Pupillary and Reaction Time Measures of Sustained Processing of Negative Information in Depression

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Background: *Disruptions of emotional information processing (i.e., attention to, memory for, and interpretation of emotional information) have been implicated in the onset and maintenance of depression. The research presented here investigated cognitive and psychophysiological features of a particularly promising correlate of depression: sustained processing of negative information 4–5 sec after an emotional stimulus.*

Methods: *Pupil dilation data and reaction times were collected from 24 unmedicated depressed and 25 nondepressed adults in response to emotional processing tasks (lexical decision and valence identification) that employed idiosyncratically generated personally relevant and normed stimuli. Pupil dilation was used to index sustained cognitive processing devoted to stimuli.*

Results: *Consistent with predictions, depressed individuals were especially slow to name the emotionality of positive information, and displayed greater sustained processing (pupil dilation) than nondepressed individuals when their attention was directed toward emotional aspects of information. Contrary to predictions, depressed participants did not dilate more to negative than positive stimuli, compared to nondepressed participants.*

Conclusions: *These data suggest depressed individuals may not initially attend to emotional aspects of information but may continue to process them seconds after they have reacted to the information.* Biol Psychiatry 2001; 49:624–636 © *2001 Society of Biological Psychiatry*

Key Words: Sustained processing, depression, emotional information processing, pupil dilation, rumination

Introduction

This study examined the time course of emotional information processing in depressed and nondepressed individuals using pupil dilation and reaction times. Since the "cognitive revolution" of the early 1970s it has been suggested that depressed individuals pay attention to, remember, and interpret emotional information differently from nondepressed individuals, and that such "biased" emotional processing is central to the onset and maintenance of depression (see MacLeod and Mathews 1991 for a review). Many theorists have speculated that such biases in depression are characterized primarily by elaborative processes (i.e., generation of associations) occurring long after the initial perception of an emotional stimulus (e.g., MacLeod and Mathews 1991; Williams and Oaksford 1992). Depressed individuals are specifically hypothesized to associate negative information with negative memories, or ruminate upon it. This conclusion is drawn largely from research suggesting that depressed individuals have better memory for negative than other types of information (see Matt et al 1992 for a review). Additionally, work suggesting that the presence of negative information interferes with processing other task-relevant stimuli supports a late-term elaborative processing hypothesis (e.g., Williams et al 1996). Few studies have used measures that allow inference of sustained recruitment of cognitive resources in depressed individuals in the seconds following the presentation of emotional information. The research presented here sought to clarify the nature of emotional information processing biases in depression by identifying psychophysiological correlates of sustained cognitive processes, on the order of a few seconds after depressed individuals react to emotional information.

Additionally, understanding how the context in which emotional information is presented affects emotional information processing biases can help to specify useful brain processes and cognitive features relevant to depression. Of specific interest is whether directing attention to emotional features of information (e.g., by asking an individual about what the emotion associated with information is) more strongly engenders biases and sustained processing than directing attention toward features of a stimulus that are not inherently emotional (as suggested by Ingram 1984), such as its color. Similarly, it is unclear whether biases are strongest for personally relevant information (information that relates to concerns or events relevant to an individual's life, as suggested, e.g., by Segal

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et al 1995). To the extent that these contexts and types of information are differentially associated with biases and sustained processing, the generality or specificity of processes hypothesized to be disrupted in depression (e.g., feedback between structures responsible for representing emotional and nonemotional aspects of information) can be inferred.

Many studies have demonstrated pupil dilation to be a reliable correlate of cognitive load, in that the pupil dilates more under conditions of higher attentional allocation, memory use, or interpretation of more difficult material (for reviews, see Beatty 1982b; Steinhauer and Hakerem 1992). As individuals are asked to remember larger numbers of digits, for example, their pupils reliably dilate (e.g., Granholm et al 1996; Kahneman and Beatty 1966). Pupil dilation has also been observed to increase with the difficulty of mental arithmetic (Ahern and Beatty 1979; Hess and Polt 1964). Of particular interest is the finding that pupils remain dilated during conditions of sustained cognitive load (Beatty 1982a).

The following procedure was therefore adopted to measure information processing. Depressed and never-depressed individuals' reaction times and pupil dilation were obtained on multiple well known emotional information processing measures. Each measure directed participants' attention to different stimulus characteristics and involved reading emotional and nonemotional words. Measures included an affective lexical decision task (e.g., Challis and Krane 1988; Macleod et al 1986; Matthews and Southall 1991; Ruiz Caballero and Bermudez Moreno 1992; G.J. Siegle et al, in press) and an affective valence identification task (Hill and Kemp-Wheeler 1989; Mathews and Milroy 1994). Both personally relevant and nonpersonally relevant words were employed. Unmedicated depressed individuals were recruited to eliminate confounds of medication with psychophysiological and cognitive responsiveness. In addition to reaction times and pupillary dilation, correspondences between observed results and a self-report measure of rumination (Nolen-Hoeksema 1993) were also examined. Rumination is frequently thought to involve increased attention to negative information, particularly depressive symptoms (Nolen-Hoeksema 1993).

Using a Formal Model to Generate Predictions

Siegle's computational neural network model of affective information processing (Siegle 1999a, 1999b) was used to make predictions regarding the time course of attention to emotional information in depression. The model implements the notion that attention to emotional information involves feedback between brain mechanisms responsible for processing affective and nonaffective aspects of information (e.g., Bower 1981; LeDoux 1996; Mayberg 1997; Metcalfe and Mischel 1999). Depression is operationalized in the model as prolonged exposure to certain negative (personally relevant) information, resulting in enhanced connections between these systems, using a Hebb rule (pathways between simultaneously active features become strengthened).

The computational model that was exposed to large amounts of negative information tended to associate any incoming information with the (negative) information to which it was over-exposed. The representation of this overtrained negative information then remained active. It thus quickly identified the valence of negative information (simulated valence-identification), was slow to recognize the content of other nonovertrained negative information (simulated lexical decision), and processed the overtrained associations for a prolonged period on both simulated tasks in response to the presentation of positive, negative, and neutral information. It displayed the greatest sustained processing in response to negative information. These behaviors were not apparent in a network that was not overexposed to negative information.

