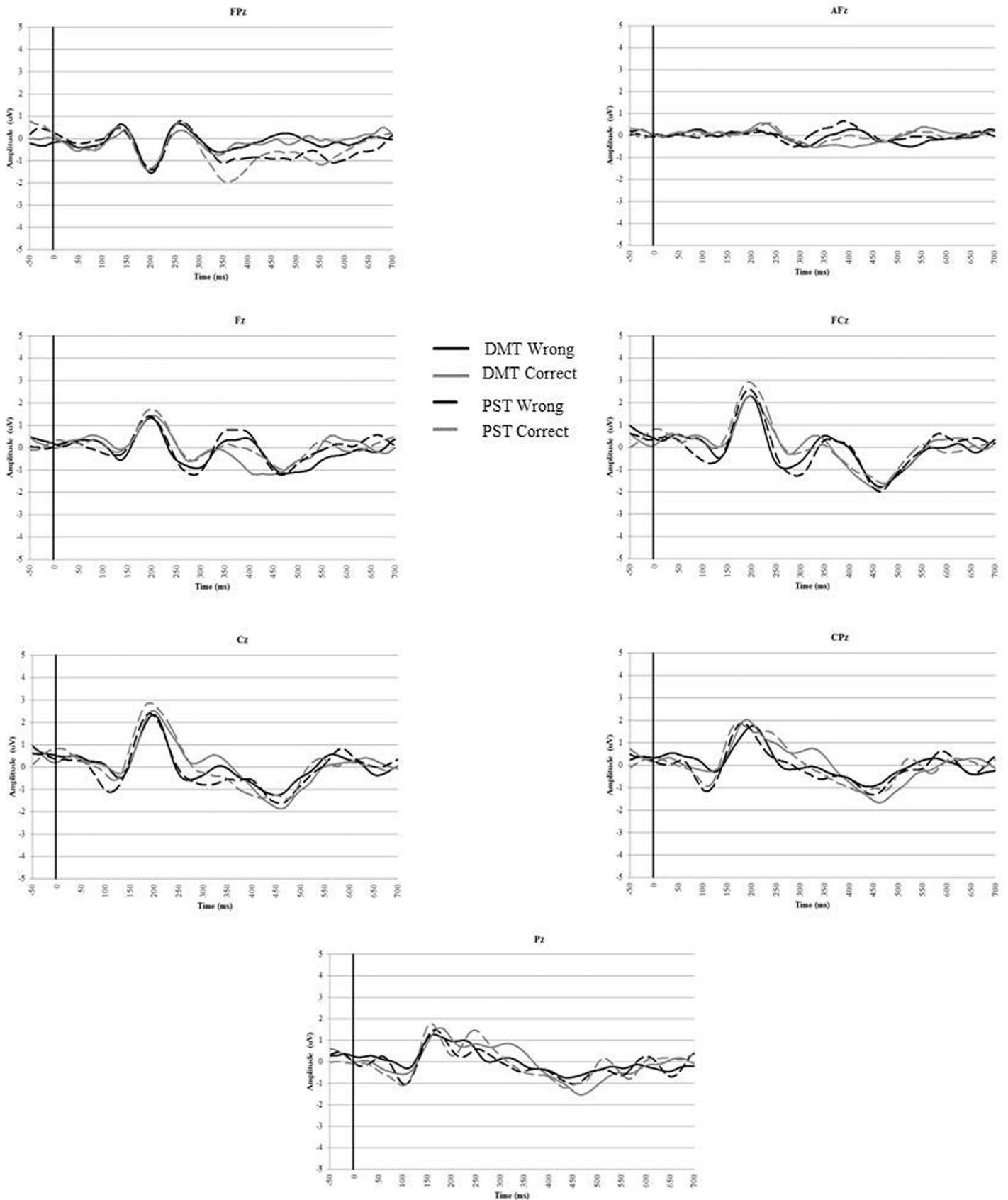


Fig. 1. ERP average wave forms elicited in response to wrong and correct feedback for the diagnostic math test (DMT) and problem solving task (PST) conditions. Correct, correct feedback grand average wave form; Wrong, wrong feedback grand average wave form. Note positive amplitudes are plotted up.

