EFFECTS OF A CONCURRENT TASK ON SUSTAINED EMOTIONAL PROCESSING

By

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To my Mom & Dad

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TABLE OF CONTENTS

page

ACKNOWLEDGMENTS 4

LIST OF TABLES 7

LIST OF FIGURES 8

ABSTRACT 9

CHAPTER

1 INTRODUCTION 11

Effects of a Secondary Task on Motivated Attention 12
Autonomic and Somatic Defensive Reactivity 13
The Current Investigation 14

2 EXPERIMENT ONE 15

Methods 15
Participants 15
Materials and Design 16
Apparatus and Physiological Response Measurement 17
Procedure 18
Data Reduction and Analysis 19
Results 20
Task Accuracy and Reaction Time 20
Defensive Reactivity during Picture Viewing 21
Startle magnitude 21
Skin conductance responses 21
Average heart rate 22
Corrugator EMG 22
Defensive Reactivity after Picture Viewing 23
Discussion 23

3 EXPERIMENT TWO 29

Methods 29
Participants 29
Materials, Design, and Procedure 29
Data Reduction and Primary Analysis 30
Exploratory Analysis of Individual Differences 31
Results 31
Defensive Reactivity during Picture Viewing 31
Startle magnitude 31

Skin conductance responses 32
Average heart rate 32
Corrugator EMG 33
Defensive Reactivity after Picture Viewing 33
Individual Differences in Negative Emotionality 34
Discussion 35

4 GENERAL DISCUSSION 40

Defensive Reactivity during Concurrent Task Performance 40
Sustained Emotional Processing 42
Individual Differences in Negative Emotionality 42
Conclusion 43

LIST OF REFERENCES 44

BIOGRAPHICAL SKETCH 48

LIST OF TABLES

Table page

2-1. Experiment 1: Mean *(SD)* activity in physiological measures during picture viewing, by picture content and task condition. 28

3-1. Experiment 2: Mean *(SD)* reactivity to unpleasant, neutral, and pleasant pictures, during passive viewing and task performance. 39

LIST OF FIGURES

Figure page

2-1. Design of the passive viewing (no task) and task conditions.. 25

2-2. Experiment 1: Startle and autonomic reactivity 26

2-3. Experiment 1: Corrugator EMG. 27

3-1. Experiment 2: Startle and autonomic measures..... 36

3-2. Experiment 2: Corrugator EMG 37

3-3. Individual differences in negative emotionality. 38

Abstract of Thesis Presented to the Graduate School
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Emotionally arousing content captures attention, facilitating perceptual processing and automatically prompting heightened physiological reflexes. The present study tests the persistence of this "attention capture" effect, examining to what extent it is altered when attentional resources are limited. In two experiments, we specifically examined autonomic and somatic reactivity elicited by sustained emotional content while participants concurrently performed a visual-cognitive task.

In each experiment, undergraduates viewed separate series of unpleasant, neutral, and pleasant pictures under a passive viewing condition as well as two concurrent task conditions that required them to rapidly respond to single digit targets from a constantly changing stream. Startle reflex magnitude, heart rate, electrodermal activity, and facial frowning were continuously measured. The first experiment examined the effect of task difficulty on these defensive physiological responses; the second addressed to what extent the order of task performance affected reactivity, and assessed whether individual differences in temperamental negative affect were associated with differences in reactivity under free viewing and task conditions.

Results revealed that startle reflex potentiation persisted during task performance, and was enhanced in individuals endorsing higher negative affect, highlighting its role as an index of emotional arousal independent of attentional demands. Additive effects of task demand and emotional content were revealed in autonomic measures, as heart rate and electrodermal activity were reliably modulated by unpleasant content in all conditions, despite an overall increase in metabolic load. In contrast, facial frowning was eliminated during distraction, suggesting that increased concentration may have interfered with emotion-specific facial expressivity. Thus, emotional reactivity generally persisted despite ongoing performance of a secondary task, demonstrating that emotionally arousing content facilitates enhanced autonomic and somatic responses, even when attentional resources are limited. In conjunction with current neuroimaging and cortical event-related potential research, these data highlight the predominance of motivated attention.