The following specific predictions based on the computational model's observed behaviors were examined experimentally: 1) Depressed individuals were expected to be quicker to assign an affective valence to negative than positive information (i.e., on the valence-identification task). 2) Depressed individuals should be slower to name nonaffective features of negative information than other types of information (i.e., on the lexical decision task). 3) Depressed individuals should display especially increased sustained pupil dilation (i.e., cognitive processing) in response to personally relevant negative information, in comparison to other types of information on both tasks. 4) Depressed individuals should display little initial cognitive processing and greater sustained pupil dilation in response to all information in comparison to nondepressed individuals on both tasks.

Methods and Materials

Participants

Participants included 28 patients diagnosed with unipolar major depression by DSM-IV criteria (American Psychiatric Association 1994) and 26 never-depressed control subjects. Depressed patients had been unmedicated for at least 2 weeks (5 weeks for participants previously on Prozac). Patients were recruited through the University of California, San Diego (UCSD) Mental Health Clinical Research Center. Depressed participants were diagnosed using the Structured Clinical Interview for DSM-IV Diagnosis (SCID; Spitzer et al 1992) and had significant dysphoria, as indicated by a requirement that participants score above 14 on the Beck Depression Inventory (BDI; Beck 1967) within 2 weeks of testing. Control participants endorsed no symptoms of depression, and had no Axis I disorder using the

SCID interview. They reported no personal or family history of psychiatric disorder. All participants had normal vision (20/30 using a Snellen wall chart), were determined to have no notable health problems on a full medical examination, and stated during a structured interview that they had not abused alcohol or psychoactive drugs within the past 6 months. Participants who reported having used nonperscription psychoactive drugs in the months before testing were tested for drug use. Patients on nonpsychotropic medications with anticholinergic side effects were excluded because of potential effects on pupil dilation. Patients who had been on Prozac before 5 weeks before testing, or any other medication before 2 weeks before testing were not excluded.

Apparatus

Stimuli for information processing tasks were displayed in white on a black computer screen. Participants sat approximately 71 cm from the bottom of the stimulus. Stimuli were lowercase letters approximately 1.59 cm high, subtending 1.21 degrees of visual angle. Reaction times were recorded using a game pad capable of reading reaction times with msec resolution. It was modified to contain three buttons, arranged in a triangle, so that respondents' fingers were initially equidistant from each possible response. To account for differential response latencies to different buttons, the mapping of game-pad buttons to responses was counterbalanced across participants.

Pupil dilation was recorded using methods previously described and tested by Granholm (e.g., Granholm et al 1996). In brief, data were collected using a Micromeasurements System (Micromeasurements, Berkeley, CA) 1200 pupillometer. The pupillometer consisted of a video camera and infrared light source that were pointed at a participant's eye, and a device that tracked the location and size of the pupil using these tools. Pupil size and location were recorded at 60Hz (every 16.7 msec) and were passed in digital form from the pupillometer to both the computer that controlled the display of stimuli, and a computer that stored the acquired data. Additionally, signals were transmitted from the data collection computer to the analysis computer to mark the beginning and ending of trials as well as the end of fixation, stimulus onset time, and reaction time. The pupilometer's resolution for a typical participant was 0.05 mm pupil diameter.

Target Stimulus Materials

For the computer-administered tasks, 10 positive, 10 negative, and 10 neutral words balanced for normed affect, word frequency, and word length were chosen using a computer program (Siegle 2000) designed to create normed affective word lists. Nonwords were created by perturbing the spelling of 6 positive, 6 negative, and 6 neutral words such that they were not words, but were pronounceable (e.g., "cousip," "mendion"). To obtain personally relevant stimuli, participants were asked to generate words between 3 and 11 letters long, at least 1 day in advance of testing. Participants were instructed to generate "10 personally relevant negative words that best represent what you think about when you are upset, down, or depressed," as well as "10 personally relevant positive words that best represent what you think about when you are happy or in a good mood," and "10 personally relevant neutral (i.e., not positive or negative) words that best represent what you think about when you are neither very happy nor very upset, down, or depressed."

Procedure

Two appointments were scheduled with participants after their initial clinical interview, at least 1 day apart. At the first appointment, participants were told about the experiment, signed consent forms and generated a list of personally relevant words. At the second appointment, participants received a brief vision test and completed information processing measures followed by questionnaire measures. Testing occurred in a moderately lit room (486 lux) in which the experimenter was present, behind a curtain. Time of day was not controlled for in testing. The order of administration of a lexical decision and valence identification task was counterbalanced across participants.

LEXICAL DECISION TASK. For the lexical decision task, each word and nonword was presented in the following manner: A fixation square appeared and remained on the screen until the participant's gaze was within one degree of visual angle of the center of the square for 200 msec. The fixation square was then replaced by a row of X's (forward mask) for 2000 msec. The X's in the middle of the string were replaced by letters spelling a word or nonword (the target stimulus). After a stimulus duration of 150 msec, the letters were masked by a row of X's again, and the participant was allowed to respond. All masks and stimuli were drawn in white on a black background. Pupil dilation continued to be recorded for 6 sec after the initial onset of the word or nonword stimulus, regardless of when the participant responded. Research participants were instructed to push buttons labeled "Yes" or "No" as quickly and accurately as they could, indicating whether or not the target stimulus was a word. Labels for these responses were on a card in the participant's field of view. The research participant's pupil dilation throughout the trial, as well as reaction time and response, were recorded on the computer for each stimulus.

VALENCE IDENTIFICATION TASK. For the valence identification task, each word was presented to the participant as in the lexical decision task. Research participants were instructed to name the emotionality of stimuli by pushing buttons for "Positive," "Negative," or "Neutral" as quickly and accurately as they could, in response to each stimulus. Labels for these responses were on a card in the participant's field of view. The same word set was used for the valence identification and lexical decision tasks.