Table 1
Effects of stereotype threat and feedback on power, coherence, and phase locking.

Main effects for threat condition							
Effect	Source	Freq	Control	Threat	β_{01}	S.E	<i>p</i>
Coherence-ACC	OLLG ₁	beta	0.100	0.069	−0.031	0.013	0.029
Coherence-ACC	Cereb _{1,2}	beta	0.103	0.073	−0.031	0.012	0.014
Phase Lock-ACC	Cereb _{1,2}	beta	0.274	0.230	−0.043	0.015	0.007
Main effects for feedback							
Effect	Source	Freq	Wrong	Correct	β_{10}	S.E	<i>p</i>
Power	ACC _{1,2}	theta	11,307.150	7788.972	−3518.178	950.999	<.001
Power	ACC _{1,2}	alpha	4709.100	2049.383	−2659.717	594.587	<.001
Power	ACC ₁	beta	3936.333	2185.217	−1751.116	346.858	<.001
Power	ACC _{1,2}	gamma	3141.815	1705.937	−1435.877	340.308	<.001
Power	DLPFC _{1,2}	alpha	408.887	293.525	−115.362	23.161	<.001
Coherence-ACC	DLPFC ₂	beta	0.098	0.139	0.041	0.014	0.008
Phase Lock-ACC	DLPFC ₂	beta	0.253	0.302	0.050	0.016	0.004
Threat condition × feedback interactions							
Effect	Source	Freq	Descriptives		β_{11}	S.E.	<i>p</i>
Power	Fusiform gyrus ₁	theta	See Fig. 3		−756.773	301.430	0.017
Power	Fusiform gyrus ₁	beta			−164.588	71.042	0.027
Phase Lock-ACC	DLPFC ₁	theta			−0.104	0.038	0.010

Note: Subscripts indicate the orientation of the source.

showing robust neural responses to wrong feedback (e.g., Cavanagh et al., 2009), power in several frequency bands was significantly greater following wrong than correct feedback in the ACC and DLPFC sources. We also found a two way interaction between feedback and condition for theta and beta power in the fusiform gyrus source (Fig. 2). Interactions were decomposed using recommendations by Preacher, Curran, and Bauer (2006). Simple slopes revealed that participants in the PST condition showed greater theta power in the fusiform gyrus source to correct compared to wrong feedback ($b = 526.564, SE = 217.978, p = .021$). In contrast, participants in the DMT condition showed nonsignificantly greater power in the

fusiform gyrus source to wrong compared to correct feedback in the theta band ($b = -230.209, SE = 208.197, p = .277$), and significantly greater power in the fusiform gyrus to wrong compared to correct feedback in the beta band ($b = -105.963, SE = 48.804, p = .037$). No other simple slopes in these interactions were significant, p 's > .16.

3.5. Phase locking analyses

We next examined whether phase locking between the ACC source and other brain sources varied across conditions. Table 1 provides complete results for these analyses. Of relevance to

