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Original Article

ORIGINAL ARTICLE

How the Brain Converts Negative Evaluation into Performance Facilitation

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Abstract

Surpassing negative evaluation is a recurrent theme of success stories. Yet, there is little evidence supporting the counterintuitive idea that negative evaluation might not only motivate people, but also enhance performance. To address this question, we designed a task that required participants to decide whether taking up a risky challenge after receiving positive or negative evaluations from independent judges. Participants believed that these evaluations were based on their prior performance on a related task. Results showed that negative evaluation caused a facilitation in performance. Concurrent functional magnetic resonance imaging revealed that the motivating effect of negative evaluation was represented in the insula and striatum, while the performance boost was associated with functional positive connectivity between the insula and a set of brain regions involved in goal-directed behavior and the orienting of attention. These findings provide new insight into the neural representation of negative evaluation-induced facilitation.

Key words: decision-making, neuroimaging, performance, psychological reactance

With an incredible number of success stories comes a story of overcoming near insurmountable odds, conquering self-doubt, and dispelling the discouraging advice offered by the cynical few. This is nicely surmised by Bertie Forbes who stated that "History has demonstrated that the most notable winners won because they refused to become discouraged" (B.C. Forbes, 1880–1954). The counterintuitive idea that negative evaluation might not only motivate people to pursue their paths, but might also foster greater achievements can be exemplified by Charles Darwin being told he would amount to nothing (Desmond and Moore 1994) or Thomas Edison being told he was "too stupid to learn anything" (Josephson 1992). Such anecdotes not only serve to illustrate the human drive to surmount negative evaluation and the powerful motive of proving others wrong, but also underscore the entrepreneur spirit that has characterized many of the pioneering human innovations.

The idea that feeling restricted to engage in a certain path might be a catalyst to inspire, rather than deter behavior is predicted by psychological reactance. According to this theory, a threat to a behavioral freedom will induce a motivational state aimed at restoring the threatened freedom by engaging in the restricted behavior (Brehm 1966). For instance, being advised not to engage in a particular course of action because one is being judged incapable of performing the task should lead to reactance, as this is tantamount to threatening one's freedom to pursue a goal. Although there is some behavioral evidence that recommendations can lead to psychological reactance (Fitzimons and Lehmann 2004) on the one hand, and that negative feedback can increase performance on the other hand (for a review see Kluger and DeNisi 1996), to our knowledge, no study has investigated the potential relationship between motivation and performance boost following negative evaluation. In addition, neuroimaging studies have demonstrated that negative arousal affects motivation (Schmidt et al. 2009) and that motivation and self-determined choice can enhance performance (Bengtsson et al. 2009; Murayama et al. 2013; Schouppe et al. 2014). Yet, the potential neural candidates underlying negative evaluation induced-motivation and performance facilitation have remained unexplored.

To address these issues, we designed a task where participants were either encouraged, discouraged or given no evaluation as to whether taking up a risky challenge based on their performance on a related task performed the previous week. Taking up the challenge, which consisted in deciding whether a letter presented for a very short duration was a vowel or a consonant resulted in earning extra money but also involved a probability of getting a mild electric shock at the end of the experiment in case of failure (Fig. 1). Importantly, these letters were presented too fast for participants to be aware of them, thereby ensuring that they had no insight regarding their performance.