CHAPTER 1
INTRODUCTION

Emotional picture content captures attentional resources and facilitates perceptual processing, prompting heightened physiological responses that are consistent with states of affective arousal (Lang, 1995). Behavioral studies of this "motivated attention" (Lang, Bradley, & Cuthbert, 1997) demonstrate that emotional picture stimuli are preferentially detected with greater speed and accuracy than neutral stimuli (e.g., Öhman, Flykt, & Esteves, 2001; Keil & Ihssen, 2004). Furthermore, electrophysiological and neuroimaging studies report facilitated perceptual processing of pleasant and unpleasant pictures, showing that these motivationally relevant cues elicit larger cortical event-related potentials (ERPs) associated with visual perception (e.g., Cuthbert, Schupp, Bradley, Birbaumer & Lang, 2000; Keil, et al, 2001), as well as enhanced activation in key neural structures (e.g., amygdala: Sabatinelli, Bradley, Fitzimmons, & Lang, 2004; and visual cortex: Bradley, et al, 2003; Junghofer, et al, 2001; Junghofer, et al, 2006).

This facilitated processing purportedly activates specialized networks that mediate appetitive and defensive motivational behavior, triggering autonomic and somatic physiological reflexes such as potentiated startle responses, cardiac and electrodermal activity, as well as facial expressivity, that together reflect affective arousal (Lang, 1995). Various investigations suggest that these reflexes can be elicited by minimal stimulus information, occurring even when pictures are briefly presented (e.g., Codispoti, Bradley & Lang, 2001; Smith, Bradley, & Lang, 2006), are followed by perceptual masks (e.g., Öhman, et al., 2001; Öhman & Soares, 1998), or are small in size (2.92º x 1.96º; Codispoti & De Cesarei, 2007).

This research suggests that humans' attentional systems are adaptively primed to detect and process motivational cues. The current study investigates to what extent such facilitated

perception and subsequent response mobilization is altered when attentional resources are limited by a secondary cognitive task and to what extent different indices of motivated attention—behavioral, neural, autonomic, somatic—are similarly or differentially modulated under these conditions.

Effects of a Secondary Task on Motivated Attention

A growing literature has thus begun to examine the distracting effects of a secondary task on motivated attention. For example, using emotional face stimuli, several studies suggest that the neural activity associated with emotional face processing can be eliminated when resources are consumed by a difficult spatial attention task (Eimer, Holmes, & McGlone, 2003; Holmes, Vuilleumier, & Eimer, 2003; Pessoa, Kastner, & Ungerleider, 2002; for a counterexample, see: Vuilleumier & Schwartz, 2001). EEG studies employing more evocative picture stimuli also suggest that, while early event-related potential components associated with emotional pictures may be eliminated when task demand is very high (Schupp, et al., 2007), emotional modulation of relatively later ERPs and neural activation persists despite concurrent tasks of varying difficulty (Erk, Abler, & Walter, 2006; Hajcak, Dunning, & Foti, 2007; Lane, Chua, & Dolan, 1999). Moreover, clinical studies illustrate that individuals reporting high anxiety show greater attention allocation to fear-relevant stimuli under conditions of divided attention, specifically demonstrating that performance on a secondary task is poor when presented concurrently with threatening emotional stimuli (e.g., Amir, McNally, Riemann, & Burns, 1996; Becker, Rinck, Margraf, & Roth, 2001; Constans, et al., 2004; Carter, Maddock, & Magliozzi, 1992; Kindt & Brosschot, 1997).

Taken together, these investigations suggest that facilitated processing of evocative emotional picture stimuli persists, even when attentional resources are depleted by a secondary task, and that individual differences in this attention capture effect may relate to anxiety. The

experiments to be described here re-examine this view, addressing the effects of a secondary task on the important autonomic and somatic reflexes that are mobilized specifically during unpleasant emotional perception.

