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TASK FEEDBACK EFFECTS ON CONFLICT MONITORING AND EXECUTIVE CONTROL:

RELATIONSHIP TO SUBCLINICAL MEASURES OF DEPRESSION

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Abstract

Emerging evidence suggests that depression is associated with executive dysfunction, particularly after committing errors or receiving negative performance feedback. To test this hypothesis, 57 participants performed two executive tasks known to elicit errors (the Simon and Stroop Tasks) during positive or negative performance feedback. Participants with elevated depressive symptoms (Beck Depression Inventory scores ≥ 13) were characterized by impaired post-error and post-conflict performance adjustments, especially during emotionally negative task-related feedback. Additionally, for both tasks, depressive symptoms were inversely related to post-conflict reaction time adjustments following negative, but not positive, feedback. These findings suggest that subclinical depression is associated with impairments in behavioral adjustments after internal (perceived failure) and external feedback about deficient task performance.

Keywords: Depression, Conflict Monitoring, Feedback, Executive Functioning

TASK FEEDBACK EFFECTS ON CONFLICT MONITORING AND EXECUTIVE CONTROL:

RELATIONSHIP TO SUBCLINICAL MEASURES OF DEPRESSION

Over the years, the investigation of neuropsychological dysfunction in depression has attracted considerable interest (Rogers et al., 2004). Among the most replicated findings are reports of impaired executive functions, which typically emerge in experimental settings requiring adaptive action monitoring and flexible behavioral adjustments (Austin, Mitchell, & Goodwin, 2001; Paradiso, Lamberty, Garvey, & Robinson, 1997; Porter, Gallagher, Thompson, & Young, 2003; Siegle, Steinhauer, & Thase, 2004). Interestingly, executive dysfunctions have been observed after remission of depressive symptoms (e.g., Trichard et al., 1995), and have predicted poor response to antidepressant treatments (Dunkin et al., 2000). Although these findings indicate that executive dysfunctions confer increased vulnerability to depression, the precise mechanisms giving rise to these impairments remain largely unexplored.

Findings from recent neuropsychological studies in both clinically depressed and dysphoric subjects suggest that the observed executive deficits may be partially due to abnormal responses to negative feedback or perceived failure. Accordingly, depressed subjects have been shown to display circumscribed and specific behavioral impairments in trials immediately following errors or negative feedback concerning task performance (Elliott et al., 1996; Elliott, Sahakian, Herrod, Robbins, & Paykel, 1997; Murphy, Michael, Robbins, & Sahakian, 2003; Pizzagalli, Peccoralo, Davidson, & Cohen, 2006). These neuropsychological findings are in line with independent reports emphasizing that depressed and dysphoric participants are characterized by (1) amplification of the relative

significance of their failures (Wenzlaff & Grozier, 1988); (2) difficulty in suppressing

failure-related thoughts (Conway, Howell, & Giannopoulos, 1991); and (3) increased

depressed mood after encountering negative social feedback (Henriques & Leitenberg,

2002). As a corpus, this research indicates that depressed patients are less able to utilize

information conveyed by errors or feedback to modulate their subsequent performance.

This is consistent with literature associating depression with enduring negative cognitive

schemata and processing biases (Clark, Beck, & Alford, 1999) and suggests a link

between deficits in executive functioning and negative affect in depression.

In parallel, research in cognitive psychology and cognitive neuroscience has

demonstrated that errors and task-relevant feedback can elicit adaptive shifts in behavior

(Gauggel, Wietasch, Bayer, & Rolko, 2000; Laming, 1979; Rabbitt, 1966; Tucker, Luu,

Frishkoff, Quiring, & Poulsen, 2003). This is consistent with the conflict monitoring

theory which suggests that the occurrence of errors and conflicts between mutually

incompatible responses triggers the engagement of control processes resulting in

adjustments in performance (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999). These

online, or trial-to-trial, task adjustments have been traditionally measured in participants'

reactivity to errors and conflict trials (e.g., incongruent trials in a Stroop task) over the

course of an experiment. For instance, studies have shown that healthy subjects typically

display increased accuracy but slowed reaction time immediately following an error, a

post-error adjustment known as the Rabbitt/Laming effect (Laming, 1979; Rabbitt, 1966).

Similarly, participants generally exhibit decreased error rates and slowed reaction time

following conflict trials, a post-conflict adjustment phenomenon known as the Gratton

effect (Gratton, Coles, & Donchin, 1992).

The Present Study

In order to assess putative action monitoring dysfunctions in subjects with elevated

depressive symptoms, versions of the Simon and Stroop tasks known to induce conflict

monitoring and errors were adapted to include a task-relevant feedback manipulation.

Based on prior findings in the literature (Gratton et al., 1992; Rabbitt, 1966; Laming,

1979), trials requiring greater levels of performance monitoring (high conflict trials, post-

error trials, and post-conflict trials) were hypothesized to be associated with behavioral

adjustments reflecting the recruitment of additional cognitive resources. As in previous

studies, congruence (Simon/Stroop), post-error (Rabbitt/Laming), and post-conflict

(Gratton) effects were expected across all participants.

Most importantly, in light of evidence highlighting executive deficits in depression,

particularly in response to negative feedback or perceived failure, the present study aimed

to investigate action monitoring processes (i.e., conflict monitoring, error processing, and

feedback evaluation) in individuals with varying levels of sub-clinical depressive

symptoms. Based on the literature associating depression with (a) dysfunctional action

monitoring (Ruchsow et al., 2004; Tucker et al., 2003; Elliott et al., 1996; Elliott et al.,

1997; Murphy et al., 2003; Pizzagalli et al., 2006; Siegle et al., 2004); and (b) difficulty

in suppressing thoughts related to failure (Conway et al., 1991), it was hypothesized that

subjects with elevated depressive symptoms would show decreased performance

following high-conflict trials and errors. Moreover, because both clinical depression and

dysphoria have been associated with abnormal affective, cognitive, and neural reactions

to both internal (implicit) and external (explicit) feedback of poor performance (Conway

et al., 1991; Elliott et al., 1996; Elliott et al., 1997; Henriques et al., 2002; Murphy et al.,

2003; Ruchsow et al., 2004; Tucker et al., 2003; Wenzlaff & Grozier, 1988),

dysfunctional action monitoring processes were hypothesized to be amplified in the

context of negative feedback pertaining to ongoing task performance. Finally, participants

reporting increased levels of cognitive-affective symptoms were expected to be

particularly vulnerable to these deficits.