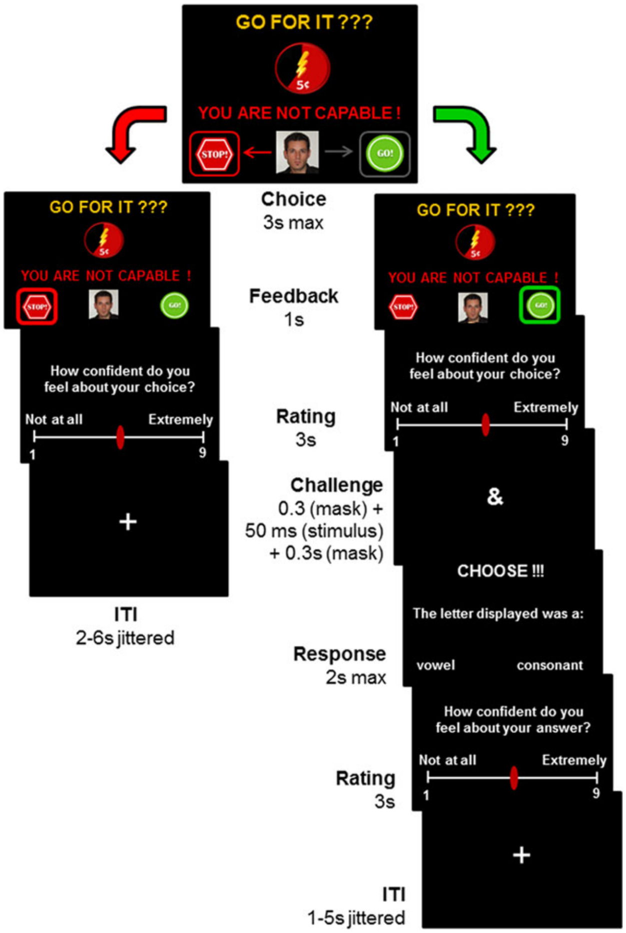

Figure 1. Test phase. On each trial, participants were given 3 s to decide whether taking up a challenge to earn 5 extra cents but risking receiving a mild electric shock at the end of the experiment as indicated by the red portion of the chart ($P = 0.5$, 0.6, or 0.7) if they failed the challenge, or not taking up the challenge and not earning extra money nor receiving any shock. They were given evaluation on a trial basis as to whether a judge thought they were capable (Encouragement condition), or not capable (Discouragement condition) to succeed at the challenge based on their performance in the Evaluation Phase, or not given any evaluation (Control condition). In this example, the judge thinks the participant is not capable of succeeding and recommends not taking up the challenge. After participants' choice was highlighted for 1 s, they were given 3 s to indicate the degree of confidence about their decision within a 3 s time period. If they decided not to go for the challenge, the trial ended with a 2–6 s jittered intertrial interval (ITI) (left column). If they decided to take up the challenge, a mask was displayed for 300 ms before and after the stimulus, which was a letter displayed for 50 ms (right column). They were then given 2 s to decide whether the letter displayed was a vowel or a consonant, before being asked to indicate their level of confidence about their answer within a 3 s time window. The trial ended with a 1–5 s jittered ITI.

We hypothesized that: 1) negative evaluation in the form of discouragement would have a differential effect across participants such that it would increase or decrease the motivation to take up the challenge depending on the participant (i.e., reflecting more or less psychological reactance). Moreover, 2) given that psychological reactance is expressed through increased motivation to engage in a certain behavior, we predicted that an increased likelihood to take up the challenge when being discouraged should recruit brain areas instantiated in motivational processes such as the striatum and insula (Pessiglione et al. 2007; Dosenbach et al. 2008; Schmidt et al. 2009). For example, the striatum is involved in increased vigor, motivational drive, and performance facilitation (Liljeholm and O'Doherty 2012). We further hypothesized that 3) negative evaluation would result in greater performance. Given the role of the insula in the enhancement of learning in aversive contexts (Pessiglione et al. 2006; Samanez-Larkin et al. 2008), we tested for the possibility that performance facilitation under discouragement was associated with positive connectivity between the insula and brain areas involved in goal-directed behavior and the orienting of visual attention (i.e., so as to increase chances to succeed at the challenge).

Materials and Methods

Participants

A total of 25 right-handed participants (11 females) with a mean age of 23.84 ± 3.42 participated in the study. All participants were free of neurological or psychiatric disorders, had no history of cardiac condition and had normal or correct-to-normal vision. Written informed consent was obtained from all participants, and the study was approved by the Columbia University research ethics committee.

Experimental Task

This experiment involved 2 parts which were performed 7–10 days apart. The Evaluation phase (Day 1) was behavioral only whereas participants underwent scanning while performing the Test phase (Day 2). Before both parts, participants were asked to read instructions which were then explained to them.

Both phases involved probabilistic shock delivery in the case of failure at the proposed challenge. Shocks stimuli were delivered using a Biopac MP150 with an STM100C module (Biopac Systems, Inc.) connected to a 200 V maximum stimulus isolation unit (STMISOC, Biopac Systems, Inc.). Shocks were administered via pre-gelled radio-translucent electrodes on the underside of the participant's left wrist, and connected to the STMISOC with shielded leads. Shock magnitude was calibrated before both parts for each individual at a level which was perceived as uncomfortable but tolerable. To ensure that no learning was taking place while performing the tasks, shocks were not administered on a trial basis. Instead, all the shocks due for any given participant were recorded by the computer and delivered at the end of each part in succession, separated by a 10 s time period.

To make sure that participants understood the task, they were trained on a practice version prior to starting each part. The tasks were programmed using the Matlab toolboxes Cogent 2000 and Cogent Graphics (http://www.vislab.ucl.ac.uk/cogent.php).

Day 1: Evaluation Phase

Participants were video-taped while performing this first part of the experiment. On each trial, participants were asked whether they agreed or disagreed to take up a challenge within a 3 s time period. Subsequently, their choice was highlighted in green or red for 1 s, depending on whether they decided to go for the challenge or not, respectively. Every time they selected the "GO!" icon, they received 5 extra cents on top of their earning, but they were also taking the risk of receiving a mild electric shock at the end of the experiment with the probability indicated by the red portion of the chart (50%, 60%, or 70%) if they failed the challenge. Selecting the "STOP!" icon resulted in getting no extra money and no shock. The challenge consisted in deciding whether a number presented on the screen for 50 ms was below or above the number 5 (note that only the following numbers were used: 1, 2, 3, 4 and 6, 7, 8, 9). Participants were told that even though the stimulus would be presented for variable durations, it would be too fast for them to perceive consciously. In reality, the stimulus was always displayed for 50 ms to ensure that it was below the threshold for subjective conscious perception. After making their choice, participants had 3 s to indicate how confident they felt about their decision by moving a cursor along a Likert scale going from 1 ("Not confident at all") to 9 ("Extremely confident") with increments of 1. If they decided not to take up the challenge, the trial ended with an intertrial interval (ITI) of 4 s plus a jitter of ±2000 ms. Conversely, if participants decided to take up the challenge, a mask representing the number sign was displayed for 300 ms, followed by the stimulus for 50 ms, and then again by the mask for 300 ms. Next, participants were given 2 s to decide whether the stimulus was a number above or below the number 5. Note that the challenge was considered to be failed if participants did not make their response within the 2 s response period. After their answer was highlighted by a white frame for 1 s, they had 3 s to indicate how confident they felt about their choice using the same procedure as described above. The trial ended with an ITI of 3 s plus a jitter of ±2000 ms. Note that the ITI was purposely longer when declining the challenge because participants were instructed that always declining the challenge would not make the experiment shorter. Importantly, participants were never told whether they had succeeded or failed at the challenge and had thus no insight regarding their performance.