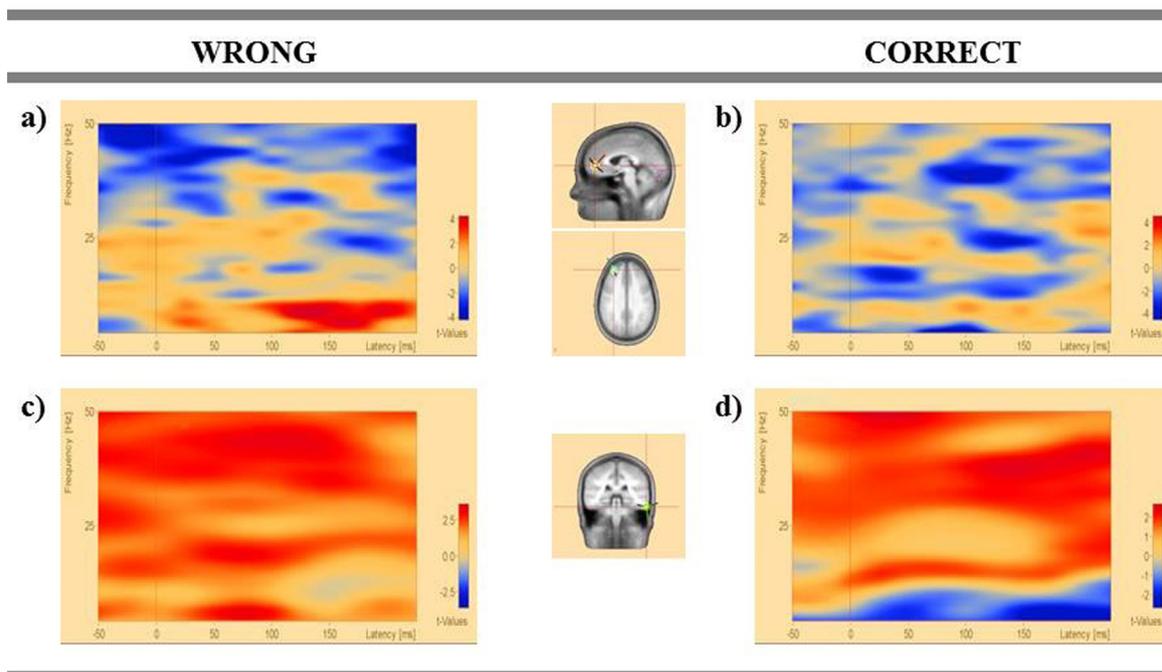


Fig. 2. Pairwise comparisons for phase locking (a and b) and power (c and d) analyses in response to wrong and correct feedback. All comparisons contrast the DMT condition with the PST condition. Warmer colors depict areas where DMT values were greater than PST values; cooler colors depict areas where the PST condition had greater values compared to the DMT condition. (a) and (b) Phase locking comparisons between the anterior cingulate (ACC) source and the dorsolateral prefrontal cortex (DLPFC) source in response to wrong (a) and correct (b) feedback. (c) and (d) Power comparisons in the left fusiform gyrus source in response to wrong (c) and correct (d) feedback.

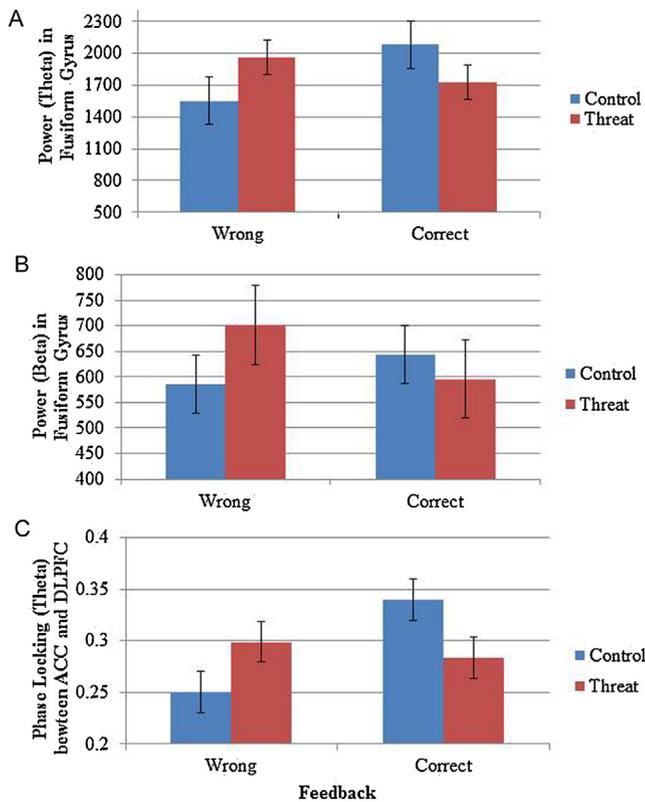


Fig. 3. Significant condition \times feedback interactions predicting (a) theta power in left fusiform gyrus, (b) beta power in left fusiform gyrus, and (c) theta phase locking between ACC and DLPFC. Error bars represent standard error of the mean.