Methods

Participants

Seventy-four subjects were recruited from the Harvard University Study Pool,

which includes both Harvard University undergraduate students and community subjects.

Prior to behavioral testing, participants provided written informed consent to a protocol

approved by the Committee on the Use of Human Subjects at Harvard University.

Participants received course credit or monetary compensation ($10/hour) for their

participation. Seventy-three subjects were right handed (one was ambidextrous), as

assessed by the Chapman and Chapman handedness scale (Chapman & Chapman, 1987).

All participants had normal or corrected-to-normal vision, and normal color vision as

assessed by the Ishihara Test for Color Blindness (Ishihara, 1973). Six subjects were not

included in the analysis because following the experiment they reported that the feedback

manipulation (see below) was not veridical. These participants did not differ

demographically, or in their self-reported measures of mood from individuals who

believed the feedback. Following prior recommendations, seven participants with a Beck

Depression Inventory (BDI) score of 0 or 1 were excluded because such scores may be

indicative of non-normative functioning (Beck, Ward, Mendelson, Mock, & Erbaugh,

1961; Kendall, Hollon, Beck, & Hammen, 1987). Two participants were excluded from

all analyses because their age was greater than three standard deviations from the mean

age of all subjects. Two additional participants performed worse than chance levels in the

Simon Task and their data were excluded from that portion of the analysis. Two

participants were excluded from the Stroop task data analysis because they were not

fluent in English. The final sample consisted of 57 participants for both the Simon

(61.40% Caucasian; 68.40% female; mean age = 22.33, SD: 6.68, mean education 14.54,

SD: 1.71) and the Stroop (63.20% Caucasian; 66.70% female; mean age = 22.07, SD:

6.44, mean education 14.51, SD: 1.68) tasks.

Procedure

Each subject performed both behavioral (Simon and Stroop) tasks during a single session

according to an order counterbalanced across subjects. Before each task, subjects were

presented with a practice block to familiarize them with the paradigm. After the

behavioral tasks, the Beck Depression Inventory-II (BDI-II; Beck, Steer, Ball, & Ranieri,

1996) and the trait form of the Spielberger State-Trait Anxiety Inventory (STAI;

Spielberger, Gorsuch, & Lushere, 1970) were administered, among other questionnaires, to assess levels of depressive symptoms and negative affect, respectively. Following the task, participants completed a questionnaire asking whether they believed the feedback manipulation. Subjects who did not believe the manipulation were excluded from the analysis.

Apparatus

The experiment was presented on an IBM 2.4 GHz with 1GB of RAM using Eprime software version 1.1 (Psychology Software Tools, Inc., Pittsburgh, PA). Subject responses were collected by key press on a button box (Response Pad 200; Electrical Geodesic, Inc, Oregon).

Tasks

Based on criticisms that trial-to-trial adjustments might be due to stimulus-specific priming effects (Mayr, Awh, & Laurey, 2003), for each task, the number of previously congruent trials prior to each incongruent trial as well as the number of previously incongruent trials prior to each congruent trial was fully randomized using software developed for neuroimaging research to maximize the statistical orthogonality of experimental conditions (http://surfer.nmr.mgh.harvard.edu/optseq/). Accordingly, any individual incongruent trial could be preceded by one to four congruent trials. Additionally, no more than three repetitions of a given stimulus type were allowed. To increase task difficulty, and thus induce more errors, there were 98 congruent trials and

only 54 incongruent trials in each block (37.5% incongruent trials per block). Reaction

time (RT) and accuracy measures were collected throughout the tasks. Each task

consisted of four blocks, each lasting 7:36 min.

Simon Task

Participants were instructed to perform a speeded variant of the Simon task,

known to elicit response conflict and a high error rate. Instructions emphasized

responding as quickly as possible to each probe while still remaining accurate, and were

re-administered after each block. Probes were presented for 200 ms on either the left or

right of a fixation cross and participants were instructed to make spatial responses with

either their left or their right index finger. Prior to the task the participants received

instructions, both verbally and in writing. Next, subjects were presented with the

congruent and incongruent stimuli they would encounter during the task. For a congruent

probe, participants were asked to respond with the index finger that corresponded to the

side the stimuli appeared. For incongruent probes, the participants were asked to respond

with their index finger that corresponded to the side opposite from where the stimulus

appeared. The trials consisted of one congruent probe (green circle) and three incongruent

probes (red circle, red square, and green square). Multiple levels of incongruence were

used to prevent participants from building a simple association between the color of the

stimulus and the response set. Following the probe, the inter-trial interval was jittered

between 2300 and 3300ms (2300, 2800, and 3300). Throughout the task, a fixation cross

('+') was presented in the center of the screen.

Stroop Task

Participants performed a speeded variant of the Stroop task. The stimuli consisted of three words (RED, GREEN, and BLUE) printed in three different colors of ink (red, green, and blue). Trials could be either congruent (when the ink matches the word) or incongruent (when the ink does not match the word). Participants were instructed to respond, as quickly as possible while still remaining accurate, to the ink color of each word. Participants responded with a button press using the middle three fingers of their right hand, with one finger representing each color. Probes were presented for 200 ms in the center of the screen. Following the probe the inter-trial interval was jittered between 2300 and 3300ms (2300, 2800, and 3300). Between probes, a fixation cross ('+') was presented in the center of the screen for the duration of the task.

