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A Multi-Modal Study of Cognitive Processing under Negative Emotional Arousal

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Abstract

It is a truism of everyday life that anger and fear affect cognition. In high-risk perceptually complex contexts, such as air combat, the effects of negative arousal on performance can be significant and potentially catastrophic. To better understand the interaction between emotion and cognition, we studied the effects of negative emotional stimuli on pre-attentive sensorimotor gating and selective attention in 39 healthy adults, as well as their relationship to neural, cardiac, and endocrine variables associated with the arousal response. Subjects were tested for pre-pulse inhibition under neutral and arousal conditions, as well as on emotionally-valent Flanker and Stroop tasks. Physiological arousal reactivity was measured using functional MRI, 24-hour EKG, electrodermal activity, cortisol testing, and dexamethasone suppression. Subjects were clinically assessed for levels of anger, anxiety, and perceived stress. Affect-valent conditions were induced using the International Affective Picture Scale, the Morphed Eckman Facial Stimuli, and affect-valent words matched for length and frequency. All conditions were counter-balanced for order. Our results indicate that even under relatively mild emotional challenge, the introduction of negative emotion significantly affected nearly all components of our cognitive battery, and correlated with changes in heart rate and electrodermal activity. Pre-attentive sensory gating and habituation were diminished, which may reflect the underlying neural conditions necessary for an increased orienting response. On tasks that required selecting a target in the presence of distractors, such as the Flanker Task, arousal had the effect of reducing both response time and accuracy. Our results were also consistent with our previous research on the higher-order effects of arousal on reasoning, indicating that individuals make decisions with less information under emotional arousal. On tasks such as the Stroop, in which orienting to the source of arousal conflicts with selective attention to a target, response time was lengthened. Importantly, the effects of negative arousal were widely variable across individuals, falling roughly into classes of individuals who showed strong physiological arousal response with strong cognitive effect, individuals who showed little physiological arousal response with little cognitive effect, and individuals who showed strong physiological arousal response with little cognitive effect. It is the third group that we are investigating most closely with fMRI, to determine which limbic feed-back mechanisms produce the most efficient cognitive performance under stress. This information, in turn, will permit more effective screening for high-risk environments to select only those individuals that are “hard-wired” for neural aptitude during fear.

Background

Emotional arousal primes the organism for imminent danger by increasing the orienting response, which permits the organism to find and focus on the source of danger. Once oriented to the source of danger, emotional arousal strengthens attention to the source of danger and diminishes attention to stimuli unrelated to its source, narrowing the amount of peripheral information simultaneously accessible with the target. This two-pronged approach has both costs and benefits: cognition is limited with respect to breadth, with the individual attending to less information at a time, but is more flexible in terms of the ability to switch attention from one target to another. Under most dangerous conditions in our evolutionary past, these costs and benefits were appropriate for survival: in the presence of a predator, it makes sense to focus on the predator, to ignore peripheral information such as ambient noise, and to be able to quickly switch attention between two or more predators that together present a collective threat.

While the cognitive changes associated with arousal in humans are appropriate for predator/prey contexts, most states of arousal (fear, stress, anxiety) in modern societies today occur under far different circumstances, in which the source of arousal is often not a concrete palpable entity to which one can readily orient. Even individuals in actually dangerous situations, such as fighter pilots in combat, protect themselves by defying their instincts: a fighter pilot needs to attend not only to the “predator” shooting at him, but equally to the myriad of dials and instruments that keep his plane aloft and his artillery engaged. Thus, while emotional arousal can benefit cognitive performance by increasing focused attention on a target and decreasing attention to distracting irrelevant information, emotional arousal today can just as often wreck havoc on cognitive performance by triggering the orienting response in the absence of an appropriate target and by disregarding potentially relevant peripheral stimuli (“tunnel vision”).