CUED REACTION TIME TASK. To be sure that results common to the Valence Identification and Lexical Decision tasks were due to emotional processing and not a general bias, a cued reaction time task was also administered to the last 23 depressed and 17 control participants at the end of the experiment. This task followed the same time course as the other tasks. As in the other tasks, participants saw a fixation square, which was replaced by a mask. Two seconds later, the mask changed to a string of "a"'s rather than a word. Participants were instructed to push the middle button as quickly as possible after they detected the change. The change from fixation square to the mask thus served as a cue, or 2-sec warning, for the stimulus.

Response Styles Questionnaire

The Response Styles Questionnaire (RSQ; Nolen-Hoeksema et al 1993) was given after the information processing measures to assess a trait-like disposition to sustain attention to negative information. The RSQ is a 71-item, self-report measure containing rumination and distraction subscales. The 22-item rumination subscale assesses the frequency with which individuals think about their symptoms of depression, when they feel sad or depressed on a four-point scale from "almost never" to "almost always." It contains items such as "think about how alone you feel" and "think about how passive and unmotivated you feel." Previous studies have shown the RSQ rumination scale to be internally consistent and factor-analytically derivable. Higher scores are related to more severe and longer episodes of depression (e.g., Nolen-Hoeksema et al 1993) as well as distorted interpretations of hypothetical life events (Lyubomirsky et al 1998).

Data Selection, Cleaning, and Reduction

SELECTION OF STIMULI FOR ANALYSIS. Trials with reaction times below 150 msec or over 5000 msec were discarded as outliers, because previous results suggest that reaction times in this range indicate that a response was made without regard for the stimulus (Matthews and Southall 1991). This procedure eliminated very little data (on average less than one trial per person, and never more than five trials for any person). Trials in which stimuli were incorrectly identified on the lexical decision task, and trials for which the valence rating was incongruent with the normed valence on the valence identification task were not removed from the data set, because it was assumed that essential cognitive processes leading to a decision were similar regardless of the decision. Although positive and neutral personally relevant stimuli were included in the experiment so that participants would be exposed to equal numbers of positive, negative, and neutral stimuli, no hypotheses regarded these conditions. Thus, they are not included in the planned analyses of reaction times and pupil dilation. Analysis was restricted to those words for which the normed or generated valence was consistent with the participant's ratings on a word-rating task given at the end of the experiment. This technique was used to be sure that participants interpreted words as belonging to the categories in which they were analyzed (e.g., to be sure that words analyzed as "positive" were really considered positive by the participant). This procedure resulted in the elimination of under 15% of trials.

CALCULATION OF REACTION TIMES. Harmonic means of reaction times were used to reliably index the central tendency of an individual's reaction times within a condition (as recommended by Ratcliff 1993). To eliminate spurious skew due to outliers while preserving rank-ordering of data, outliers more than 1.5 times the interquartile range from the median harmonic mean on any variable were scaled to the closest obtained value below this cutoff plus the difference between this value and the next closest value.

Table 1. Demographic Characteristics of Participants

Group	Measure	Mean	SD	Minimum	Maximum
Depressed	Age (years)	47.83	9.56	32	68
	Education (years)	14.52	2.37	11	21
	Male (no.)	14			
	White (no.)	16			
Control	Age (years)	42.08	12.30	23	62
	Education (years)	16.20	2.02	12	20
	Male (no.)	9			
	White (no.)	20			

PUPIL DILATION. Data were cleaned using methodology previously described by Granholm (e.g., Granholm et al 1996). Blinks were identified as large changes in pupil dilation occurring too rapidly to signify actual dilation or contraction. Trials comprised of over 50% blinks were removed from consideration. Linear interpolations replaced blinks throughout the data set. Data were smoothed using a 10-point moving average. Pupil diameter, measured as the average dilation over the 1 sec preceding the onset of the stimulus, was subtracted from pupil diameter after stimulus onset to produce pupil dilation difference score indices.

To identify unique components of depressed and nondepressed individuals' physiologic reactions to emotional stimuli, each participant's averaged pupil dilation waveforms in each valence condition on the lexical decision and valence identification tasks, time-locked to their reaction times, were subjected to a principal components analysis (PCA). This technique is frequently used in analyzing other types of psychophysiological data (Coles et al 1986) and is equivalent to Cattel's (Nesselroade and Cattel 1988) T-technique, in which time is factorized. Each pupil dilation sample for each person, in each condition, was considered a variable, yielding a time $\times$ person/condition matrix. Factors thus represented groups of time points with high bivariate correlations. Varimax rotation was used to produce orthogonal factors, in which pupil dilation samples were strongly associated with only one factor. This technique was adopted rather than using bins of adjacent pupil dilations (e.g., 1 per sec) to eliminate the potential for correlated errors confounding analyses; PCA produces orthogonal factors. Another reason for adopting this technique is that analysis of pupil dilation during relatively long trials (~9 sec) is new, and thus, relevant components of resulting waveforms have not been empirically identified; PCA serves this function empirically, minimizing the number of necessary relevant hypothesis tests.

Results

Demographic characteristics are presented in Table 1. The depressed group was slightly but significantly older [$t(42.3) = 2.07$, $p = .045$, $d = .58$]. The groups did not

Table 2. Mean Harmonic Mean Reaction Times for the Lexical Decision and Valence Identification Tasks, in Seconds

Valence	Depressed lexical decision		Nondepressed lexical decision		Depressed valence identification		Nondepressed valence identification	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Personally relevant								
Negative	0.75	0.19	0.68	0.11	1.36	0.51	1.00	0.23
Positive	0.74	0.21	0.59	0.11	1.16	0.34	0.79	0.21
Neutral	0.72	0.18	0.64	0.12	1.56	0.56	1.15	0.27
Nonpersonally relevant								
Negative	0.77	0.20	0.69	0.16	1.18	0.31	1.03	0.25
Positive	0.76	0.22	0.65	0.16	1.22	0.38	0.85	0.23
Neutral	0.81	0.22	0.69	0.16	1.46	0.43	1.08	0.28

differ significantly in gender or education. Though participants and controls were not matched for age, age was not related to participants' mean peak pupil dilation, calculated for each trial ($r = -.095$, $p = .52$).