Task-Related Performance Feedback

For both tasks, participants were presented with positive or negative feedback at the beginning of each block. The participants were informed that this feedback reflected their performance on the previous block compared to subjects who had already completed the study. For the first block, participants were told that the feedback reflected their performance on the practice block. In reality, the feedback received was not contingent upon subjects' performance but was pre-determined to allow for a balanced design. For the positive manipulation, the following feedback was presented: "*Compared to subjects who have already participated in the study your performance in the last block was*

ABOVE AVERAGE. Please remember to respond as quickly as possible to the stimuli while remaining accurate." For the negative manipulation, the following feedback was presented: "*Compared to subjects who have already participated in the study your performance in the last block was significantly BELOW AVERAGE. Please remember to respond as quickly as possible to the stimuli while remaining accurate.*" The order of feedback was pseudo-randomized and fully counterbalanced across participants (negative-positive-positive-negative or positive-negative-negative-positive).

Data Reduction

To minimize the influence of outliers on RTs, trials with RTs (after natural log transformation) falling outside the range of mean ± 3SD for each trial type were excluded from analyses (Simon Task: 1.54%±1.88%; Stroop Task: 1.07%±0.06%). Outliers were identified separately for congruent and incongruent trial types and each subject. Only trials where the subject made a response were considered for the analyses.

As summarized above, substantial evidence suggests that the occurrence of conflict and errors triggers the engagement of control processes resulting in adjustments in performance (Botvinick et al., 1999). In cognitive studies these on-line task adjustments have been typically studied in the form of the Simon/Stroop, Laming/Rabbitt, and Gratton effects. The Simon/Stroop effect is a measurement of interference elicited by the task, and is computed as: $[RT_{Incongruent\ trials} - RT_{Congruent\ trials}]$ and $[Accuracy_{Congruent\ trials} - Accuracy_{Incongruent\ trials}]$; higher scores are indicative of general impairments in cognitive control. The Laming/Rabbitt effect (Laming, 1979; Rabbitt, 1966) is a measurement of

post-error adjustment, and is calculated as: [RT$_{\text{After incorrect trials}}$ − RT$_{\text{After correct trials}}$] and

[Accuracy$_{\text{After incorrect trials}}$ − Accuracy$_{\text{After correct trials}}$]. The Gratton effect (Gratton et al.,

1992) is a measure of post-conflict adjustment, and is operationalized as: [RT$_{\text{Incongruent trials}}$

$_{\text{following congruent trials}}$ − RT$_{\text{Incongruent trials following incongruent trials}}$] and [Accuracy$_{\text{Incongruent trials following}}$

$_{\text{incongruent trials}}$ − Accuracy$_{\text{Incongruent trials following congruent trials}}$]. For both the Laming/Rabbit and

Gratton effects higher scores are indicative of increased cognitive control.

An additional, potentially more sensitive, method of examining behavioral adjustments

after conflict trials includes examining whether an individual exhibits decreased RT on

incongruent trials preceded by incongruent trials (iI) relative to incongruent trials

preceded by congruent trials (cI), as well as decreased RT on congruent trials preceded by

congruent trials (cC) relative to congruent trials preceded by incongruent trials (iC; Kerns

et al., 2004). This effect can be studied through the calculation of a so-called "post-

conflict RT adjustment score" [(iC - cC) + (cI - iI)]. For this effect, higher scores also

indicate increased cognitive control.

Statistical Analyses

For each task, exploratory analyses revealed no significant effects of gender or form of

compensation (course credit vs. payment); consequently, data were collapsed across these

variables. Two sets of statistical analyses were performed. The first aimed to assess the

relationship between feedback and levels of depressive symptoms on behavioral

adjustments. To this end, accuracy and RT scores were separately calculated for the

negative and positive feedback manipulation, and entered in a mixed 2 x 2 x 2 analysis of

variance (ANOVA) with *Group* (low BDI vs. high BDI subjects) as a between-subject

factor and *Condition* (e.g., post-error vs. post-correct accuracy) and *Feedback* (negative

vs. positive) as repeated measures. Participants with a BDI-II score less ≤ 5 were

assigned to the low BDI group, those with a BDI-II score ≥ 13 to the high BDI group

(Beck et al., 1996). For the Simon task, the low BDI (3.50±0.88) and high BDI

(16.57±3.34) included 21 and 13 subjects, respectively. For the Stroop task, the low BDI

(3.43±0.87) and high BDI (16.38±3.40) included 20 and 14 subjects, respectively. The

low and high BDI groups did not differ in their demographic variables for both the Simon

[ethnicity $\chi^2(1) = 0.22$, $p > 0.63$; gender $\chi^2(1) = 1.09$, $p = 0.30$; age $t(32) = 0.14$, $p > 0.88$;

education $t(32) = 1.51$, $p > 0.22$] and Stroop [ethnicity $\chi^2(1) = 1.40$, $p > 0.23$; gender $\chi^2(1)$

$= 1.40$, $p > 0.23$; age $t(32) = -0.25$, $p > 0.80$; education $t(32) = 1.78$, $p > 0.08$] task.

To assess modulations on the Simon/Stroop effects, the performance for congruent vs.

incongruent trials was entered for the *Condition* factor. For the Laming/Rabbitt effect, the

performance following a correct vs. incorrect response was used. Lastly, for the Gratton

effect, the performance for incongruent trials following a congruent trial was compared to

the performance during incongruent trials following an incongruent trial. A significant

Group x *Condition* interaction when considering, for example, post-correct and post-

incorrect trials, indicates that the high and low BDI groups differ in their Laming/Rabbitt

effect. In light of reports highlighting temporal decay of affective states (Hemenover,

2003), only the first half of the trials within each block were utilized for the ANOVAs.[1] In

the case of significant interactions emerging from the ANOVAs, post-hoc Newman-Keuls

tests were performed.

In a second and complementary approach, hierarchical regression analyses were run to examine whether individual differences in depressive symptoms predicted unique variance in adjustment effects during the negative feedback condition. The regression analyses were conducted on all participants (n = 57). Specifically, these regressions tested whether BDI scores (entered in the second step) predicted a given behavioral adjustment effect during the negative feedback after adjusting for the same effect during the positive feedback (entered in the first step). Regression analyses were run on the Simon/Stroop, Rabbitt, and the post-conflict RT adjustment effect [(iC - cC) + (cI – iI); Kerns et al., 2004]. The latter was preferred over the Gratton effect because it was expected to provide a more sensitive measure of post-conflict behavioral adjustments.