Easterbrook, in 1959, seems to have been the first to fully articulate the hypothesis that arousal produces attentional narrowing, while Bacon (1974) was instrumental in relating attentional narrowing to the orienting response. Their hypotheses have since been

supported by a wide range of studies on humans and animals that used induced arousal by reward (Bruner et al., 1955), electric shock (Cornsweet, 1969), loud noise (Hockey, 1970a), threatening words (Combs & Taylor, 1952), test anxiety (Rockett, 1956), and pre-parachuting anxiety (Hammerton & Tickner, 1967) on various tests of information processing. Research on selective attention in actual dangerous environments, in which simulation acted as the control for arousal, demonstrate that the tendency to overlook incidental (peripheral) cues in real-life situations can have severe implications for actual performance. Significant decline in performance has been shown for complex tasks that were performed during combat (Walker & Burkhardt, 1965), during deep-sea diving (Baddeley, 1972), as well as during realistically-simulated experiments in which subjects thought they were in mortal danger and were required to perform selective attention tasks (Berkun et al., 1962) (Weltman & Egstrom, 1971).

While useful and informative, these early experiments had several limitations, the most prominent of which was that they investigated mean performance effect without considering the effects of individual variability. Yet the factors that predict vulnerability or resilience to the cognitive effects of arousal have tremendous practical importance, particularly in screening for occupations that require complex cognitive processing under dangerous conditions. Other limitations were the failure to discriminate between selective attention and orienting responses, two processes that are presumed to be linked but nonetheless distinct, as well as the failure to distinguish between the effects of arousal on pre-attentive sensory gating versus the effects of arousal on attentive selective attention, two processes that intuitively might be linked but whose relationship has not been extensively studied.

The purpose of our study was therefore threefold. Our first aim was to establish or replicate findings on mean cognitive changes that occur in the general population in the context of mild emotional arousal; specifically pre-attentive sensory gating (emotional pre-pulse inhibition), selective attention (emotional flanker task), and orienting (emotional Stroop task). Our secondary aims were to compare the role that emotional arousal plays in selective attention and the orienting response, and to evaluate the interaction of sensorimotor gating and selective attention. Our third aim was investigate the effects of individual variability, specifically relating to neural, endocrine, and subjective assessment of baseline stress, anxiety, and anger, on task performance.

Methods

Subjects: We tested 39 adults (18 male, 21 female) between the ages of 18 and 50 (mean = 30.92; SD = 9.103). All subjects were screened and shown to be free from neurological and DSMIV Axis I & 2 psychiatric illness using the Schedule for Affective Disorders – Lifetime Version (Endicott & Spitzer, 1978).

Tasks: We used pre-pulse inhibition (PPI) as a pre-attentive measure of sensorimotor gating. PPI, which has been well validated under non-emotional conditions, measures the inhibition of the startle response when an ordinarily startling stimulus is immediately preceded by a “pre-pulse,” and is thought to reflect pre-attentive thalamic “gating” of non-novel stimuli. We used standard acoustic methods, as per Blumenthal (1993). During the task, subjects viewed stimuli presented on a 21-inch computer screen in a completely dark room. The visual protocol consisted of a two-minute orienting cross on a black background, followed by 48 pictures from the International Affective Picture Scales (IAPS) (Lang, Bradley, & Cuthbert, 1995), counter-balanced for order. These IAPS pictures were Neutral during one session and Negative Arousal during the other session. Sessions were also counter-balanced for order, with a duration of 4 minutes, 58 seconds each. The sessions were separated by a 15 minute unrelated task, to avoid habituation or “bleeding” between the conditions. Inter-trial intervals were calculated to prevent a trial commencing less than 2s before or after a picture change, to avoid the picture change itself acting as a pre-pulse. Data was produced separately for Neutral and Negative Arousal conditions, allowing for comparison between the two conditions.