hypotheses, analyses yielded a condition \times feedback interaction predicting ACC–DLPFC phase locking in the theta band (Fig. 3). Simple slope analyses indicated that participants in the PST condition showed greater ACC–DLPFC phase locking to correct than wrong feedback ($b = .089$, $SE = .018$, $p = .003$). In contrast, participants in the DMT condition showed statistically similar phase locking to wrong and correct feedback ($b = -.016$, $SE = .028$, $p = .572$). However, whereas there were no differences in ACC–DLPFC phase locking to correct feedback between the DMT and PST condition ($b = -.055$, $SE = .034$, $p = .115$), ACC–DLPFC phase locking to wrong feedback was marginally greater in the DMT compared to PST condition ($b = .050$, $SE = .025$, $p = .056$). Given the role of the ACC and DLPFC in the working memory network (e.g., Osaka et al., 2007), one interpretation of these findings is that participants showed greater working memory recruitment to wrong than correct feedback under stereotype threat, while this asymmetry was reversed in stereotype-neutral contexts.

3.6. Performance

To examine whether neural responses to feedback affected performance, we assessed the relationship between performance (i.e., number of problems solved correctly) and neural oscillatory patterns at each source as a function of feedback and condition. Power and phase locking for each source were modeled as outcome variables, centered feedback was entered as a level-1 predictor, and centered condition, mean-centered performance, and the condition by performance interaction were entered as level-2 predictors.¹

¹ To most accurately account for the within-person and between-person variance of neural activity, we employed HLM. We modeled neural activity as the outcome variable because HLM analyses require the outcome variable to be modeled at

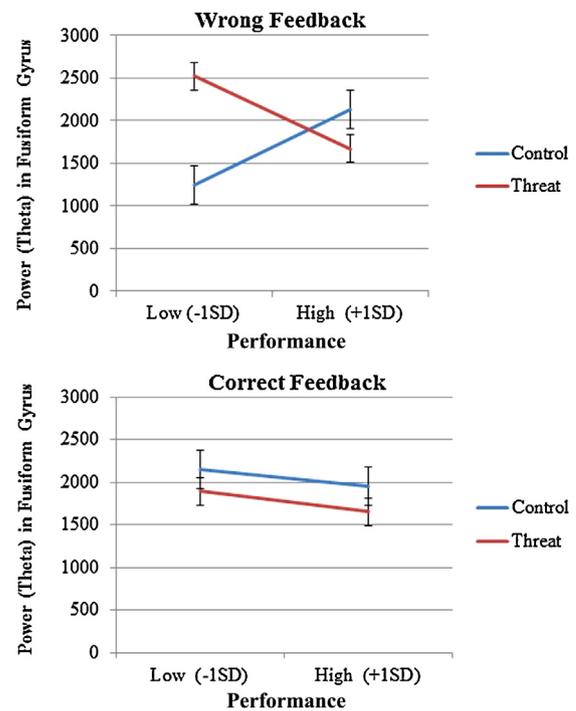


Fig. 4. Relationship between theta power in left fusiform gyrus and performance as a function of feedback valence and condition. Error bars represent standard error of the mean.

Condition, mean-centered performance, and their interaction term were allowed to interact with feedback. Finally, slopes and intercepts of each variable were random.

Several effects emerged when theta power in the left temporal gyrus (in or around the fusiform gyrus) was modeled as the outcome variable. The model revealed a marginally significant performance by condition interaction, $b = -94.469$, $SE = 55.118$, $p = .096$ and a condition by feedback interaction, $b = -681.270$, $SE = 300.073$, $p = .03$, which were qualified by a 3-way interaction between performance, condition and feedback, $b = 180.135$, $SE = 71.184$, $p = .017$ (Fig. 4). Simple slope analyses revealed that in response to correct feedback, theta power in the fusiform gyrus was unrelated to performance in both the PST and DMT conditions, p 's $> .4$. In response to wrong feedback, however, the relationship between theta power in the fusiform gyrus and performance varied as a function of condition: In the PST condition, greater fusiform theta power elicited in response to wrong feedback marginally predicted better performance, $b = 95.282$, $SE = 55.799$, $p = .097$, whereas in the DMT condition, greater fusiform theta power elicited in response to wrong feedback predicted significantly lower performance, $b = -89.255$, $SE = 33.485$, $p = .012$. Additional analyses showed that in the DMT condition, low performance ($-1SD$) corresponded with significantly greater fusiform theta power to wrong compared to correct feedback, $b = -626.477$, $SE = 299.655$, $p = .045$. Conversely, in the PST condition, lower performance ($-1SD$) corresponded with greater fusiform theta power to correct compared to wrong feedback, $b = 897.824$, $SE = 282.405$, $p = .003$. Finally, low performers in the DMT condition showed greater fusiform theta

level-1, and participants had repeated measures of neural data for each feedback type. Thus, it would be impossible to model performance as an outcome variable, as participants had only one value for performance. Though we modeled performance as a statistical predictor of neural activity, we treat performance as a conceptual outcome of neural activity. Nevertheless, performance and neural activity were measured during the same experimental session, thus we are cautious about making claims of causality between neural activity and performance.