If significant findings emerged, two follow-up regression analyses were performed to further assess their specificity. The first tested whether two BDI subscores, which have been previously identified in factor analytic studies of the BDI-II within undergraduate samples, differentially contributed to a given behavioral adjustment effect during the negative feedback. According to the BDI-II manual (Beck, Steer, & Brown, 1996), a cognitive-affective subscore (sadness, past failure, loss of pleasure, guilty feelings, punishment feelings, self-dislike, self-criticalness, suicidal thoughts, crying, agitation, loss of interest, indecisiveness, worthlessness, irritability) and a somatic subscore (loss of energy, changes in sleeping pattern, changes in appetite, concentration difficulty, tiredness or fatigue) were computed. The second regression analysis assessed whether BDI scores predicted a given behavioral effect during the negative feedback after adjusting for negative affect, as assessed by the trait form of the STAI.

Results

Simon Task: ANOVA Analyses

Congruence (Simon) effects. For both RT and accuracy, a main effect of *Condition* (congruent trials vs. incongruent trials) emerged (RT: $\underline{F}_{1,32}$ = 134.06, $\underline{p}$ < 0.00; partial η^2 = 0.81; accuracy: $\underline{F}_{1,32}$ = 18.55, $\underline{p}$ < 0.00; partial η^2 = 0.37). As expected, participants were faster and more accurate during congruent than incongruent trials. For accuracy, a *Group* x *Feedback* interaction also emerged ($\underline{F}_{1,32}$ = 4.15, $\underline{p}$ < 0.05; partial η^2 = 0.12). Post-hoc Newman-Keuls tests revealed a trend for high BDI ($\underline{p}$ > 0.08), but not low BDI ($\underline{p}$ > 0.60), subjects to show decreased overall accuracy during the negative compared to the positive feedback condition (Fig. 1a).

Post-error adjustment (Laming/Rabbitt) effects. For RT, the effect of *Condition* (post-error trials vs. post-correct trials) revealed a trend, which was due to slower RT following an incorrect than a correct trial ($\underline{F}_{1,32}$ = 3.53, $\underline{p}$ < 0.07; partial η^2 = 0.10). No other effects emerged for RT. For accuracy, the ANOVA revealed a *Group* x *Feedback* interaction ($\underline{F}_{1,32}$ = 9.75, $\underline{p}$ < 0.01; partial η^2 = 0.23), which was qualified by a *Group* x *Condition* x *Feedback* interaction ($\underline{F}_{1,32}$ = 5.95, $\underline{p}$ < 0.03; partial η^2 = 0.16; Fig. 1b). Post-hoc Newman-Keuls clarified that the *Group* x *Feedback* interaction was due to significantly lower accuracy during the negative compared to the positive feedback for high BDI ($\underline{p}$ < 0.03), but not low BDI ($\underline{p}$ > 0.18), subjects. To evaluate the triple interaction, follow-up *Group* x *Condition* ANOVAs were performed for the positive and negative feedback separately. For the positive feedback, no effects emerged (all $Fs_{1,32}$ < 2.57, all $\underline{ps}$ > 0.11),

suggesting that the two groups did not differ in the Laming/Rabbitt effect during the positive feedback condition. For the negative feedback, the only significant effect was the *Group* x *Condition* interaction, $F_{1,32} = 5.19$, $p < 0.03$, indicating that high and low BDI groups differed in their Laming/Rabbitt effects during the negative feedback condition (Fig. 1c). Compared to low BDI subjects, high BDI subjects had significantly lower accuracy after incorrect ($p < 0.005$), but not correct ($p > 0.10$), trials, as assessed with post-hoc Newman-Keuls tests. Moreover, low ($p = 0.05$), but not high ($p > 0.23$), subjects had higher accuracy after incorrect than correct trials. Accordingly, only low BDI subjects showed a significant Laming/Rabbitt effect in the negative feedback condition.

Conflict-adaptation (Gratton) effects. For RT, a *Group x Condition (*incongruent trials following congruent trials vs. incongruent trials following incongruent trials) *x Feedback* interaction emerged ($F_{1,32} = 4.51$, $p < 0.05$; partial $\eta^2 = 0.12$), indicating that the high and low BDI subjects differed in their Gratton effects depending on the nature of the feedback (Fig. 1d). As above, follow-up *Group* x *Condition* ANOVAs were run separately for the positive and negative feedback. For the positive feedback, no effects emerged (all $Fs_{1,32} < 1.58$, all $ps > 0.20$). For the negative feedback, a trend for the interaction was observed, $F_{1,32} = 6.08$, $p < 0.08$. Post-hoc Newman-Keuls tests for this interaction were, however, not significant. For accuracy, a main effect for *Condition* was found indicating that participants responded less accurately on incongruent trials following congruent trials relative to incongruent trials following incongruent trials ($F_{1,32} = 3.34$, $p < 0.02$; partial $\eta^2 = 0.16$). No further effects emerged.

Simon Task: Regression Analyses

Congruence (Simon) effects. For both RT ($\Delta R^2 = 0.000$, $\Delta F(1,54) = 0.01$, $p > 0.90$) and accuracy ($\Delta R^2 = 0.002$, $\Delta F(1,54) = 0.11$, $p > 0.75$), BDI scores did not predict the Simon effect during the negative feedback after adjusting for the effect during the positive feedback.

Post-error adjustment (Laming/Rabbitt) effects. No effects emerged when considering RT ($\Delta R^2 = 0.005$, $\Delta F(1,54) = 0.29$, $p > 0.59$) or accuracy ($\Delta R^2 = 0.025$, $\Delta F(1,54) = 1.43$, $p > 0.23$).