We used a modified Flanker (Fan et al., 2001) to investigate affect-valent selective attention, as well as an emotional Stroop task (D’Alfonso et al., 1999) to measure affect-valent orienting response. During all three tasks, the subject was monitored for EKG and respiration. Physiological data were collected and recorded via the Biopac Systems MP150 module. Subjects performed the tasks under two conditions, Neutral and Negative Arousal, at the same time on two consecutive days, counter-balanced for order. All three tasks used emotionally-valent words (Times New Roman 66 pt. Font) to induce the two conditions. Words for the two conditions were matched for frequency and word length, and came from lists used in previous studies (Dalglish, 1995, John, 1988, McKenna, & Sharma, 1995). Subjects performed the tasks on a computer, sitting 24 inches from the screen. The tasks were scored for both accuracy and average response time, calculating total score as well as scores for the first and last thirds to measure habituation effects.

The Flanker Task was adapted from the Attentional Network Task (Fan et al., 2001). For each affect conditions, the subject was presented with a series of 48 stimulus pairs. The first screen of the pair was an emotionally-valent word, presented for 1s. The second screen of the pair presented a series of 5 white arrows on a black background. The subject was instructed to identify the direction of the middle arrow by pressing a right or left button on a keypad. The subject’s response immediately advanced the task to the next stimulus pair. There were 12 variations for arrow appearance, relating to position on screen, congruence, and direction of arrows, which were programmed to present randomly.

For the Stroop Task, during each affect condition the subject was presented with 60 words that were printed in one of four different colors: Red, Green, Yellow and Blue (15 for each group). The words were presented pseudo-randomly such that no color was repeated twice in a row. The subject was instructed to press the key corresponding to the color of the word shown. A practice run made up of symbols instead of words was presented before the task in order to get the subject comfortable using the keypad without looking down at the keys.

Neuroimaging data was acquired with a 3T Siemens system at the Nathan S. Kline Institute for Psychiatric Research in Orangeburg, New York. During scanning, subjects viewed a series of facial stimuli with negative (angry and fearful) and neutral expressions. Passive viewing of an orienting cross was used as a control condition. The subject's head was secured in a custom-made head-holder and headphones were provided for magnet noise attenuation and for experimenter/subject communication. 198 T2*-weighted coronal echoplanar images (EPI) were acquired covering the frontal and temporal lobes, with TR=3000ms, TE=40ms, Flip angle = 90°, Matrix=64x64, and a FOV=224mm. Our voxel size was 3.5 mm³ and 31 contiguous coronal slices were obtained.

Following the EPI, we collected 31 T2*-weighted gradient-echo (GE) images which were used in the data-analysis process to correct for distortion found in the EPI images. The parameters for the gradient-echo sequence were TR=3000ms, TE=40ms, Matrix=64x64, with a FOV=224mm. Again our voxel size=3.5mm³, and 31 contiguous coronal slices were acquired.

Anatomic information for regions of interest (ROI) analysis was obtained with an MP-RAGE sequence. T1-weighted images were collected with TR=3000ms, TE=minimal, Flip angle = 18°, Matrix=256x192 (zero filled to 256), and a FOV=250mm. The voxel size was .9 mm x .9 mm x 1.3 mm and 120 contiguous sagittal slices (zero filled to 128) were obtained. For our image processing we used the 198 EPI images, 31 GE images, and 128 MP-RAGE images collected during the scanning session. The primary steps of the image processing were: motion correction, distortion correction, spatial normalization, smoothing, and statistical analysis. First, the EPI images were realigned, using an estimation of head movement, relative to the last image (the last image is used because it immediately precedes the GE sequence). The EPI files were co-registered and re-sliced using a sinc interpolation to generate a mean EPI image as well as registered EPI images. The mean EPI image was registered to the GE, a distortion-free image, in order to generate a warp file that will be applied to all the EPI images to correct for distortion. The next step was spatial normalization in which the images were transformed to a standard anatomical space (Talairach and Tournoux, 1988) using a T1 brain template. This procedure facilitates intersubject comparison. Finally, images were smoothed with a 7 mm Gaussian kernel (twice the voxel size) so that they were appropriate for statistical analyses.

Salivary samples were obtained at 10am and 4pm for cortisol levels; in addition, we administered 1mg of dexamethasone and measured 10am salivary cortisol the following morning.