The different probabilities of receiving an electric shock when failing the challenge (namely 0.5, 0.6, and 0.7) were each presented 20 times in a random order, resulting in a total of 60 trials. These probabilities were determined based on the results from several pilot experiments. To be able to show the effect of interest, namely the influence of negative evaluation on choice and performance, we sought to focus on the probability for which choices would be perceived as more difficult, and thus be more prone to external influence (Formisano et al. 1982). Indeed, it has been suggested that more difficult choices required increased evidence in order to make a final decision (Mobbs et al. 2006) and were more likely to be influenced by the recommendation from others (Formisano et al. 1982). Based on prior work suggesting that choice difficulty can be inferred from longer response times (RTs) (Demb et al. 1995; McClure et al. 2004), we used RTs as an indicator of choice difficulty.

Day 2: Test Phase

The second part of the experiment differed from the Evaluation phase in 2 ways. First, the challenge now consisted of guessing whether the stimulus was a vowel or a consonant (note that only the following letters were used: a, e, o, u, and c, n, r, s) and the mask represented an ampersand (Fig. 1). In addition, participants were also now presented with some evaluation from 1 of 3 independent judges on a trial basis. At the beginning of each trial, a picture of 1 of the 3 judges' face was presented along the following feedback: "You are capable!" (Encouragement condition), "You are not capable!" (Discouragement condition) or "No feedback" (Control condition). More specifically, participants were told that 3 participants involved in a related experiment conducted in our lab each watched a portion of the video of their performance in the Evaluation phase they performed during the previous week and that along with this information some graphs depicting how well they did, each of them was asked to predict and place a wager on their performance on a portion of the task they were about to perform in the scanner. Therefore, participants knew that the judges' evaluation was solely based on their performance in the Evaluation Phase and was not related to their current performance in the Test Phase. In reality, to allow robust statistics with an equal and sufficient number of trials per condition as well as ecological validity, participants were presented with a pre-determined sequence of events. Judge 1 was programmed to give positive evaluation 75% of the time and negative evaluation 25% of the time, while judge 2 never gave evaluation (note that "No evaluation" was displayed on the screen above judge 2's face to equate for visual information across conditions) and judge 3 gave negative evaluation 75% of the time and positive evaluation 25% of the time. The rationale for using letters as stimuli in this phase as opposed to numbers as in the Evaluation Phase was to ensure that the judges' evaluation was perceived as a simple recommendation since detecting a different category of stimuli might result in a different performance. Indeed, if the challenge had involved the same class of stimuli, participants may have been more likely to consistently follow the judge's recommendation since they thought the evaluation was based on their prior performance about which they had no insight. On the other hand, using a different class of stimuli allowed participants to think that the judge's recommendation might not be as reliable since it was based on detecting numbers and they may be better at detecting letters than numbers. Thus, this strategy allowed us to increase participants' propensity to exhibit reactant behavior.

When participants received the positive evaluation ("You are capable!"), an arrow pointing toward the "GO!" icon and a frame around this icon appeared in green, so as to highlight the judge's recommendation. On the contrary, when participants received the negative evaluation ("You are not capable!"), a red frame and a red arrow pointing toward the "STOP!" icon appeared, to highlight the judge's recommendation.

The 3 probabilities of shock were presented 55 times each: 15 times along judge 1's positive evaluation, 5 times along judge 1's negative evaluation, 15 times along judge 2's absence of evaluation, 15 times along judge 3's negative evaluation and 5 times along judge 3's positive evaluation. This resulted in a total of 165 trials divided in 3 runs. To ensure an equal number of trials across evaluation conditions, the 5 trials where judge 1 gave negative evaluation and judge 3 gave positive evaluation were excluded from analyses (note that including those trials did not qualitatively alter our results). The associations between the different faces and evaluation conditions were randomized across subjects and all trial combinations were presented in a random order.

Although participants were asked to pay close attention to the judges' evaluation, they were explicitly told that it was their personal choice to go for the challenge or not.

As in the Evaluation Phase, participants were given 3 s to indicate how confident they felt 1) about their decision following the choice period and 2) about their answer at the challenge when they decided to take it up.

Following the scanning session, participants were asked to fill in a short post-experiment questionnaire and a standard self-esteem questionnaire (mean score = 5.28 ± 1.06) (Robins et al. 2001).

Data Scquisition

Imaging was performed on a 1.5-Tesla GE Twin Speed scanner. T2*-weighted echo-planar images (EPIs) were acquired in an interleaved order with blood-oxygen-level dependent (BOLD) contrast. Whole-brain functional images were acquired in 28 slices aligned along the axis connecting the anterior and posterior commissures (64 × 64 voxels, 3.5 × 3.5 mm^2 in plane resolution, 4 mm slice thickness, no gap, repetition time of 2 s). T1-weighted structural images were also acquired, coregistered with the mean EPI and normalized to a standard T1 template. EPI images were analyzed in an event-related manner, within a general linear model (GLM), using the statistical parametric mapping software SPM5 (Wellcome Department of Imaging Neuroscience, London, UK). The first 3 volumes of each session were discarded to allow for T1 equilibration effects. Before the analysis, the images were corrected for slice time artifacts, spatially realigned, normalized using the same transformation as structural images, and spatially smoothed with an 8 mm full-width at half maximum Gaussian kernel. The output from the realignment procedure (i.e., motion parameters) was used in functional magnetic resonance imaging (fMRI) data analysis as regressors of no interest to account for residual motion effects.