Post-conflict adjustment RT effects. BDI scores explained unique variance in post-conflict RT adjustment scores during negative feedback even after adjusting for individual differences in positive feedback effects, $\Delta R^2 = 0.115$, $\Delta F(1,54) = 7.32$, $p < 0.01$ (Fig. 2a). Accordingly, the higher the BDI scores, the lower the post-conflict behavioral adjustments in reaction time during the negative feedback manipulation. Analogous regression analyses performed on the two BDI subscores revealed that the cognitive-affective dimension ($\Delta R^2 = 0.139$, $\Delta F(1,54) = 8.87$, $p < 0.01$), but not the somatic dimension ($\Delta R^2 = 0.034$, $\Delta F(1,54) = 1.93$, $p > 0.15$), predicted post-conflict RT adjustment scores during the negative feedback after adjusting for effects during the positive feedback. Finally, the second hierarchical linear regression analysis showed that BDI scores tended to explain unique variance in post-conflict RT adjustment scores during negative feedback even when removing variance associated with individual differences in STAI trait scores[2], $\Delta R^2 = 0.034$, $\Delta F(1,54) = 2.89$, $p < 0.10$.

Stroop Task: ANOVA Analyses

Congruence (Stroop) effects. For both RT and accuracy, the main effect of *Condition*

(congruent trials vs. incongruent trials) was significant (RT: $\underline{F}_{1,32}$ = 108.94, $\underline{p}$ < 0.00;

partial η^2 = 0.77; accuracy: $\underline{F}_{1,32}$ = 37.44, $\underline{p}$ < 0.00; partial η^2 = 0.54). Participants were

quicker and more accurate during congruent than incongruent trials. Additionally, for RT,

a *Feedback* x *Condition* interaction emerged, $\underline{F}_{1,32}$ = 7.20, $\underline{p}$ < 0.02, partial η^2 = 0.18; this

effect was not further explored since was irrelevant to the primary goals of the study.

Post-error adjustment (Laming/Rabbitt) effects. As expected, a main effect of *Condition*

(post-error trials vs. post-correct trials) emerged due to slower ($\underline{F}_{1,32}$ = 12.61, $\underline{p}$ < 0.02;

partial η^2 = 0.30), but more accurate responses ($\underline{F}_{1,32}$ = 7.68, $\underline{p}$ = 0.10; partial η^2 = 0.21)

after incorrect than correct trials. No additional effects emerged for RT or accuracy

scores.

Conflict-adaptation (Gratton) effects. When considering RT, a main effect of *Condition*

(incongruent trials following congruent trials vs. incongruent trials following incongruent

trials) emerged ($\underline{F}_{1,32}$ = 14.44, p < 0.02; partial η^2 = 0.31); participants responded more

slowly on incongruent trials following congruent trials than incongruent trials following

incongruent trials. In addition, a reliable *Group* x *Condition* interaction indicated that the

high and low BDI subjects differed in their Gratton effects irrespective of the feedback

manipulation ($\underline{F}_{1,32}$ = 5.14, p < 0.04; partial η^2 = 0.14). Post-hoc Newman-Keuls tests

revealed that the low BDI ($\underline{p}$ < 0.01), but not high BDI ($\underline{p}$ > 0.50), subjects were faster for

the incongruent following incongruent trials relative to the incongruent following

congruent trials (Fig. 3). Accordingly, for the low BDI, but not high BDI, subjects the

Gratton effect was significant. When considering accuracy, no significant ANOVA effects emerged.

Stroop Task: Regression Analyses

Congruence (Stroop) effects. For both RT ($\Delta R^2 = 0.033$, $\Delta F(1,54) = 1.82$, $p > 0.18$) and accuracy ($\Delta R^2 = 0.027$, $\Delta F(1,54) = 1.53$, $p > 0.22$), BDI scores did not predict the Stroop effect during negative feedback after adjusting for the Stroop effect during the positive feedback condition.

Post-error adjustment (Rabbitt) effects. No effects emerged for either RT ($\Delta R^2 = 0.007$, $\Delta F(1,54) = 0.35$, $p > 0.56$) or accuracy ($\Delta R^2 = 0.000$, $\Delta F(1,54) = 0.00$, $p > 0.97$).

Post-conflict adjustment RT effects. As for the Simon task, BDI scores explained unique variance in post-conflict RT effect scores during negative feedback after adjusting for positive feedback, $\Delta R^2 = 0.093$, $\Delta F(1,54) = 5.60$, $p < 0.03$ (Fig. 2b). Likewise, the follow-up regression analyses indicated that the cognitive-affective BDI subscore ($\Delta R^2 = 0.121$, $\Delta F(1,54) = 7.60$, $p < 0.01$), but not the somatic BDI subscore ($\Delta R^2 = 0.010$, $\Delta F(1,54) = 0.55$, $p > 0.46$), uniquely predicted post-conflict RT adjustment scores during negative feedback. Further highlighting the specificity of these findings, a final regression analysis indicated that BDI scores explained unique variance in post-conflict RT adjustment scores during negative feedback even when considering individual differences in STAI trait scores[3], $\Delta R^2 = 0.076$, $\Delta F(1,54) = 8.12$, $p < 0.01$.

Discussion

Consistent with the cognitive conflict theory (Botvinick, Braver, Barch, Carter, & Cohen, 2001), the present results provide direct empirical evidence for trial-to-trial behavioral adjustments during conflict trials as well as immediately following both conflict and error trials. Specifically, for both the Simon and Stroop tasks, participants showed significantly reduced accuracy and increased reaction time during incongruent relative to congruent trials. Similarly, during both tasks, participants were significantly more accurate and faster for incongruent trials following an incongruent trial compared to incongruent trials following a congruent trial, thus exhibiting reliable post-conflict accuracy and RT adjustments. Additionally, as expected, participants showed significant post-error adjustments, which were manifested in higher accuracy (Stroop task) and RT (Stroop and Simon task) scores after incorrect relative to correct trials. Collectively, these results indicate that the intended behavioral task adjustments were achieved using the present versions of the Simon and Stroop task. More generally, the current findings support the hypothesis that response conflict and errors act as a signal to allocate increased levels of cognitive control on subsequent trials, resulting in adaptive performance adjustments (Botvinick, Cohen, & Carter, 2004; Botvinick et al., 2001).

Motivated by growing evidence implicating dysfunctional executive functioning in depression, in particular after perceived failures or negative feedbacks (Elliott et al., 1996; Elliott et al., 1997; Murphy et al., 2003; Ruchsow et al., 2004; Tucker et al., 2003; Pizzagalli et al., 2006), the primary aim of the present study was to examine action monitoring processes in individuals with elevated levels of depressive symptoms in the presence of emotionally positive or negative feedback concerning task performance.