Separate analyses were performed for reaction times and pupil dilation, for the lexical decision and valence identification tasks. Familywise α for all planned pairwise contrasts was controlled at .05 using a Bonferroni correction, unless all pairwise contrasts were tested, in which case a Tukey correction was performed (as suggested by Maxwell and Delaney 1990).

Reaction Times

Harmonic mean reaction times to all conditions are shown in Table 2. Planned multivariate analysis of variance (MANOVA) contrasts revealed information processing biases in depressed individuals on the valence identification task. As predicted, depressed participants responded more slowly to positive than to negative nonpersonally relevant words, whereas nondepressed individuals responded more quickly to positive than negative words [$F(1,44) = 14.81$, $p = .0004$, $\eta^2 = .252$]. The same contrast was not significant for neutral words ($p = .87$, $\eta^2 = .001$), or personally relevant negative words ($p = .985$, $\eta^2 < .001$). Depressed individuals did not respond faster to negative than positive personally relevant words.

In contrast, planned contrasts did not reveal predicted information processing biases in depressed individuals on the lexical decision task. That is, depressed individuals' differences in reaction time to nonpersonally relevant negative words and other words were was not significantly different from those for nondepressed individuals ($p > .115$, $\eta^2 < .054$, for all contrasts). Depressed individuals were not significantly faster to respond to personally relevant information than information of other valences ($p > .19$, $\eta^2 < .046$ for all contrasts).

Pupil Dilation

Average dilation curves, time-locked to the occurrence of the response, for depressed and nondepressed participants are shown in Figure 1. Thus, stimulus onsets generally occurred in the -1.5 to -0.5 range on the graph, before which a forward mask was present (generally beginning off the graph from -3.5 to -2.5 sec before the reaction time). When examining this graph, it is useful to note that pupil dilation is characterized by a lag of at least 300 msec following a cognitive event. Following the stimulus, but before the response, there is an increase in pupil diameter that reaches its maximum approximately 300 msec after the response, after which the diameter decreases. As shown in the graph, depressed individuals appeared to dilate less initially but showed more dilation in the seconds after they reacted to stimuli, in comparison to nondepressed individuals, on both emotional processing tasks but not to the same extent on the cued reaction-time task.

Statistical comparisons of factor scores, derived through PCA, were used to test the significance of these observations. On each emotional processing task, exploratory analyses suggested that five factors accounted for the majority of variance in the data. A second PCA was therefore performed for each emotional processing task, restricting extraction to just five factors. The factor structures for each task were essentially the same. Separate analyses for depressed and nondepressed individuals revealed similar factor structures for each group. Each factor was characterized by a single distinct rise, peak, and fall in loadings.

The factors accounted for variance in pupil dilation in opposite order of their occurrence in time. The fifth factor loads primarily at the beginning of the waveform, often occurring more than 1 sec before the onset of the stimulus, and thus probably represents preattentive or exclusively preparatory processing (e.g., as described by Jennings et al

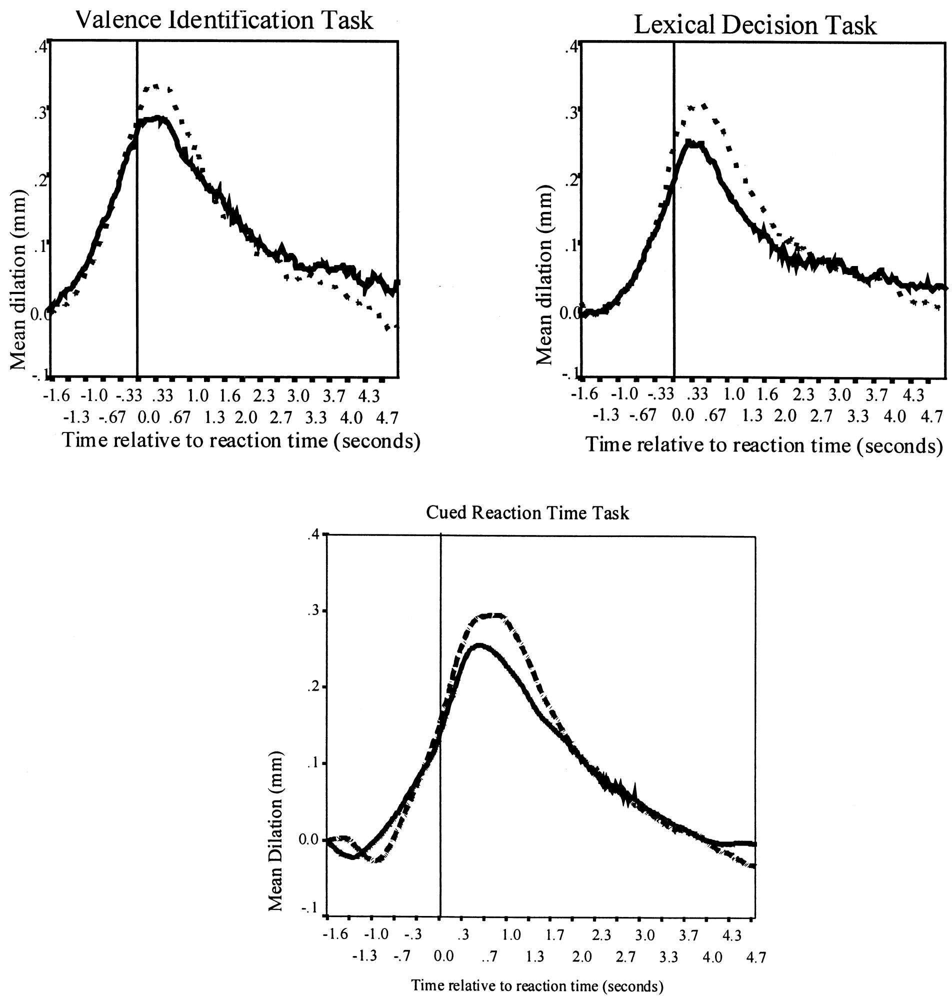

Figure 1. Mean of median pupil dilations averaged over valences, for each group. Vertical lines at 0 msec represent the reaction time, relative to which the waveform is time locked. Depressed individuals (solid line) displayed lower initial cognitive load (as indexed by pupil dilation) but more sustained load than nondepressed individuals (broken line), in response to multiple emotional information processing tasks.