Autonomic and Somatic Defensive Reactivity

As previously described, heightened autonomic and somatic physiological reflexes are associated with facilitated processing of emotional cues. Unpleasant pictures, specifically, are hypothesized to activate neural circuits mediating defensive behavior, eliciting distinctive responses in several physiological systems, such as the startle reflex. Extensive research with animals and humans has shown that this protective response is potentiated during states of fear, as when laboratory animals anticipate an aversive electric shock or when human participants view unpleasant picture content (Davis & Lang, 2003). Further comprehensive study has traced the neural circuitry underlying this fundamental reflex, establishing "fear-potentiated startle" as a primary marker of defensive activation (Davis, 1997).

Emotional cues elicit an enhanced orienting reflex indexed by autonomic activation. Whereas all novel stimuli provoke heart rate deceleration and increased skin conductance, reflecting attentional engagement and response preparation, unpleasant content, prompts prolonged cardiac deceleration and greater electrodermal activity, reflecting the intensity of the particular aversive cue (Bradley, 2001). Finally, facial frowning, indexed by tension in the corrugator muscle, is associated with unpleasant emotion. This activity is proportionally linked to the degree of perceived "unpleasantness", adaptively serving a social-communicative function; however, in general, facial expressivity can be voluntarily controlled, and muscle tension has been shown to increase with concentration (Tassinary & Cacioppo, 2000).

The above responses are sustained, and may be enhanced when pictures of similar unpleasant content are viewed in a prolonged series. Startle potentiation and corrugator tension have been shown to sensitize with exposure to persisting unpleasant content, and sometimes are maintained, even after the stimulus is no longer present (Bradley, Cuthbert, & Lang, 1996; Smith, Bradley, & Lang, 2005). Smith and colleagues (2005) also found that this "mood" or tonic state of defensive activation is greater in individuals reporting higher anxiety (Smith, et al., 2005). To what extent such a tonic state may be affected when participants' attention is divided by a secondary task has been largely unexplored.

The Current Investigation

In the present study, we examined defensive physiological reactivity associated with sustained emotional picture processing under varying levels of attentional interference in two experiments. Participants viewed prolonged series of unpleasant, neutral, and pleasant pictures during a passive viewing condition and during two concurrent task conditions that varied in difficulty. In both tasks, single digit numbers were presented in the center of each picture; the "Easy" condition required simple detection and a rapid response to a target number, whereas a "Difficult" condition added a working memory component, such that the required target response depended on the preceding digit (1-back). Focusing on defensive activation, we examined autonomic and somatic physiological responses elicited by high arousing unpleasant content, in comparison to that associated with processing of neutral and pleasant stimuli. Thus, the first experiment assessed the effects of "easy" and "difficult" concurrent tasks on defensive reactivity during and after sustained emotional processing. The second follow-up study more closely examined order effects (i.e., whether a passive picture viewing condition preceded or followed task performance), and the effects of individual differences in anxious temperament during free viewing and task conditions.

CHAPTER 2
EXPERIMENT ONE

The first experiment examined the hypothesis that defensive autonomic and somatic responses to unpleasant emotional content persist despite ongoing attentional interference by a secondary task. This view is supported by ERP and neuroimaging studies that highlight the predominance of attention capture under conditions of divided attention (e.g., Erk, et al., 2006; Hajcak, et al., 2007; Lane, et al., 1999). The alternative hypothesis—that defensive reactivity is significantly attenuated or eliminated when a task is performed concurrently with picture viewing—was also considered, and is supported by two recent studies reporting that emotional modulation of neural activity was eliminated by very difficult task demands (e.g., Erthal, et al., 2006; Schupp, et al., 2007), as well as by a behavioral study reporting a reduction in participants' ratings of negative mood when they performed mental arithmetic simultaneously with unpleasant picture viewing (Van Dillen & Koole, 2007).

In light of previous findings suggesting that defensive reactivity is maintained during and, to some extent, after sustained emotional picture viewing (Smith, et al., 2005), we predicted that such responses would be elicited during viewing of prolonged, unpleasant picture series, and that such reactivity (especially startle potentiation and corrugator muscle tension) would persist after exposure to unpleasant content.

Methods

Participants

Thirty-two (16 male, 16 female) introductory psychology students at the University of Florida received course credit for their participation in this study, which was approved by the University of Florida Department of Psychology Institutional Review Board. Written informed consent was obtained from each participant prior to the start of the experiment.