power to wrong feedback compared to low performers in the PST condition, $b = 1263.513$, $SE = 376.310$, $p = .002$. No other effects were significant.

4. Discussion

Results from this study indicate that stereotype threat biases attentional processing toward negative feedback very early in the information processing stream. Compared to women completing a supposed problem solving task, women taking a supposed diagnostic math intelligence test exhibited increased midline/posterior P100 amplitudes, increases in power in or around the fusiform gyrus, a region integral for basic information and attentional processing (Bentin et al., 1996; Colom et al., 2013) and greater phase locking between the ACC and DLPFC, two regions integral for attention and working memory processes (e.g., Bush et al., 2000; Bunge et al., 2000; D'Esposito et al., 1995; Osaka et al., 2007), in response to wrong feedback. Furthermore, stereotype threatened women performed worse on the math test to the extent they elicited theta power in the fusiform gyrus source in response to wrong feedback. This finding is consistent with past research that found increased activation in this region when stereotype threatened women completed a mental orientation task that would also likely recruit working memory resources (Wraga, Helt, Jacobs, & Sullivan, 2007). This pattern was reversed among women in the control condition, who tended to exhibit an attentional bias toward correct feedback, and was nonexistent among both conditions in relation to correct feedback.

These findings provide unique insight into the pervasive, deleterious consequences stereotype threat has on information processing. Specifically, findings indicate that stereotype threat biases attentional and encoding processes almost immediately after exposure to stereotype confirming evidence, manifesting as early as 75 ms post feedback, as opposed to later in the information processing stream, i.e., where FRN and P300 potentials manifest. Conversely, in stereotype-neutral contexts women may be more likely to attend to positive compared to negative performance related information, but this positive bias has no implications for performance. This suggests there is something unique about receiving stereotype confirming evidence in stereotype threatening contexts with respect to performance specifically. Such findings are also consistent with past literature indicating that stereotype threatened individuals exhibit hypervigilance for error feedback (Forbes et al., 2008), signs of discrimination (Kaiser et al., 2006), and anxiety-oriented words (Johns et al., 2008).

The neural generators identified by the source localization analyses are consistent with past work as well, as the ACC (Cavanagh et al., 2009; Hanslmayr et al., 2008), fusiform gyrus (Bentin et al., 1996; Colom et al., 2013) and cerebellum (Ito, 2013) are all known to play a prominent role in information and performance monitoring processes and may be part of broader error processing networks in general (Ullsperger & Von Cramon, 2001). It was particularly provocative that only stereotype threatened women underperformed on the math task to the extent they elicited theta power in response to wrong feedback. Insight in to why this relationship manifested could be found in past research that has identified the left fusiform gyrus as integral for general recognition processes (e.g., faces, body, words, numbers, etc.) as well as rapid reading ability, i.e., the fusiform may become tuned to recurring properties of a reading/writing system and facilitate the perception of specific words accordingly (Colom et al., 2013; McCandliss et al., 2003). Indeed, there appears to be lateralized functional segregation in the fusiform area where the right fusiform area has been linked to face processing (i.e., the Fusiform Face Area or FFA), and the left fusiform area has been linked to visual word processing specifically (termed

the Visual Word Form Area or VWFA; Pintel et al., 2014). Given our source was isolated in the left hemisphere, this suggests a unique relationship between the processing of the wrong feedback itself and underperformance on the math task under stereotype threat.