1998). The fourth factor peaks up to 1 sec before the reaction time (rt), and thus may represent early attentional processes (if it is occurring after the onset of the stimulus), a light reflex, or preparatory processes (e.g., as described by Semmlow and Stark 1973). The third factor peaks near the rt (usually 1–3 sec after the stimulus is presented) and thus may be viewed as an early cognitive component associated with stimulus identification (e.g., as described by Brown et al 1999). The second factor peaks at approximately 1 sec post-rt and thus may represent motor processes or cognitive load occurring around the time, and shortly after an individual chooses a response, e.g., early associations with a stimulus (e.g., Hyoenae et al 1995). The first factor was a late factor, peaking around 4 sec post-rt. It is thus assumed to represent late or sustained cognitive processes. Such a factor has not been observed in the past, potentially because trials in most previous experiments are much shorter than those in the tasks in our study. Table 3 presents peaks in loadings for each factor. Factor loadings for the PCAs are depicted graphically in Figure 2.

By regressing dilation scores on loadings, factor scores could thus be obtained for each person's responses to a given condition for each extracted component. Figure 3 shows differences in the average factor loadings for depressed and nondepressed individuals for stimuli of each valence on each task. The left-hand graphs represent average factor scores for depressed individuals, and the right-hand graphs represent average factor scores for nondepressed individuals. The graphs each have four lines; each line represents average factor scores on one factor, for each valence. As no hypotheses were made for processes occurring before the onset of the stimulus, analyses were conducted only on the first four factors.

Table 3. Factor Structure for the Lexical Decision and Valence Identification Tasks

Order	Approximate latency to peak loading with respect to RT (sec)	Variance accounted for in lexical decision task	Variance accounted for in valence identification task
5	−2	7.48%	6.05%
4	−1	16.16%	12.57%
3	0	16.52%	14.73%
2	1	22.44%	12.57%
1	4	22.71%	21.81%
Total		85.31%	67.73%

RT, reaction time.

On the valence identification task, as predicted, MANOVA-planned contrasts revealed that depressed individuals scored reliably higher on the first factor (rt + 4 sec) than did nondepressed individuals [$F(1,45) = 5.85$, $p = .02$, $\eta^2 = .12$], though there were no significant differences in responses to one valence or another. This finding suggests that depressed individuals displayed greater sustained processing in response to all stimuli, than did nondepressed individuals. On the second factor (peaked at rt + 1 sec; possibly reflects early associations and motor processes), there was a valence × group interaction [$F(3,43) = 3.31$, $p = .03$, $\eta^2 = .19$]. Planned contrasts revealed that nondepressed individuals displayed comparatively more cognitive processing of personally relevant negative words versus nonpersonally relevant positive words than did depressed individuals [$F(1,45) = 6.51$, $p = .01$, $\eta^2 = .13$], though both groups showed larger responses to negative than positive information. Depressed individuals were reliably lower on factor three (peaked at rt; possibly reflecting decision processes) than nondepressed individuals [$F(1,45) = 7.20$, $p = .01$, $\eta^2 = .14$]. Depressed individuals were reliably higher on factor four (rt − 1 sec; possibly reflecting stimulus identification or preparatory processes) than nondepressed individuals [$F(1,45) = 5.37$, $p = .03$, $\eta^2 = .11$].

Results were less consistent for the lexical decision task. Depressed and nondepressed individuals did not differ reliably on the first factor (rt + 4 sec); however, all individuals (collapsing across groups) generally evidenced greater sustained processing to personally relevant negative words in comparison to neutral nonpersonally relevant words [$F(1,45) = 5.55$, $p = .02$, $\eta^2 = .11$], negative nonpersonally relevant words [$F(1,45) = 8.70$, $p = .01$, $\eta^2 = .16$], and marginally, to positive nonpersonally relevant words [$F(1,45) = 3.40$, $p = .07$, $\eta^2 = .07$]. Nondepressed individuals were reliably higher on the second factor (rt + 2 sec) [$F(1,45) = 5.15$, $p = .03$, $\eta^2 = .10$], and to a lesser, nonsignificant extent, on the third component (rt) [$F(1,45) = 3.19$, $p = .08$, $\eta^2 = .07$], than were depressed individuals. No main effects or interac-

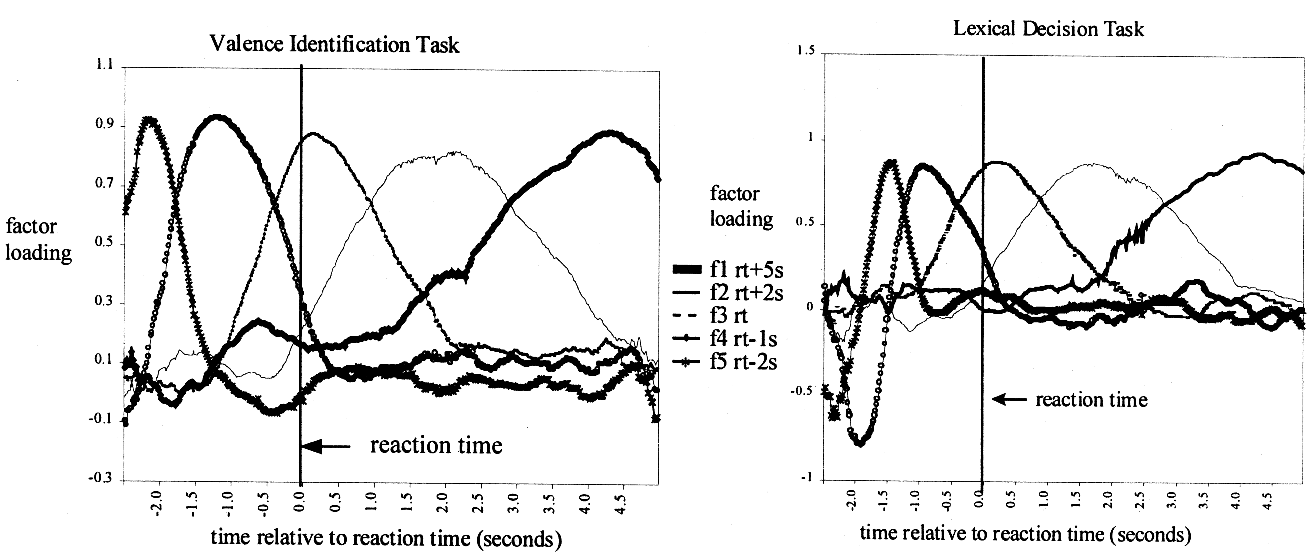

Figure 2. Factor loadings for each extracted component from principal components analysis on pupil dilations from the valence identification and lexical decision tasks. Factor loadings for each factor are plotted in a separate style. The x axis represents each time point for which factor loadings were derived. The y axis represents the magnitude of the factor loading. rt, reaction time.