Data Analysis

As explained in the experimental task description, the trials of interest (i.e., where negative evaluation has the potential to influence behavior) pertained to the condition where choices were perceived as more difficult, thus when the probability of getting shocked upon failure was 0.6 (Fig. 2). As a consequence, all analyses reported in the main text regarding the Test Phase focused on those trials. Note that including the trials where the probability of getting shocked upon failure were 0.5 or 0.7 in our ANOVAs did not alter the significance of the main effects we report in the Behavioral results section. The event-related fMRI data were analyzed by constructing sets of δ (stick) functions in 2 GLMs.

GLM 1

First, we sought to investigate the neural correlates involved in reactant behavior, by revealing the brain areas the activity of which correlated with the propensity of taking up the challenge when being discouraged as compared to the control condition where no evaluation was given. This GLM included 4 regressors at the time of choice: one for each evaluation condition (Encouragement condition, Discouragement condition, and Control condition) when the probability of getting a shock was 0.6, and one accounting for all other choices. This GLM included 3 more regressors to account for the confidence rating following choice, the time at which the challenge was performed, and the confidence rating following their answer. Thus, the design matrix consisted of 7 regressors of interest, which were all

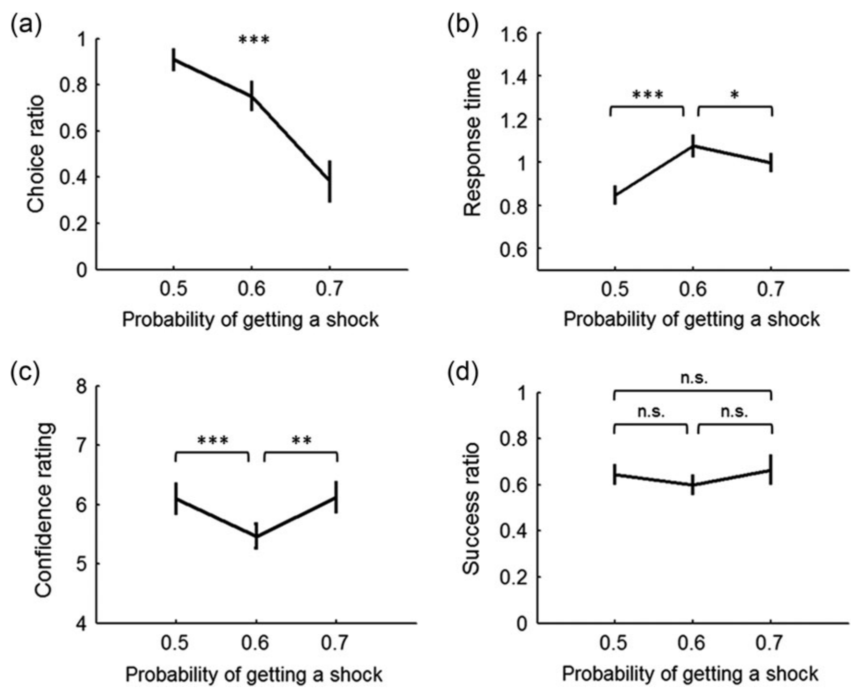

Figure 2. Evaluation Phase behavioral results. (*a*) Choice rate for taking up the challenge across shock probabilities. Participants were significantly less likely to take up the challenge as the probability of getting shocked upon failure increased (repeated-measures ANOVA, $P < 0.001$). (*b*) Response time when deciding whether to take up the challenge across probabilities. Participants were significantly slower at deciding whether to take up the challenge at $P = 0.6$ (paired *t*-tests, $P < 0.05$). (*c*) Confidence rating about their decision to take up the challenge or not across probabilities. Participants were less confident about their decision at $P = 0.6$ (paired *t*-tests, $P < 0.01$). (*d*) Success rate at the challenge across probabilities. Overall, participants were successful at the challenge 62 ± 14% of the time. Success rate was not significantly different across probabilities (paired *t*-tests, all $P > 0.3$). Error bars represent standard error of the mean (SEM). ***$P < 0.001$, ** $P < 0.01$, * $P < 0.05$, n.s. $P > 0.05$.

convolved with a canonical hemodynamic response function. The 6 scan-to-scan motion parameters derived from the affine part of the realignment procedure were included as regressors of no interest to account for residual motion effects. All of these regressors were entered into a GLM and fitted to each participant individually. The resulting parameter estimates for regressors of interest were then entered into second-level one-sample *t*-tests to generate random-effects level statistics. We then used an index of reactance (as computed by the difference between the likelihood of taking up the challenge in the Discouragement condition minus the likelihood of taking it up in the Control condition) for each participant as covariates at the second-level analysis on the contrast "Choice onset in the Discouragement condition."