Materials and Design

One hundred eighty pictures were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005). Pictures were selected on the basis of their normative valence ratings, constituting sets of 60 pictures each that represented highly arousing unpleasant content, as well as neutral and pleasant pictures. Mean (*SD*) valence ratings for pleasant, neutral, and unpleasant pictures were: 7.49 (*0.47*), 4.97 (*0.24*), and 2.44 (*0.76*), respectively; and mean (*SD*) arousal ratings were: 5.25 (*0.92*), 3.21 (*0.72*), and 6.26 (*0.66*), respectively. Pleasant pictures depicted sports/adventure, romance, cute animals, babies/families, and erotica; neutral categories were neutral faces, objects, people, scenes, and nature; unpleasant categories were accidents, animal threat, human threat, contamination, and mutilations. Sixty additional scrambled IAPS pictures were also used.

One trial consisted of a series of 20 same-valence pictures, each of which was presented for 3 s with no inter-picture interval, constituting a 60 s block of all pleasant, neutral, or unpleasant picture content. Each block was followed by a 60 s inter-block interval (IBI) during which no pictures were presented. This trial structure was implemented under three task conditions that were performed in the same order by all participants: 1) a passive viewing/"No Task" condition, 2) an "Easy" task condition and, 3) a "Difficult" task condition (Figure 2-1, B). Each condition began with a 60 s block of scrambled pictures and a subsequent off period to habituate participants to the novel task demands. Then, pleasant, neutral, and unpleasant picture series were presented in a counterbalanced order within each condition.

In the No Task condition, a fixation cross continuously appeared at the center of the screen during picture blocks and IBIs, as shown in Figure 2-1 (A). For the Easy and Difficult tasks, this was replaced by a small circle containing a number (1-9) that changed every 750 ms, such that four numbers appeared during each 3 s picture (Figure 2-1, B). Numbers were presented during

both the picture blocks and IBIs, so that the task was continuously performed. In the Easy condition, participants were instructed to press a button each time a target number ("9") appeared. In the Difficult condition, they were instructed to respond only when the target number ("9") was preceded by an odd number.

Apparatus and Physiological Response Measurement

An IBM-compatible PC running Presentation stimulus control software (www.neurobs.com) controlled picture and task presentation, and recorded reaction time and accuracy measures. Pictures were displayed in color via an LCD projector, on a screen approximately 1.5 m from the participant. The acoustic startle stimulus was a 50 ms, 98 dB burst of white noise with an instantaneous rise time that was delivered by a Coulbourn noise generator and presented over EAR-Tone air conduction headphones. Startle probes were presented at three intervals during each picture block and IBI, in one of two counterbalanced positions: 5.7 s or 8.7s after the onset of the picture block/inter-block interval, 29.7 s or 32.7 s, and 53.6 s or 56.7 s.

An IBM PC running VPM software (Version 11.7; Cook, 2002) was used for physiological data acquisition. Signals were sampled continuously at 20 Hz beginning 3 s before each picture block. To record startle responses, 4mm Ag-AgCl electrodes were placed over the left orbicularis oculii muscle according to standard guidelines (Fridlund & Cacioppo, 1986). The raw signal was amplified by 30,000 and filtered from 28 Hz to 500 Hz using a Coulbourn V75-02 bioamplifier and V75-48 bandpass filter. The signal was then rectified and integrated using a Coulbourn V-76-23A contour following integrator with a 20 ms time constant.

Facial muscle activity was recorded from 4mm Ag-AgCl electrodes placed over the left corrugator supercilii according to standard guidelines (Fridlund & Cacioppo, 1986). Raw signals were amplified by 30,000 and filtered from 13 Hz to 1000 Hz using a Coulbourn V75-01

bioamplifier, then rectified and integrated using a Coulbourn V76-23A contour following integrator with a 500 ms time constant.

Skin conductance was recorded from 8mm Ag-AgCl electrodes filled with .5 M NaCl skin conductance paste (TD-246, Mansfield R&D) placed on the hypothenar eminence of the left palm. The signal was recorded within a range of 0 to 40 μSiemens using a Coulbourn V71-23 skin conductance coupler that was calibrated prior to each session.