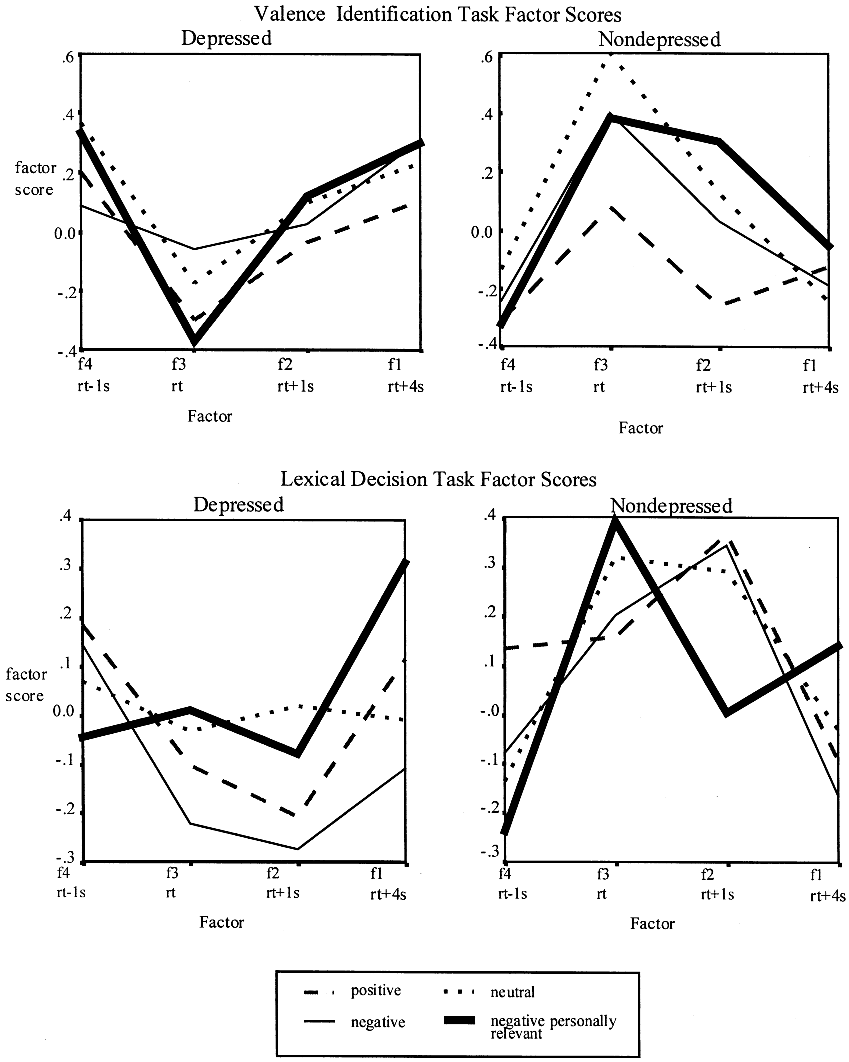

Figure 3. Factor scores for depressed and nondepressed individuals for extracted components from the lexical decision and valence identification tasks. Peaks of factor scores, plotted on the x axis, represent sequential events ordered in time. The time between peaks of sequential factor scores is not linear. Depressed individuals showed significantly more sustained processing to stimuli of all valences than did nondepressed individuals on the valence identification task.

tions were observed for the fourth component (rt − 1 sec).

On the cued reaction time task, temporal separation using PCA was not as robust (5 overlapping factors accounted for 68% of the variation), suggesting that the discreet processes observed on emotional processing tasks were not cleanly separable, potentially because of a lack of consistent processing after individuals reacted to a stimulus (as might be expected with a nonword target). Just the same, two factors had discernable peaks 4–5 sec after participants' reaction times. Depressed and nondepressed individuals did not differ significantly on any factor scores ($t < 1.2$, $p > .30$).

Relationship of Information Processing to Rumination

To assess whether aspects of sustained cognitive load, indexed by pupil dilation, were predictably related to conventional assessments of ruminative coping, bivariate correlations between the first factor score (rt + 4 sec, representing late attentional processes) on the valence identification task and the rumination scale of the RSQ were examined. Response Styles Questionnaire rumination scores were not significantly correlated with this factor for nonpersonally relevant words ($.19 < r < .24$, $p > .05$) for all valences. For personally relevant words, RSQ scores were only significantly correlated with this factor score for positive words ($r = .33$, $p = .02$). The correlation for personally relevant negative words was in the same range as for nonpersonally relevant words ($r = .26$, $p = .08$). When age, gender, and depressive severity were controlled for in a hierarchical regression, no relationship between pupil dilation factors and rumination was observed (maximum $R^2_{change} < .03$); this result was expected as rumination, measured by the RSQ traditionally covaries with depressive severity (Nolen-Hoeksema et al 1993).

Sensitivity Analyses

To examine the robustness of results to potential confounding factors, a number of sensitivity analyses were performed. In no case did the inclusion of age, education, or gender as covariates change results qualitatively. Additionally, restricting the analysis to only responses that matched the normed valence of words (i.e., responding "neutral" to neutral words) did not change the results qualitatively, though depressed individuals tended to rate nonnegative words as negative more than nondepressed individuals on the valence-identification task [$F(2,46) = 5.41$, $p = .008$]. On the lexical decision task, the mean false-alarm rate for depressed individuals was 11.4% (SD = .121), whereas the mean false-alarm rate for nondepressed individuals was 14.7% (SD = .147). The difference in false-alarm rates was not significant [$t(46) = -0.85$, $p = .40$]. Inclusion of only correct responses did not significantly change results.