GLM 2—Psychophysiological Interaction Model

We conducted a psychophysiological interaction (PPI) analysis to test whether there was a functional coupling between the insula (i.e., the main activation associated with the motivating effect of negative evaluation) and brain areas involved in goal-directed behavior and in increased attention orienting at the time of choice. This analysis was performed using the gPPI toolbox (http://www.nitrc.org/projects/gppi) (McLaren et al. 2012). The GLM used in this analysis included 4 regressors of interest modeling choice onset for trials where participants were later successful at the challenge in each of the 3 conditions (Encouragement condition, Discouragement condition, and Control condition), and a fourth regressor modeling all other choices. As in GLM 1, 3 regressors were added to account for the confidence rating following choice, the time at which the challenge was performed, and the confidence rating following their answer. Again, the 6 scan-to-scan motion parameters derived from the affine part of the realignment procedure were included as regressors of no interest. BOLD time-series extracted from insula activity consisted of voxels within an 8 mm sphere centered on the peak insula activation shown in Figure 4*a* ([*x*, *y*, *z*] [50 −2 2]) for each individual. Random-effects level statistics generated by this PPI analysis at the second-level (one-sample *t*-tests) are presented in Figure 4*b* for the contrast "Choice onset for successful trials in the Discouragement condition > Choice onset for successful trials in the Control condition". To gain more insight into the relationship between reactant behavior and success at the neural level, we then used an index of negative evaluation-related success (as computed by the difference between the success rate in the Discouragement condition minus the success rate in the Control condition) for each participant as covariates at the second-level analysis on the contrast "Choice onset for successful trials in the Discouragement condition" (Fig. 4*c*).

All reported fMRI statistics and *P*-values arise from group random-effects analyses. The 5 participants who never went for the challenge when being discouraged were excluded from fMRI analyses and 2 more participants were excluded from GLM 2 because they were never successful in at least one of the conditions (note that these participants were included in all behavioral analyses reported in Results, and that excluding them from these analyses did not change the significance level of any of the effects reported). We present our statistical maps at a threshold of $P < 0.001$, corrected for multiple comparisons at $P < 0.05$. To correct insula activity for multiple comparisons (Fig. 4*a*, left), we used whole-brain cluster correction. For other brain areas reported in Figure 4, we used small volume correction (SVC) based on a priori regions of interest in the striatum, lateral orbitofrontal cortex (lOFC) and intraprietal sulcus (IPS), using 8 mm spheres centered on the coordinates reported in relevant prior studies. The MNI (Montreal Neurological Institute) coordinates for the striatum were taken from a paper reporting a role for the ventral pallidum in unconscious motivation using a task involving subliminal stimuli ([*x*, *y*, *z*] [12 0 −6]) (Pessiglione et al. 2007). The MNI coordinates for lOFC were obtained from a study showing a role for this region in suppressing negative emotion ([*x*, *y*, *z*] [−38 45 −10]) (Goldin et al. 2008). Finally, the MNI coordinates for IPS were obtained from a study looking at voluntary orienting of attention to visual stimuli ([*x*, *y*, *z*] [25 −67 48]) (Corbetta et al. 2000). Note that the peak coordinates reported in the Results section are based on the activated clusters as they appear on our statistical maps using a height threshold of $P < 0.001$, uncorrected.

Plotting of Parameter Estimates

Plots of parameter estimates were extracted using the MarsBaR toolbox (http://marsbar.sourceforge.net/). For each participant, average parameter estimates were extracted from an 8 mm sphere centered on the coordinates reported in the aforementioned studies, thereby avoiding a nonindependence bias in the voxel selection (Kriegeskorte et al. 2009). Note that for insula activity, parameter estimates were extracted from an 8 mm sphere centered on the mean coordinates reported for the right hemisphere in WOROI ([*x*, *y*, *z*] [38 3 5]) (http://neuro.imm.dtu.dk/services/brededatabase/WOROI_67.html). The β estimates from the insula and striatal activities were correlated against the strength of our reactance index (Fig. 4*d*,*e*), while that of the IPS was correlated against negative evaluation-induced performance increase (Fig. 4*g*). Parameter estimates extracted from lOFC for the Discouragement, Control, and Encouragement conditions are plotted in Figure 4*f*.

Results

Behavioral Results

Evaluation Phase

Participants were more likely to decline taking up the challenge as the probability of getting shocked upon failure increased (repeated-measures ANOVA, $F[1,24] = 27.82$, $P < 0.001$) (Fig. 2). As predicted by our pilot experiments, participants were slower at deciding whether to take up the challenge for the intermediate probability of $P = 0.6$ (planned comparisons paired *t*-tests, $P < 0.05$) and correspondingly, they were less confident about their decision (planned comparisons paired *t*-tests, $P < 0.01$), suggesting that decisions were harder to make for this probability (Demb et al. 1995; McClure et al. 2004) and were therefore more likely to be influenced by external evaluation (Formisano et al. 1982). The rate of successful challenges did not differ across probabilities (paired *t*-tests, all $P > 0.3$) and averaged to 62 ± 14 %. RTs and confidence about their answer at the challenge did not differ across probabilities (paired *t*-tests, all $P > 0.4$).

Since we were interested in the influence of negative evaluation on behavior, we focused analyses from the Test Phase on those trials where choices were perceived as more difficult, that is when the probability of getting shocked upon failure was 0.6 (see Experimental Task description). However, note that the main effects we report below were still statistically significant when performing ANOVAs across the 3 probabilities.