Evidence pointing to dysfunctional action monitoring in high, but not low, BDI subjects emerged in various forms, particularly during the negative feedback condition.

In the Simon task, participants with elevated depressive symptoms showed significantly lower overall accuracy during negative than positive feedback, a pattern not seen in low BDI subjects. This effect was qualified by a significant *Group* x *Condition* (post-error trials vs. post-correct trials) x *Feedback* interaction, and further analyses revealed significant group differences in post-error behavioral adjustments (Laming/Rabbitt effect) for the negative, but not positive, feedback manipulation. Post-hoc analyses further clarified that high BDI subjects had lower post-error accuracy than low BDI subjects during the negative feedback condition. Highlighting the specificity of these findings, no differences emerged between the groups for trials following correct responses. Moreover, the two groups did not differ in their post-error adjustments during the positive feedback.[4]

In the Stroop task, evidence emerged indicating that high and low BDI subjects differed in their post-conflict adjustments regardless of the feedback manipulation. Unlike low BDI subjects, participants with elevated depressive symptoms failed to show significantly faster RT for incongruent trials following incongruent trials relative to incongruent trials following congruent trials. Accordingly, for the low BDI, but not high BDI, subjects the Gratton effect was significant. Complementing these findings, the regression analyses for both the Simon and Stroop tasks revealed that the more severe the depressive symptoms, the lower the subjects' ability to adjust performance after high-conflict trials during emotionally negative task performance feedback. This effect was observed in relation to the cognitive-affective, but not somatic, dimension of the BDI. Moreover, this effect

remained significant even after adjusting for individual differences in STAI trait scores,

suggesting that it was not due to general distress or negative affect.

Overall, these results highlight impairments in behavioral adjustments after internal

(perceived failure) and external feedback indicating deficient task performance in

subjects with elevated depressive symptoms. The observed dysfunctions in action

monitoring as shown by the Laming/Rabbit and Gratton effects contrasted with the lack

of group differences in the congruence (Simon/Stroop) effect. Although this null finding

was not hypothesized, it is possible that more global top-down cognitive control, which is

captured by the congruence effect, is not affected in subjects with elevated depressive

symptoms. Whether this pattern of findings will extend to a clinical sample remains an

empirical question that should be investigated in future studies.

Critically, although the findings emerging from the Simon task highlight performance

impairments in the high BDI subjects that were specific to trials following errors and the

negative feedback manipulation, it is important to note that they could not be replicated

in the Stroop task. The reasons for this discrepancy between the Simon and Stroop tasks

are not entirely clear and represent one of the main limitations of the present study. One

possibility is that the two tasks have dissimilar cognitive demands. Consistent with this

speculation, a recent neuroimaging study found that the two tasks recruited common, but

also unique, brain regions (Liu, Banich, Jacobson, & Tanabe, 2004). In general, whereas

both tasks commonly recruited regions involved in attentional control (e.g., dorsolateral

prefrontal cortex), the Simon task elicited stronger activation than the Stroop task in

regions critically implicated in the detection of response conflict, response selection, and

planning (e.g., anterior cingulate cortex). Future studies will be needed to test whether

behavioral deficits emerging from the present study are restricted to experimental settings

involving stimulus–response conflict, as in the Simon task, and/or whether a clinically

depressed sample may be characterized by more general (i.e., task-independent) action

monitoring dysfunctions.

Before discussing the present findings in further detail, some comments pertaining to the

feedback manipulation utilized in this study are warranted. First, in an attempt to

maximize the feedback effects on task performance, the analyses evaluating the effects of

the feedback manipulation considered only trials from the first half of each block. This

choice was motivated by prior findings suggesting that effects associated with

experimentally induced affective states can degrade over time (Hemenover, 2003).

Consistent with this view, the main findings of the present study involving the feedback

manipulation could not be replicated when the entire block of trials was considered.

Future studies assessing the effects of blocked, affectively laden feedback in depression

might thus profit from evaluating task performance at different stages of the experiment.

Second, unlike paradigms utilizing trial-to-trial feedback, it was not possible to examine

the effect of trials immediately following positive or negative feedback. Moreover, it is

possible that the blocked task performance feedback utilized in the present study resulted

in a transient mood manipulation. Although the primary goal of the current study was to

assess the sustained effects of blocked feedback on task performance and analyses

indicated a successful feedback manipulation[5], paradigms incorporating trial-by-trial

feedback may reveal further information about behavioral adjustment in depression (e.g., Tucker et al., 2004; Ruschow et al., 2004).

Conflict Monitoring and Error Processing in Depression

Relative to healthy controls, patients with depression have been found to display dysfunctional conflict monitoring processes (George et al., 1997; Lemelin, Baruch, Vincent, Everett, & Vincent, 1997; Moritz et al., 2002) and abnormal reactions to negative feedback (Elliott et al., 1997; Elliott, Sahakian, Michael, Paykel, & Dolan, 1998). In addition, after committing an error, clinically depressed subjects as well as dysphoric subjects were more likely to make mistakes on subsequent trials relative to comparison subjects (Elliott et al., 1996; Pizzagalli et al., 2006). The present findings indicating that these action monitoring dysfunctions followed a negative feedback manipulation are intriguing, especially in light of cognitive theories of depression postulating that vulnerability to depression is associated with enduring negative cognitive schemata and processing biases (Clark, Beck, & Alford, 1999). Notably, decreased post-conflict behavioral adjustments were observed only with increasing cognitive-affective, but not somatic, depressive symptoms. Collectively, the present findings suggest that depressive symptoms are associated with difficulty adjusting behavior after internal (perceived failure) and external (overt) feedback about deficient task performance, particularly within the context of a psychosocial "stressor" indicating that participant's performance was significantly lower than that of peers who had previously participated in the study. These findings are consistent with and extend prior findings indicating that

depressed and dysphoric subjects, specifically those with dysfunctional cognitive attitudes, are characterized by amplification of the significance of failure (Wenzlaff & Grozier, 1988), difficulty suppressing failure-related thoughts (Conway et al., 1991), and increased depressed mood after negative social feedback (Henriques et al., 2002). Further, the effects of feedback observed in the behavioral tasks could help explain the variable nature of the behavioral findings in depression (Lemelin et al., 1997; Moritz et al., 2002; Paradiso et al., 1997; Austin et al., 1999; Degl'Innocenti, Agren, & Backman, 1998).