OMNIBUS TESTS ON REACTION TIME. Because planned contrasts were used to test relevant hypotheses, it is possible that important phenomena (e.g., interactions that qualified the hypotheses, or more general behaviors, such as main effects of group differences) could have been missed. To examine this possibility, omnibus tests (group × valence × personal relevance) were conducted for reaction time data on each task. For the lexical decision task rt data, omnibus tests revealed a marginally significant valence × group interaction [$F(2,46) = 2.01$, $p = .147$, $\eta^2 = .087$] (simple effects were not significant for the depressed group), and a personal-relevance × valence interaction [$F(2,42) = 4.41$, $p = .018$, $\eta^2 = .174$] (individuals were significantly slower to respond to positive and neutral personally relevant than normed words). For the valence identification task rt data, omnibus tests revealed a statistically significant valence × personal relevance × group interaction [Wilks $\lambda = .814$, $F(2,41) = 4.699$, $p = .015$, $\eta^2 = .186$]. Results for nonpersonally relevant words were accounted for by the planned contrasts. For personally relevant words, all valences produced significantly different responses with no group differences. Depressed individuals were significantly slower to respond to personally relevant negative than nonpersonally relevant words in comparison to nondepressed individuals [$F(1,43) = 13.48$, $p < .001$]. A group × task ANOVA revealed that differences in depressed and nondepressed participants' average response times to the valence identification were greater than those for the lexical decision task, i.e., that depressed participants were particularly slow to respond to the valence identification task [$F(1,43) = 11.96$, $p = .001$, $\eta^2 = .22$].

OMNIBUS TESTS ON PUPIL DILATION. A similar set of tests was performed for pupil dilation scores, also entering components for the first four components. On the valence identification task, the ANOVA revealed a personal relevance × component × valence × group interaction [$F(4,39) = 2.75$, $p = .042$, $\eta^2 = .22$]. Simple effects analysis of nonpersonally relevant words were largely accounted for by the differences between groups in responding to the different components, described through planned contrasts. Within the depressed group, no interactions were statistically significant ($p > .24$, $\eta^2 < .27$). The only significant main effect was for component [$F(2,18) = 4.11$, $p = .03$, $\eta^2 = .31$]. In the nondepressed group, positive words generally provoked much less dilation than neutral words [$F(1,23) = 19.3$, $p < .001$, $\eta^2 = .456$]. In general, all of these results are consistent with the reported planned contrasts. Visual examination of raw data was consistent with these patterns. On the lexical decision task, there were no significant effects involving group. Rather, there was a significant personal-relevance × valence interaction [Wilks $\lambda = .86$, $F(2,42) = 3.43$, $p = .041$, $\eta^2 = .14$], which stemmed from larger dilations for positive than negative nonpersonally relevant words but larger negative than positive dilations for personally relevant words [$F(1,43) = 6.63$, $p = .014$, $\eta^2 = .13$]. Visual examination of raw data were consistent with these patterns for dilation occurring after the reaction time. When outlying dilations were rescaled to preserve rank ordering as in the reaction time analysis, and the data were subjected to PCA, the factors overlayed perfectly with those from the original analysis but switched order (sustained dilation was present on factor two), suggesting that factor loadings were not due to outliers.

CONCURRENT EXAMINATION OF VALENCE IDENTIFICATION AND CUED REACTION TIME DATA. The following strategies were adopted to be certain that sustained processing on the valence identification task was due to emotional processing, above and beyond the demands of the cued rt task. A PCA restricted to five factors was performed on the combined valence identification and cued rt pupil dilation data sets in which outliers were rescaled. The factor structure was exactly as described for previous analyses of the valence identification task, with the first factor representing late dilation, accounting for 21.6% of the variation. Were observed differences a function of processing differences not related to the task, including the cued rt factor scores as a covariate would be expected to decrease group differences. In the restricted sample of 19 depressed and 14 nondepressed individuals who were measured on the cued reaction time task, a group (2) × valence (4) ANOVA on scores on the first factor suggested that group accounted for 8.6% of observed variance [$F(1,31) = 2.92$, $p = .098$]. When cued rt was entered as a covariate, group differences increased to account for 10.4% of observed variance [$F(1,30) = 3.49$, $p = .07$]. Neither analysis yielded a main effect of valence or a valence × group interaction.

Examined another way, when first-factor scores on the valence identification task were averaged, a mixed task (cued rt/valence identification) × group (2) ANOVA on first-factor scores yielded a significant task × group interaction [$F(1,28) = 5.51$, $p = .026$, $\eta^2 = .165$], which was due to depressed individuals having higher first-factor scores than nondepressed individuals on the valence identification task ($D = .41$), whereas they were not higher on the cued-rt task ($D = -.006$). Thus, within the subset of individuals who took the cued rt task, sustained dilation is significantly higher for depressed than nondepressed individuals on the valence-identification task but not the cued rt task.

Discussion

This experiment examined whether sustained processing of negative information could be observed in depressed individuals using behavioral and psychophysiological measures. A key prediction was that depressed individuals would show atypically sustained processing on emotional information processing tasks, as indexed by sustained pupil dilation in the seconds following their responses. This prediction was supported for a task in which participants named the emotion associated with words.

Also, consistent with predictions, though nondepressed individuals were relatively quick to respond to positive, in comparison to negative information, depressed individuals were slower to respond to positive information, and displayed less cognitive load (i.e., pupil dilation) in the vicinity of their reaction time, in comparison to nondepressed individuals (as shown in Figure 1 and Figure 3, factor 3). Still their earliest physiologic responses, potentially reflecting prestimulus preparatory activity and initial stimulus identification, or possibly, residual activity from the previous trial, were larger than for nondepressed individuals (as shown in Figure 2), making the interpretation of this phenomenon ambiguous. Inconsistent with predictions, depressed individuals did not react slower to negative than positive information when asked to say whether strings of letters spelled a word (the lexical decision task). Sustained processing was not statistically significantly greater for depressed than nondepressed individuals on that task. Also inconsistent with predictions, depressed participants' cognitive load was not reliably higher for negative information than positive information, in comparison to nondepressed participants. Rather, both groups appeared to process personally relevant negative information more than positive information approximately 1 sec after their reaction time.