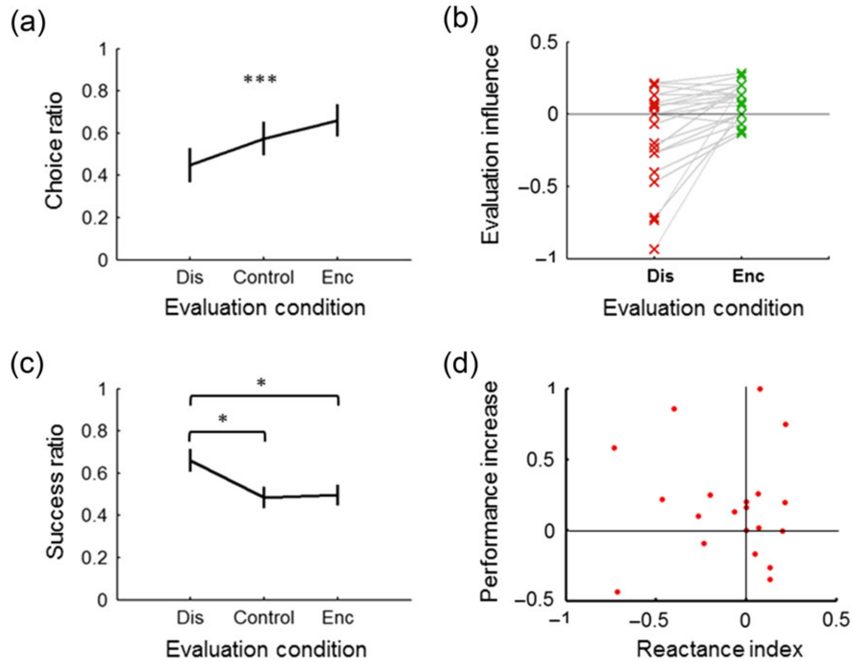

Figure 3. Test Phase behavioral results. (*a*) Choice rate to "Go for it!" across the Discouragement (Dis), Control, and Encouragement (Enc) conditions. Deciding whether to take up the challenge was significantly influenced by the evaluation condition (Repeated-measures ANOVA, $P < 0.001$). (*b*) Individual differences in the decision of taking up the challenge in the Discouragment (Dis) and Encouragement (Enc) conditions as compared to the Control condition. The horizontal line represents the choice rate to "Go for it!" in the Control condition for any given participant. Each cross represents a participant. As shown, while encouragement had a consistent motivating effect on taking up the challenge across participants, discouragement had either a deterrent or motivating effect on participants' decision. (*c*) Success rate at detecting the stimulus across conditions. Participants were significantly more successful at the challenge in the Discouragement condition as compared to the Control condition and the Encouragement condition (paired *t*-tests, $P < 0.05$). Error bars represent SEM. (*d*) Reactant behavior versus Performance increase in the discouragement as compared to the control condition for all participants. While the tendency to exhibit reactant behavior varied greatly across individuals, performance increase following discouragement was enhanced in most individuals. Each dot represents a participant. ***$P < 0.001$ and * $P < 0.05$, $n = 25$.

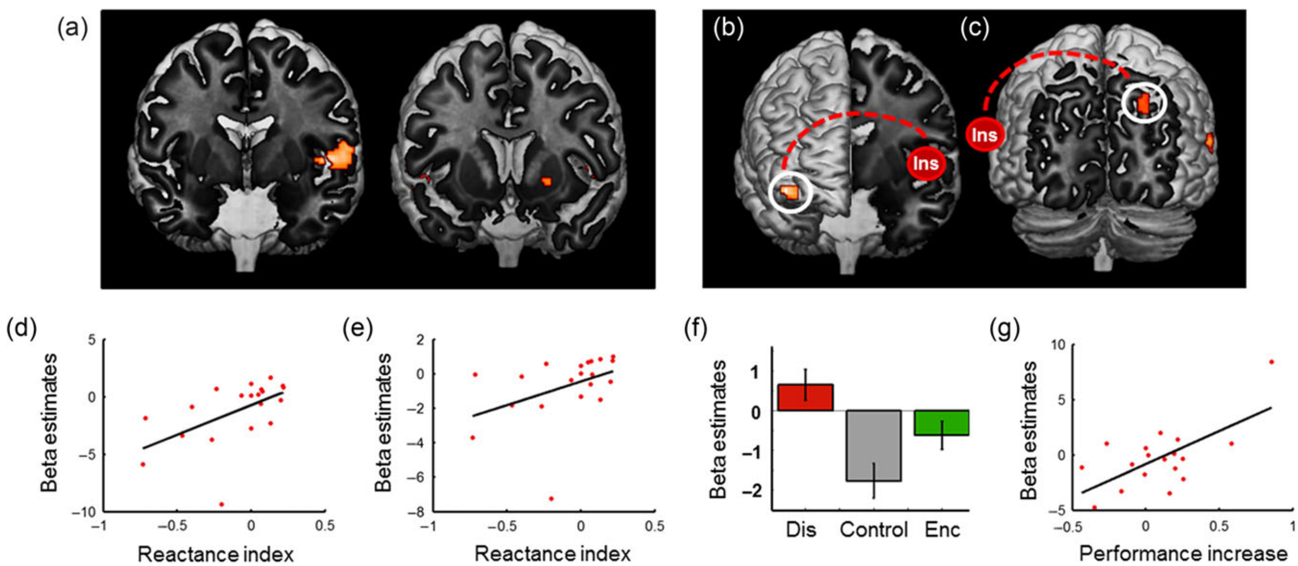

Figure 4. fMRI signals. (*a*) BOLD signal correlating with the increased likelihood of taking up the challenge when being discouraged across participants in the insula (left panel) and striatum (right panel). (*b*) lOFC exhibits an increased correlation with insula activity during successful Discouragement trials as compared to successful Control trials. (*c*) BOLD signal in IPS showing an increased correlation with insula activity and positively correlating with performance increase in Discouragement trials as compared to Control trials across participants. (*d*,*e*) Scatter plots showing the β estimates in the insula (*d*) and striatum (*e*) correlating with the increased propensity of taking up the challenge when being discouraged for each participant. (*f*) Plot showing β estimates in lOFC for successful trials in the Discouragement (Dis), Control, and Encouragement (Enc) conditions. Note that these beta estimates were extracted from the GLM used for the PPI analysis and should not be interpreted in terms of connectivity. Error bars represent SEM. (*g*) Scatter plot showing the β estimates in IPS correlating with the increased success in the Discouragement condition for each participant. All activities are reported using a height threshold of $P < 0.001$, and an SVC significant at $P < 0.05$.