In terms of potential mechanisms, the conflict monitoring theory suggests that the occurrence of conflict and errors triggers the engagement of control processes, subserved by the anterior cingulate cortex (ACC) and prefrontal cortex (PFC) regions, resulting in adjustments in performance (Botvinick et al., 1999). Interestingly, feedback stimuli notifying participants of error responses have been shown to activate dorsal ACC regions similar to those implicated in conflict monitoring (Holroyd et al., 2004; Holroyd, Larsen, & Cohen, 2004). Of note, recent findings implicate the dorsal ACC in learning the predicted likelihood of an error, highlighting a more fundamental role of this region in negative reinforcement learning (Brown & Braver, 2005). It is important to note that functional and structural cingulate abnormalities have been repeatedly observed in patients with depression (Bench et al., 1992; Davidson, Pizzagalli, Nitschke, & Putnam, 2002; George et al., 1997). Accordingly, dysfunction within various ACC regions may be linked to impairments in the recruitment of additional cognitive control during high-conflict trials and following perceived failure (errors) or overt negative performance

feedback. The present findings raise the possibility that, even in a non-clinical sample, adaptive affective-cognitive processes subserved by the ACC may be dysfunctional in subjects with elevated depressive symptoms, who have been found to be at-risk for later depressive disorders (Haavisto et al., 2004; Pine, Cohen, Cohen, & Brook, 1999).

Conclusion

In summary, the present findings confirm that individuals utilize errors and negative feedback to monitor their performance and adjust behavior accordingly. These results are consistent with the theory that response conflict and errors act as a signal to allocate increased levels of cognitive control on subsequent trials. In subjects with elevated depressive, particularly cognitive-affective symptoms, some of these behavioral adjustments were impaired. Specifically, compared to subjects with low BDI scores, subjects with elevated depressive symptoms showed decreased post-error and post-conflict performance, emerging mainly within the context of emotionally negative feedback relating to task performance. These findings indicate that depressive symptoms are associated with dysfunctional action monitoring after perceived failures or negative feedback. Whether these behavioral impairments are associated with dysfunctions in frontocingulate pathways subserving conflict monitoring, error processing, and feedback evaluation should be tested in future neuroimaging studies.

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Footnotes:

1) Consistent with likely time-limited and decaying effects of the current feedback manipulation, exploratory analyses using all available trials failed to reveal reliable findings.

2) When considering the conflict-adaptation (Gratton) reaction time (RT) effect, a similar pattern of findings emerged from the three regression analyses (findings available upon request). No findings emerged when considering accuracy.

3) The significant findings emerging from these three regression analyses were confirmed when considering the conflict-adaptation (Gratton) reaction time (RT) effect. As with the Simon task, no reliable findings emerged with the accuracy scores.

4) Although there were no significant group differences in task performance following positive feedback, a close look at Fig. 1b suggests that high BDI subjects had *higher* post-error accuracy during the positive feedback compared to the negative feedback. An exploratory paired t-test confirmed that this difference was significant, $t_{12} = 2.27$, $p < 0.05$. Further, for the positive feedback manipulation, high BDI subjects showed significantly higher accuracy following error relative to correct responses, $t_{12} = 3.03$, $p < 0.02$. Thus, whereas the low BDI group significantly improved their performance following negative feedback, subjects with elevated depressive symptoms displayed more adaptive behavioral adjustments in the positive feedback condition. In light of the fact that (1) there were no significant group differences for the positive feedback condition; and (2) post-hoc tests were not warranted given the null ANOVA findings, future studies with larger sample size are needed to evaluate the reliability of this apparent dissociation.

5) In the present study, task performance was significantly faster during the negative relative to the positive feedback block, indicating that the feedback manipulation successfully elicited changes in performance.

Figure legends

Fig. 1: Performance during the Simon Task. (A) Mean accuracy (and S.E.) following negative and positive feedback for high BDI and low BDI subjects. (B) Mean accuracy (and S.E.) for post-error and post-correct trials following negative and positive feedback for high and low BDI subjects. (C) Mean Laming/Rabbit (post-error minus post-correct accuracy score) effect (and S.E.) following negative and positive feedback for high and low BDI subjects. (D) Mean RT (and S.E.) during incongruent after incongruent and incongruent after congruent trials following negative and positive feedback for high and low BDI subjects. High BDI: n = 13; low BDI: n = 21.

Fig. 2: Scatterplot between the post-conflict RT adjustment scores following negative feedback and BDI score for (A) the Simon Task and (B) the Stroop Task. After removing the subject with the highest BDI score, the pattern of findings did not change (Simon: $\Delta \underline{R}^2 = 0.129$, $\Delta \underline{F}(1,53) = 7.88$, $\underline{p} < 0.01$; Stroop task: $\Delta \underline{R}^2 = 0.050$, $\Delta \underline{F}(1,53) = 2.83$, $\underline{p} > 0.09$).