Self-report of baseline State/Trait Anxiety and Perceived Stress were obtained using scales by Spielberger (1970) and Kuiper (1986), respectively.

Analysis

To evaluate the effects of arousal on the entire group's mean accuracy and response time, we performed a repeated measures analysis of variance, with arousal and difficulty level as the independent measures, and performance accuracy and response time as the dependent measures. Because of consistent order effects, described below in the Results section, we included testing order (whether the neutral or the arousal condition occurred first) as a covariate. To evaluate differences between tasks, we performed a bivariate correlational and linear regression analyses; task*condition*physiological variables interactions were assessed using MANOVA. To further evaluate differences between subjects, and their relationships to physiological variables, we first separated subjects into K-mean clusters, based on their fMRI activation of the left amygdala in response to neutral and aversive visual stimuli. Clusters were defined as non-responders, who showed minimal activation of the left amygdala in response to both neutral and aversive stimuli, selective high responders, who activated in response to aversive but not neutral stimuli, and non-selective high responders, who responded highly to both aversive and neutral stimuli. Using these clusters, we then performed a between-group analysis of variance to determine whether different clusters corresponded with significantly different task performance.

Results

Mean Performance Under Arousal

As shown in Table 1, arousal had a significant impact on mean cognitive performance. Prepulse inhibition was reduced an average of 3% ($p = 0.057$, $F = 3.88$) under the arousal condition, particularly in the second half, and showed diminished habituation under arousal. Increase in baseline-corrected skin conductance ($p = 0.000$, $F = 22.418$), a measure of sympathetic nervous system activation, and decrease of baseline-corrected heart-rate ($p = 0.041$, $F = 4.519$), a measure of parasympathetic nervous system activation, confirmed validity of the visual stimuli in causing an emotional response. Response time was significantly shortened for the Flanker Task ($p = 0.000$, $F = 18.022$), with accompanying decrease in accuracy; Flanker Task Efficiency (accuracy/response time) was reduced an average of 3% during the arousal condition. On the Flanker Task, congruence had a significant impact on performance: the incongruent condition had lower accuracy and longer response times than the congruent condition, which in turn had lower accuracy and longer response times than

the control condition. Response time was significantly lengthened for the Stroop task ($p = 0.000$, $F = 18.271$) in the arousal condition, with accuracy virtually unaffected; Stroop Task Efficiency (accuracy/response time) was also reduced by an average of 3% during the arousal condition.

Selective Attention versus Orienting Response

We found that efficiency on the Stroop Task, which measures the strength of the orienting response to an emotionally-valent stimulus, and efficiency on the Flanker Task, which measures the ability to focus on a (neutral) target and ignore distractors under emotionally-valent conditions, were related, as predicted. The correlation was stronger for the neutral condition ($r = 0.386$; $p = 0.015$) and weaker for the arousal condition ($r = 0.284$; $p = 0.068$). The difference between the two conditions likely resulted from subjects' performance on the orienting task being more affected by arousal ($F = 18.088$; $p = 0.000$) than their performance on the selective attention task ($F = 13.020$; $p = 0.001$). Since both tasks used similar emotionally-valent stimuli (words), these results suggest that arousal is more directly tied to the orienting response than to selective attention.

Sensorimotor Gating versus Selective Attention

While both PPI and performance on the Flanker Task were affected by arousal, the arousal condition had a stronger effect on the Flanker Task ($F = 13.020$; $p = 0.001$) than on pre-pulse inhibition ($F = 3.767$; $p = 0.061$). Our correlation and cluster analyses did not show either a direct, inverse, or hierarchical relationship between their pre-pulse inhibition and performance on the Flanker task, suggesting that pre-attentive and attentive cognitive filtering are distinct processes, mediated by different neural networks.