Test Phase

Participants' choice of taking up the challenge was strongly influenced by the evaluation condition (i.e., Discouragement, Control, or Encouragement conditions) (repeated-measures ANOVA, $F(1,24) = 13.93$, $P < 0.001$) (Fig. 3*a*). RTs about deciding whether to take up the challenge and confidence ratings about their decision did not significantly differ across evaluation conditions (repeated-measures ANOVAs, RT: $F(1,24) = 0.01$, $P = 0.97$; confidence rating: $F[1,24] = 1.74$, $P = 0.20$). As expected, while positive evaluation increased participants' likelihood to take up the challenge, negative evaluation had either a deterrent or a motivating effect depending on the participant (Fig. 3*b*). Interestingly, this difference in the propensity to take up the challenge in the discouragement versus the control condition was positively correlated with self-reports of self-esteem (linear regression, $r = 0.40$, $P < 0.05$), thereby confirming a role for self-esteem in reactant behavior (Brockner and Elkind 1985) and indicating that these individual differences cannot be accounted for by random fluctuations in behavior.

Participants were significantly more successful at the challenge when being discouraged to take it up compared to when given no evaluation or when being encouraged (repeated-measures ANOVA, $F[1,24] = 4.64$, $P < 0.05$; paired *t*-tests between Discouragement-Control and Discouragement-Encouragement conditions, $P < 0.05$) (Fig. 3*c*,*d*). To ensure that this effect was not biased by an unbalanced number of trials across conditions (since participants were more likely to take up the challenge when being encouraged), we conducted a confirmation analysis in which we equated the number of trials in each evaluation condition by identifying the condition with the least number of trials for each participant and randomly excluding trials in the other conditions until the minimum was reached. This analysis yielded the same qualitative results, thereby excluding a potential alternative explanation. Importantly, there was no correlation between participants' success rate and their propensity to take up the challenge when being discouraged ($r = -0.21$, $P = 0.38$). This result indicates that the negative evaluation-related increase in performance cannot be accounted for by the possibility that more successful participants were also more likely to take up the challenge when being discouraged. More interestingly, this finding also demonstrates that there was no direct relationship between reactant behavior and performance facilitation. Moreover, confidence ratings about their answer following the challenge did not correlate with performance (linear regression; $r = -0.03$, $P = 0.89$), supporting the idea that participants were not aware of their performance. RTs to discriminate the stimulus and confidence ratings about their judgment did not differ across evaluation conditions (repeated-measures ANOVAs, RT: $F[1,24] = 0.36$, $P = 0.56$; Confidence rating: $F[1,24] = 0.21$, $P = 0.65$). Note that there was no correlation between self-esteem and performance increase (linear regression, $r = -0.11$, $P = 0.61$).

fMRI Results

We report results from our analyses using a height threshold of $P < 0.001$, small-volume corrected (SVC) using a priori coordinates and a threshold of $P < 0.05$.

Motivating Effect of Negative Evaluation

To identify brain areas associated with the motivating effect of negative evaluation, we examined the extent to which brain activity in the relevant contrast was modulated as a function of the degree with which each participant exhibited reactant behavior at the time of choice. To do so, we computed a simple difference score between the likelihood of taking up the challenge in the discouragement condition minus the likelihood of taking it up in the control condition for any given participant, and included this reactance index as a covariate in this contrast. As predicted, we found significant activations in the insula ([x, y, z] [50, −2, 2], $T = 5.02$, $k = 404$) and striatum ([x, y, z] [22, 6, −4], $T = 4.44$, $k = 40$) (Fig. 4*a*).

Negative Evaluation-Related Increase in Performance

To test whether the increase in performance following negative evaluation was related to psychological reactance, we next performed a functional connectivity analysis to identify areas showing positive functional connectivity with the insula at the time of choice when participants were later successful at the challenge in the Discouragement condition as compared to the Control condition. lOFC activity ([x, y, z] [−40, 46, −10], $T = 4.95$, $k = 47$) was found to interact with insula activity (Fig. 4*b*). Furthermore, to gain more insight into the relationship between negative evaluation and success, we examined the extent to which brain activity showing positive functional connectivity with insula activity was modulated as a function of individual performance increase in the Discouragement condition as compared to the Control condition. We found that IPS ([x, y, z] [24 −70 48], $T = 4.21$, $k = 39$) exhibited increased correlation with insula activity as participants were more successful in the Discouragement condition (Fig. 4*c*).

Discussion

Here, we provide behavioral and neural evidence that for some individuals, negative evaluation facilitates behavior. We further demonstrate that negative evaluation boosts performance, an effect that was not linked to the propensity of exhibiting reactant behavior. These findings are consistent with psychological reactance theory, whereby a restricted freedom of choice induces motivation to restore the threatened freedom by engaging in the restricted behavior (Brehm 1966). As suggested by the current findings and elsewhere (Brockner and Elkind 1985), the propensity to exhibit reactant behavior might relate to a subjective threshold in the perception of a threat to freedom, which might itself relate to one's sense of self-esteem. Although one could argue that being encouraged to take an action might also be perceived as a threat to freedom, subjective thresholds to perceived threat are likely to be substantially higher when the threat is irrelevant to self-esteem, and is therefore expected to be considerably less vulnerable to psychological reactance.