Heart rate was recorded from 8mm Ag-AgCl electrodes placed on the left and right forearms, with a ground electrode on the left forearm. The raw signal was filtered from 8 Hz to 40 Hz using a Coulbourn V75-04 bioamplifier. A Schmitt trigger interrupted the computer upon detection of an R-wave, via a Coulbourn V21-10 dual comparator. Inter-beat intervals were recorded to the nearest millisecond and reduced offline using VPM software (Cook, 2001). These data were converted into beats per minute in half-second bins using a weighted-average method (Graham, 1980).

Procedure

After giving informed consent, the participant sat in a comfortable chair in a dimly lit room while the experimenter applied the sensors. Then, it was explained that the participant would be viewing sets of pictures and that he/she should look at each picture for the entire time it was on the screen. Before each task, the experimenter entered the room and explained the task to be performed, instructing the participant to continue to look at each picture while performing the task as accurately as possible. The participant completed a 60 s practice trial prior to each task condition. At the end of the session (approximately 25 min), the experimenter removed all sensors, debriefed the participant and awarded course credit.

Data Reduction and Analysis

The startle-elicited eyeblink data were reduced offline using a VPM program (Cook, 2001) implementing a peak-scoring algorithm to determine peak values for onset latency and amplitude **(**Balaban et al., 1986). Trials containing clear artifacts were rejected and those with no discernable response were scored as zero magnitude blinks. Raw startle magnitudes were transformed to *T*-scores (mean=50, *s.d.*=10) within participants and across all trials, to adjust for between-subject differences in baseline and response amplitudes (Funayama, Grillon, Davis, & Phelps, 2001). Individual *T*-scores greater than ±3 *s.d.* were excluded from analysis. For skin conductance, the number of responses greater than 0.05 μS (Dawson, et al., 2000) was calculated for each picture block and subsequent off period. For heart rate, artifact-free raw data in beats per minute were used. For corrugator EMG, baseline muscle activity was averaged over the two half-seconds prior to the onset of each 60s picture block and activity occurring at each half-second during the picture block and subsequent off period was deviated from this value.

To assess physiological reactivity during picture viewing, average skin conductance, heart rate, and corrugator activity was calculated in three windows across the picture series (0-20 s, 20-40 s, and 40-60 s), constituting means at early, middle, and late times within the series. Startle reflex magnitude was averaged across the three probes presented during picture viewing. To assess reactivity after picture viewing, activity across the entire inter-block interval was averaged separately for all measures. Reaction time to targets and response accuracy were calculated across each picture block and inter-block interval.

Due to equipment error, reaction time and task accuracy data were lost for two participants. Likewise, data from several participants were excluded due to equipment error and movement artifacts, resulting in the following sample sizes: startle, n=30; skin conductance responses, n=29; heart rate, n=29; corrugator, n=30.

Data were analyzed separately during picture blocks and inter-block intervals using SPSS (Version 11.0) univariate repeated measures ANOVA. First, the effects of task condition and picture content (emotional valence) on task accuracy and reaction time were examined using a 2(Task: easy, difficult) x 3(Valence: pleasant, neutral, unpleasant) within-subjects design. For the physiological measures, during picture viewing, the effects of task condition, picture valence, and time within the picture series on physiological reactivity were examined using a 3(Task: none, easy, difficult) x 3(Valence: pleasant, neutral, unpleasant) x 3(Time: early, middle, late) within-subjects design. Planned follow-up comparisons examined the effect of picture valence within each condition separately, following a significant omnibus valence effect. To assess the effects of task condition and the emotional valence of the preceding picture block on physiological reactivity *after* picture viewing, a 3(Task) x 3(Valence) design was employed. Greenhouse-Geisser corrections for multiple comparisons were employed, and corrected *p*-values are reported.