Individual Variability

We found a large range of variability on all cognitive variables between our healthy test subjects. For example, on the Pre-Pulse Inhibition (PPI) Task, 58% showed a relative decline in PPI under the arousal condition (ranging from 2% to 9% decreased PPI), while 42% showed a relative increase in PPI under the arousal condition (ranging from 1% to 2% increased PPI). On the Flanker Task, while 47% of all subjects showed a relative decline in efficiency under the arousal condition (ranging from 3% to 58% decline), another 51% showed a relative increase in efficiency under the arousal condition (ranging from 1% to 34% improvement). Two percent had identical scores on the neutral and arousal conditions. On the Stroop Task, 60% of all subjects showed a relative decline in efficiency under the arousal condition (ranging from 1% to 36% improvement), another 38% showed a

Conclusions

Our study of emotional arousal's impact on cognition demonstrates that even the mild arousal induced in a controlled laboratory setting is sufficient to show

relative increase in efficiency under the arousal condition (ranging from 3% to 27% improvement). Two percent had identical scores on the neutral and arousal conditions. Thus results, including our own, that report a mean decrease in sensorimotor gating and cognitive efficiency for selective attention and orienting tasks under arousal are statistically correct but are missing an interesting and potentially important part of the picture.

As shown in Figures 1, 2, and 3, our cluster analyses indicate that neural reactivity was a significant factor in predicting whether individuals' cognition (specifically sensory gating and selective attention) was positively or negatively affected by arousal (for overall, trend: $p = 0.106$, $F = 3.000$; for Flanker Task: $p = 0.037$, $F = 6.250$). For pre-attentive sensorimotor gating, selective attention, and orienting, individuals who showed selective high activation of the amygdala to aversive visual stimuli showed improvement on the arousal condition, while individuals who showed non-selective high activation of the amygdala to both neutral and aversive visual stimuli showed strong decline on the arousal condition. Non-responders, those individuals who showed minimal amygdala activation to either condition, showed small decline on the arousal condition.

Endocrine and subjective perception of baseline perceived stress were predictive of mean performance and physiological reactivity (electrodermal activity and heart rate). Afternoon (4pm) cortisol levels had significant between-subject effects for heart rate ($p = 0.043$, $F = 4.270$) and electrodermal activity ($p = 0.051$, $F = 4.270$), as well as a trend between-subjects effect for PPI ($p = 0.100$, $F = 2.947$). Post-dexamethasone cortisol, a measure of endocrine negative feedback loops, was related to mean PPI for both conditions ($p = 0.029$, $F = 5.432$). Mean PPI decreased with subjective perception of baseline perceived stress ($p = 0.087$, $F = 44.000$). For example, individuals with Perceived Stress Scale scores that clustered around 4.50 ("Low Stress," $SD = 2.393$) on the Perceived Stress Scales showed mean PPI of 50.993, individuals with scores that clustered around 13.18 ("Moderate Stress," $SD = 2.538$) showed mean PPI of 42.222, and individuals with scores of 21.33 ("Pronounced Stress," $SD = 2.739$) showed mean PPI of 26.314. On the Stroop Task, Low Stress individuals showed mean response times of 924.809 ms, Moderate Stress individuals showed mean response times of 935.104 ms, and Pronounced Stress individuals showed mean response times of 979.127 ms. This pattern was not observed for the Flanker Task, although Low Stress individuals still showed shorter response times than Pronounced Stress individuals ($p = 0.009$, $F = 5.650$).

There were no prominent age or gender effects.

consistent changes under two conditions, both of which are common in actually dangerous contexts. For tasks performed under conditions of arousal but without the possibility of orienting to the aversive stimulus (such as the Flanker Task), we recorded decrease in response time

and accuracy. For tasks with the possibility of orienting to the aversive stimuli but which require attending away from the aversive stimulus (such as the Stroop Task), we saw no loss of accuracy, but recorded significant increase in response time. Our analysis indicates that selective attention, which is fully attentive, and the orienting response, which is only semi-attentive, are related. Prepulse inhibition, which is wholly pre-attentive, was not correlated with either the Flanker or the Stroop Tasks. Finally, our analysis of variability indicates that, while most individuals are negatively influenced by arousal, others are not. Our use of neural clusters suggests that it is the *selectivity* of the neural arousal response, rather than its amplitude, that corresponds with the direction of impact; future studies examining neural activation and performance under more severe stress may shed light on the practical implications of these results.