Consistent with the idea that receiving negative evaluation before deciding to take up a challenge might not only increase the likelihood of engaging in it but might also facilitate performance, we show that participants' success rate at the challenge was increased following negative evaluation, but not after receiving no evaluation or being encouraged. Given that all accepted challenges led to the same monetary reward, the asymmetry we observe between the discouragement and encouragement conditions might relate to a more intrinsic kind of reward. Indeed, one could argue that although taking up the challenge involves the possibility of getting shocked in the 3 conditions, only the discouragement condition involves the possibility of proving the judge wrong, and thereby gain social approval. Speculatively, proving that one is capable of succeeding at the challenge when being told that they are not capable might further enhance one's sense of self-esteem and act as a positive reinforcement loop.

This finding accords well with studies showing increased performance following increased motivation to do well (Bengtsson et al. 2009) and approach motivation (Murty et al. 2011), after being primed for self-esteem (Bengtsson et al. 2011) or after making self-determined decisions (Murayama et al. 2013; Schouppe et al. 2014). Although at first sight this result might seem inconsistent with a large body of research on stereotype threat which has repeatedly shown that negative primes hinder performance (Schmader et al. 2008), we highlight that this decrease in performance has been associated with narrowed attention due to the experience of anxiety (Johns et al. 2008). However, given the well-established relationship between anxiety and decreased self-esteem on the one hand (Sowislo and Orth 2013) and reactant behavior and increased self-esteem on the other hand (Brockner and Elkind 1985), it is tempting to speculate that an increase in anxiety levels not only prevents performance facilitation, but results in poorer performance instead (Osborne 2001). Although the current data do not provide direct evidence for this claim, the idea that anxiety hinders performance in reward-related processes has received support elsewhere (Callan and Schweighofer 2008). Yet, note that it is worthwhile mentioning that the current paradigm differs from stereotype threat paradigms in important ways. While research on stereotype threat involves priming stereotypes, here participants were given individual evidence-based evaluation that had no social relevance.

At the neural level, we found the increase in motivation following negative evaluation to be represented in the insula and striatum, brain areas known to be involved in motivation and negative affect (Pessiglione et al. 2007; Dosenbach et al. 2008; Schmidt et al. 2009; Knutson et al. 2014; Orr and Banich 2014). Notably, the insula has been reported in studies where arousal was found to increase motivation (Schmidt et al. 2009) or when external biases interfered with voluntary task choice (Orr and Banich 2014). Insula and striatal activities have also been observed when participants decided to switch from a default option (Yu et al. 2010), or after engaging in a high versus low mental effort (Hernandez Lallement et al. 2014). Although the recruiting of these regions was expected given that reactant behavior integrates crucial aspects of the processes aforementioned, our results extend the role of these structures to negative evaluation-induced motivation.

Performance facilitation following negative evaluation was associated with a network of brain regions previously implicated in aggressive stance in response to threat perception, attention, and goal-directed behavior. In particular, success in the discouragement condition was associated with the coupling between insula and lOFC activities at the time of choice. lOFC has consistently been recruited in both reappraisal processes and the suppression of negative emotions (Goldin et al. 2008; Kanske et al. 2011). In the current task, reappraising a negative evaluation or suppressing the negative feeling associated with this evaluation might contribute to the facilitation of successful goal-oriented behavior as suggested elsewhere (Hooker and Knight 2006). Interestingly, lOFC has been associated with aggression and anger (Dougherty et al. 1999; Antonucci et al. 2006), and along with the insula, lOFC has also been shown to be recruited when experiencing frustration (Yu et al. 2014b) or unfairness (Yu et al. 2014a), highlighting a possible "fight" response that might boost performance in the current study.

Consistent with the idea that visual attention was crucial to performance in our task, lOFC has also been reported to play a part in attention focus, together with parietal areas (Hampshire and Owen 2006). Furthermore, performance facilitation across participants between our discouragement and control conditions correlated with increased functional positive connectivity between the insula and the IPS. The IPS has repeatedly been implicated in visual attentional processes across species (Wojciulik and Kanwisher 1999; Rushworth et al. 2001; Hampshire and Owen 2006; Carrasco 2011) and has been shown to play a pivotal role in the orienting of attention (Corbetta et al. 2000; Ptak and Schnider 2011), the detection of stimuli (Corbetta and Shulman 2002) and ultimately behavioral performance (Lau and Passingham 2006; Wen et al. 2012).

To conclude, the current study demonstrates that negative evaluation has the potential to motivate behavior and boost performance, and suggests that in some instances, negative evaluation might be adaptive by motivating the need for success. Nonetheless, it is worth mentioning that although the present findings could serve as a basis for future research seeking to develop strategies to motivate people and enhance their performance, they should be interpreted with caution. First, these results provide only correlational data and the mechanisms supporting reactance will need to be further explored. Second, we found no relationship between reactance and performance, suggestion that this construct only accounts for taking up a challenge and not performance facilitation. Third, as corroborated by stereotype threat research (Steele and Aronson 1995), negative arousal can have opposite consequences on behavior and performance depending on a number of factors such as the proneness of the task or primes used in inducing anxiety and in manipulating one's sense of self-esteem. This last point may also help to explain the somewhat surprising null finding on the correlation between psychological reactive and performance boost; the relationship is likely complex, mediated by multiple mechanisms.

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