To the extent that these data are replicable (i.e., null results are not due to low power), they could suggest that depressed and nondepressed individuals may both process negative information more than other types of information but this process is only associated with sustained activity and interference (i.e., delayed reaction times) in depressed individuals in contexts in which they actively attend to emotional aspects of presented material. Judging whether letters spell a word may not engender as much emotional processing as judging the emotionality of the same word. Sustained processing of emotional information in depression may be preceded by decreased processing relevant to actually doing the task and heightened initial sensitivity to or preparation for incoming information. As differences in sustained processing were not observed for a cued reaction-time task, it is suggested that the observed effects are likely specific to contexts involving some emotional processing.

A marginally significant interaction of valence by group suggested that depressed individuals may be somewhat faster at responding to negative than nonnegative words on the lexical decision task. Such an effect has been predicted by researchers who suggest that depressed individuals may direct attention to negative words early in processing, though such effects have rarely been observed empirically (e.g., Challis and Krane 1988; Macleod et al 1986; Matthews and Southall 1991; Ruiz Caballero and Bermudez Moreno 1992).

Although some interactions between examined variables and personal relevance of stimuli were observed, behavioral and physiologic indicators did not indicate uniquely sustained processing of personally relevant negative information in depression. That is, depressed individuals were not observed to respond particularly quickly or slowly to personally relevant negative words. They did not appear to show differential pupil dilation for personally relevant words in comparison to other words 4 sec after their reaction time.

If this result is not due to low power to detect differences between information of different valences, it could indicate that depressed individuals allocate similar sustained cognitive load to all types of information by placing a negative interpretation on the information (e.g., Siegle 1999a). For example, a depressed person might see a typically neutral stimulus and associate it with something negative (e.g., associating a car with car accidents). Such a process might lead to similarly sustained cognitive activity in response to information of differing valences, and particular difficulty in the recognition of positive information as positive. Thus, sustained pupil dilation would be expected to occur in response to all stimuli.

Biased reaction times would only occur on tasks in which individuals are made to react specifically to the emotional content of stimuli. This explanation is consistent with the behavior of Siegle's computational neural network of emotional information processing in depression (Siegle 1999a). Still, the model's simulated sustained activation was greater for personally relevant than other stimuli. The discrepancy between empirical data and modeled predictions, if replicable, could suggest a need for revision of the model, involving factors that would temper its response to personally relevant information. The extent to which such revisions would change the model's other behaviors, and thus it's overall predictive validity, is unclear.

Sustained processing, as indexed by pupil dilation, was not related to a traditional measure of "rumination." This finding could suggest that sustained processing did not exclusively involve the type of rumination measured by the Response Styles Questionnaire, i.e., attention to symptoms of depression. Research has begun to suggest that there are many types of rumination, some of which are associated with prolonged consideration of an individual's depression, whereas others are more related to prolonged thoughts about a particular event or stimulus (e.g., Fritz 1999). It is expected that the valence identification task would index rumination about particular negative events. As a result, future studies are planned in which sustained pupil dilation is related to multiple indices of rumination.

Sensitivity analyses revealed a few unexpected findings. Depressed individuals were particularly slow to respond to the valence identification task versus the lexical decision task, in comparison to nondepressed individuals. This finding could suggest that depressed individuals engaged in more "paralyzing" emotional processing on the valence identification task (e.g., elaborating negative associations with presented stimuli), overall. Depressed individuals were particularly slow to respond to personally relevant negative words, potentially as a result of focussing so much on these words that they didn't respond to the task. Depressed participants frequently reported that personally relevant negative words "hit" them harder than other words; two participants cried upon seeing personally relevant negative words.

Certain explanations for these findings appear unlikely. As the entire sample was unmedicated, medication effects were probably not responsible for obtained results. Similarly, an attempt was made to control for substance use. Several limitations of the current study must, however, be acknowledged. Because recruitment of an unmedicated clinically depressed population was difficult, the sample was smaller than initial power estimates originally suggested was necessary to detect effects for reaction times on the lexical decision task. On the other hand, obtained effect sizes do not suggest that additional recruitment would lead to statistically significant hypothesis tests. An additional potential confound is that the depressed group contained proportionally more male subjects than the nondepressed group, though the differences in genders were not significant, and initial exploratory analyses did not suggest that gender interacted with variables of interest. The depressed group was, on average, 6 years older than the nondepressed group, though there is no theoretical reason to believe that such a difference in age would be related to obtained results. As depressed individuals were not restricted to a "cognitive" subtype, potentially stronger biases exist for certain subsets of depressed individuals. The ecological validity of using words to represent the types of emotional stimuli that individuals experience in their lives is questionable. The extent to which personally relevant words were truly personally relevant, and normed words were truly not personally relevant is unclear as participants did not rate presented words for personal relevance; were normed words to have been as relevant as idiosyncratic words, some of the contrasts may have been confounded. As time of day was not accounted for in testing, systematic variation in Circadian rhythms could have affected results, though it is unclear how this variable would interact with observed effects. Finally, the cross-sectional nature of the current design precludes causal interpretations of the relationship between sustained processing and depression.

These limitations aside, the present study yields a number of potentially important observations about depression. Based on the current results, depressed individuals may not pay attention to emotional information immediately after it is presented, but may continue to process it, even after it is taken away, e.g., relating it to whatever they are distressed about. This tendency is associated with reacting quickly to negative information when attention is directed toward emotional aspects of information. Together these findings suggest that depression is a disorder characterized by sustained processing, and potentially, by interpreting or elaborating on that information in a particularly negative way. In short, these phenomena suggest a psychophysiological basis for the lay notions that depressed individuals go over and over negative things, or put a negative "spin" on events.

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