In light of this, one possibility for these findings could be that under stereotype threat, the fusiform gyrus may have facilitated recognition of negative stereotypic confirming evidence, thus making wrong feedback “pop out” to threatened individuals so-to-speak. This, in turn, may have compromised or interfered with attentional and recognition processes that would normally be devoted to solving problems that recruit working memory resources. It was also interesting that this relationship was particularly evident in the theta band as opposed to the beta band but both frequency bands (as well as alpha and gamma) are posited to be positively related and interact in space and time to enable the necessary operations of working memory and selective attentional processes (Dipoppa & Gutkin, 2013; Gevins, Smith, McEvoy, & Yu, 1997; Lee, Whittington, & Kopell, 2013; Spitzer, Wacker, & Blankenburg, 2010; Tesche & Karhu, 2000). As such we interpreted increases in theta and beta power, and beta power's relationship with wrong feedback and performance, as indicative of increased attentional processing overall.

That stereotype threat increased ACC and DLPFC source phase locking within the theta frequency band in response to negative feedback, and decreased phase locking between these sources in response to positive feedback suggests that stereotype threat dynamically biases multiple neural networks, including attention and working memory networks toward negative feedback. It is important to note that enhanced ACC-DLPFC phase locking was specific to negative feedback (i.e., this value was derived in relation to presentation of the feedback itself), as opposed to say the time during which individuals derived solutions to a given problem. If the latter pattern was observed one might expect that greater ACC-DLPFC communication would actually be a desirable outcome as past research has linked this pattern to better working memory and cognitive control (Hanslmayr et al., 2008; Osaka et al., 2007). However, given that this enhanced communication was evident in response to negative feedback, it suggests that negative stereotype confirming evidence was occupying working memory resources in a biased manner and thus possibly hijacking resources that are otherwise needed for optimal performance on working memory intensive tasks like the math task used in this study.

Whether attentional bias based underperformance under stereotype threat was the product of divided attention toward threat-oriented, task-relevant or task-irrelevant cues, or a failure to inhibit distracting information (stereotype confirming evidence) is an important question for future research. The integrated process model (Schmader et al., 2008) would posit that all of the aforementioned may be responsible for taxing working memory resources and engendering underperformance. Nevertheless, the current work extends previous research demonstrating a link between stereotype threat and diminished cognitive resources (Beilock et al., 2007; Schmader & Johns, 2003) by elucidating how these effects can manifest at very fast speeds of attentional processing.

These studies were not devoid of limitations, however. While results were highly consistent with past literature, it is always important to stress the limitations of source localization analyses. Thus, while we may not be able to definitively conclude that location of the neural generators for the midline P100 effects were specific to the ACC, Fusiform, etc., given the high density array used for data collection and the location of the sources residing in cortex, we can say with some confidence that the sources were in or around regions such as the ACC. It was also interesting that there were no FRN or P300 differences between the two conditions. This could be due to a few reasons, including (a) the effects of stereotype threat on information processing manifest earlier in the processing

stream, (b) at a more explicit level of processing wrong feedback is evaluated similarly by everyone or (c) the task provided feedback in a manner that was not optimal for facilitating prediction errors. We also didn't account for individual differences like math identification, valuing, or gender identity, which are known to moderate stereotype threat effects, including ACC responses to errors (Forbes et al., 2008; Schmader, 2002; Spencer et al., 1999).

Future research should examine downstream consequences of enhanced attentional processing of negative feedback and whether effects are specific to feedback. For example, what effects might increased attention toward negative feedback, or possibly negative cognitions in the absence of feedback, have on other cognitive processes like memory encoding? Given that the degree to which individuals attend to and maintain bits of information in working memory has been associated with enhanced encoding of that information (Rutman et al., 2009), our findings suggest that stigmatized individuals might do more than just exhibit hypervigilance for negative information. They might actually process and subsequently encode negative information more efficaciously than positive information in stereotype threatening contexts. If this were true it could help explain why women tend to have more negative math perceptions in general (Nosek, Banaji, & Greenwald, 2002).

In sum, employing a social neuroscience approach, results from this study highlight the deleterious consequences stereotype threat has on bottom-up and top-down information processing, biasing neural networks integral for attention and working memory toward negative, stereotype confirming feedback at very early speeds of information processing. This bias, in turn, plays a role in undermining performance. Such findings have implications for both stigmatized individuals' perceptions and performance in the moment as well as how they may perceive themselves in the stigmatized domain in general.

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