Fig. 3: Performance during the Stroop Task. Mean RT (and S.E.) during incongruent after incongruent and incongruent after congruent trials for high BDI and low BDI subjects. High BDI: n = 14; low BDI: n = 20.
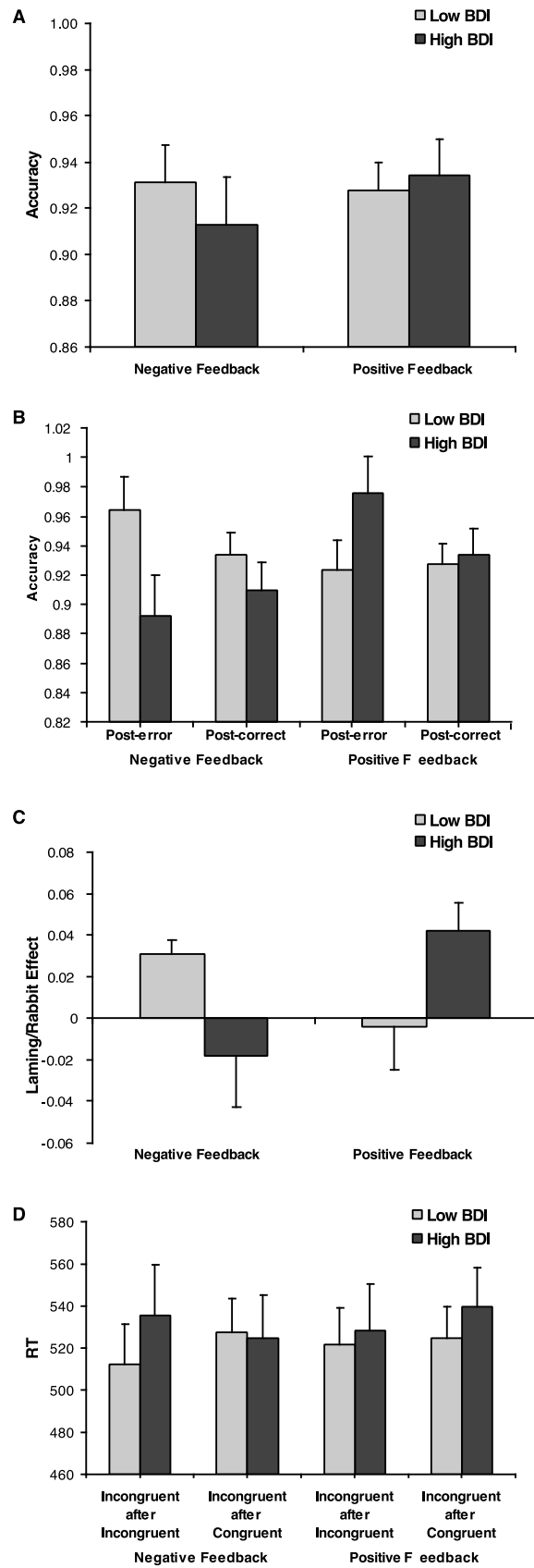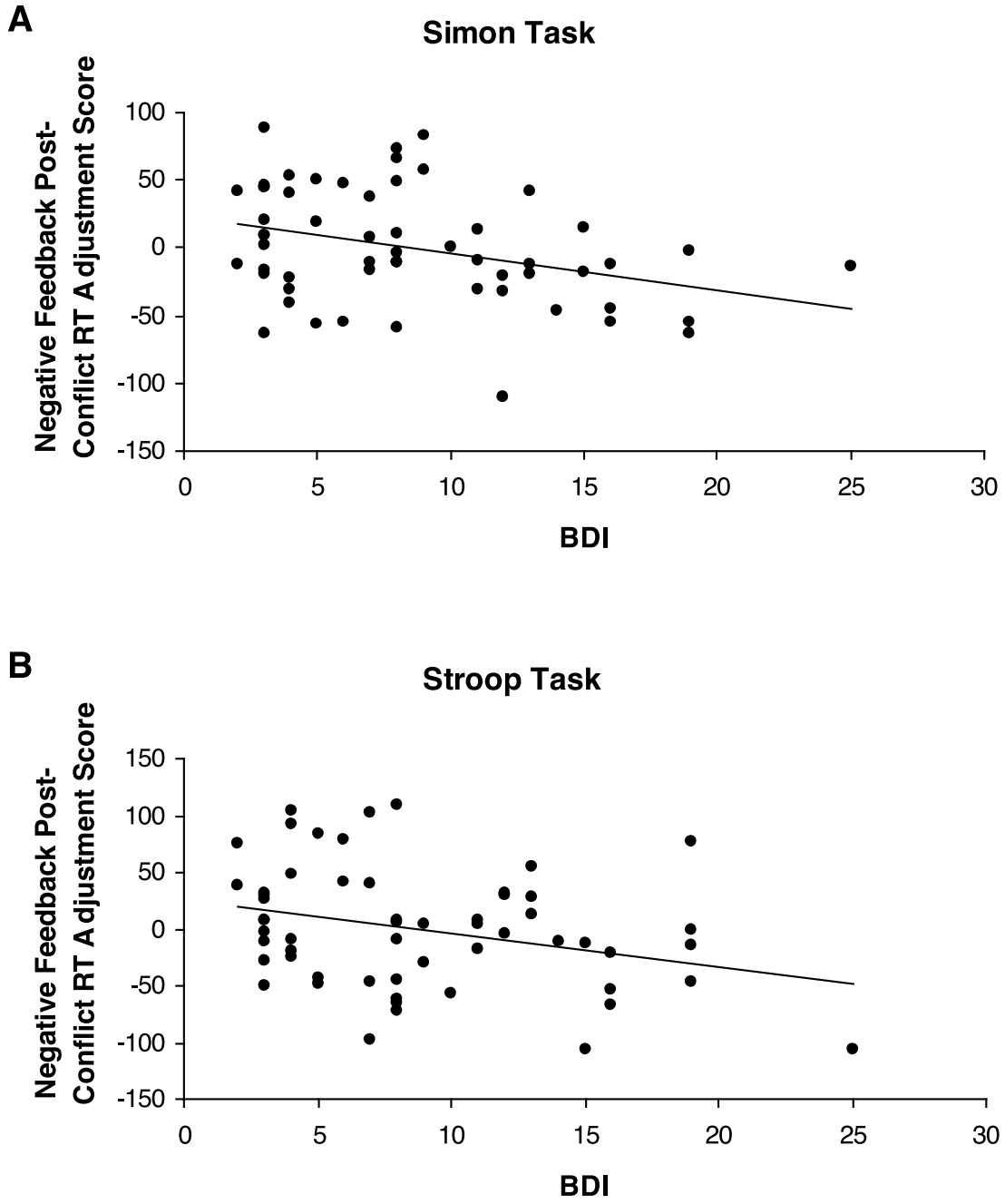
Fig. 1

Fig. 2

A

Simon Task

B

Stroop Task

Fig. 3