Figures

Table 1: Estimated Marginal Means for Cognitive/Physiological Measures During Neutral & Arousal Conditions

Measure (N = 39)	Condition	Mean	Std. Error
Prepulse Inhibition	neutral	40.486	4.481
	arousal	39.173	4.854
Flanker Task Acc	neutral	.970	.010
	arousal	.966	.012
Flanker Task RT	neutral	652.208	43.341
	arousal	637.963	37.253
Stroop Acc	neutral	.959	.011
	arousal	.966	.009
Stroop RT	neutral	984.073	48.350
	arousal	1007.698	46.796
Baseline Corr HR	neutral	-1.216	.307
	arousal	-2.315	.509
Baseline Corr EDA	neutral	.131	.055
	arousal	.189	.075

Evaluated at covariate: TSTORDER = 1.4595.

Table 2: Tests of Within-Subjects Contrasts for Cognitive/Physiological Changes During Neutral vs. Arousal Conditions

Measure (N = 39)	F	Sig.
Prepulse Inhibition	3.883	.057
Flanker Task Acc	2.307	.138
Flanker Task RT	18.022	.000
Stroop Acc	.197	.660
Stroop RT	18.271	.000
Baseline Corrected Chge in HR	4.519	.041
Baseline Corrected Chge in EDA	22.418	.000

Figure 1: Preattentive Sensorimotor Gating for NonResponder, Selective High Responder, and Nonselective High Responder Groups Defined by Activation of the Left Amygdala

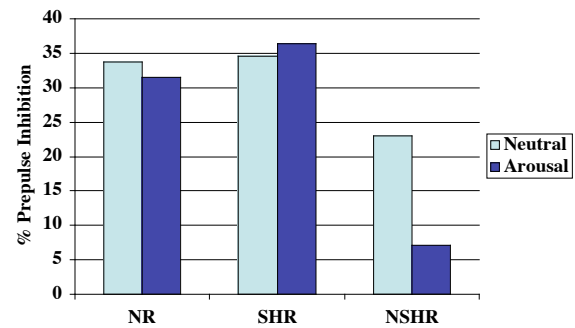


Figure 2: Selective Attention for NonResponder, Selective High Responder, and Nonselective High Responder Groups Defined by Activation of the Left Amygdala

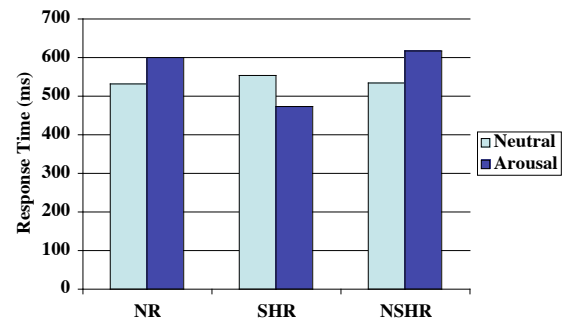
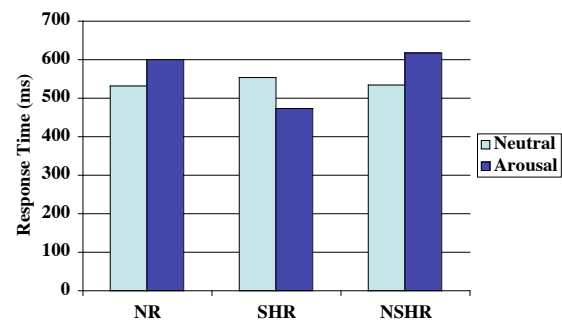


Figure 3: Selective Attention for NonResponder, Selective High Responder, and Nonselective High Responder Groups Defined by Activation of the Left Amygdala



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