Results

Task Accuracy and Reaction Time

Response accuracy was high for both the Easy and Difficult conditions, with average hit rates (*SD*) of 96.7 (*6.13*) %, and 86.7 (*18.25*) %, respectively. Accuracy was significantly higher, however, when participants performed the easy tracking task compared to the difficult working memory task (Task main effect, $F[1,29]=15.17$, $p=.001$). Mean (*SD*) reaction times to targets presented in the Easy and Difficult tasks were 515.7 (*62.3*) ms and 672.5 (*145.2*) ms, respectively. Overall, responses were faster to targets in the Easy condition, compared to targets presented in the Difficult condition (Task, $F[1,28]=64.0$, $p<.001$). Neither response accuracy nor reaction time were significantly affected by picture valence in either task condition (*F*s<1).

Defensive Reactivity during Picture Viewing

Table 2-1 summarizes the mean activity observed in the following physiological measures during picture viewing, within each picture series and task condition.

Startle magnitude

Overall, startle magnitude decreased during task performance, independent of picture valence ($F[2,58]=7.98$, $p<0.001$, $\eta^2_p=0.216$), such that average startle magnitude was reduced during the Easy and Difficult task conditions compared to passive picture viewing (ps<0.005). Average startle magnitude did not differ between the two tasks ($p>0.05$). Despite this overall attenuation, startle magnitude was potentiated during unpleasant, compared to neutral ($p=0.009$) and pleasant ($p=0.007$) picture blocks (Valence, $F[2,58]=6.69$, $p=0.004$, $\eta^2_p=0.187$), and this modulation was comparable across task conditions (see Figure 2-2; Task x Valence: $F<1$). Follow-up tests confirmed significant startle potentiation during unpleasant, compared to pleasant, pictures within each condition (Fs[2,58]<4.59, $ps<0.045$; unp v. pl: ps <0.034).

Skin conductance responses

Independent of emotional picture content, a greater number of SCRs were elicited during both the Easy ($p<0.001$) and Difficult ($p<0.001$) task conditions compared to passive picture viewing ($F[2,56]=15.84$, $p<0.001$, $\eta^2_p=0.361$), but did not differ between the two tasks ($F<1$). Despite this overall increase, unpleasant ($p=0.009$) and pleasant ($p=0.039$) pictures elicited more SCRs compared to neutral (Valence, $F[2,56]=4.5$, $p=0.017$, $\eta^2_p=0.138$). This effect was similar within each condition (Task x Valence, $F<1$), with follow-up comparisons confirming more frequent SCRs during unpleasant, compared to neutral picture blocks during passive viewing and task performance, as seen in Figure 2-2 (Fs[2,56]<4.40, ps<0.09, η^2_ps<0.132).

Across valence and task conditions, electrodermal activity decreased overall across the 60 s picture block (F[2,56]=6.59, p=0.007, η^2_p=0.190), such that more SCRs were elicited early, compared to in the middle (p=0.002) and late (p=0.015) in the block. Time did not significantly interact with picture content or task condition (Fs < 2.45).

Average heart rate

Across picture contents, average heart rate increased as the secondary task became more difficult (F[2,56]=12.8, p<0.001, η^2_p=0.314), such that heart rate was greatest during the Difficult compared to the Easy task, and during the Easy task compared to passive viewing (all ps<0.038). Independent of this increase, however, heart rate was independently modulated by picture emotionality (Valence, F[2,56]=22.56, p<0.001, η^2_p=0.446). As seen in Figure 2-2, average heart rate decreased during both pleasant and unpleasant blocks, compared to neutral (ps<0.001), and the decrease was more pronounced for unpleasant, compared to pleasant blocks (p=0.001). Valence modulation was not dependent upon task condition (task x valence, F<1), and follow-up comparisons confirmed significant effects of emotional content within all three conditions (Fs[2,56]< 6.85, ps< 0.004, η^2_ps<0.326; unp v. neu & pl, all ps<0.01). Time did not significantly interact with picture valence or task condition (Fs<1.04).

Corrugator EMG

Corrugator muscle activity increased during unpleasant picture blocks, compared to neutral (p=0.033) and pleasant (p=0.002) blocks (F[2,58]=15.84, p=0.017, $_p$=0.138). While the Task x Valence interaction did not reach significance (F[4,116]=1.87, p=0.12), planned follow-up comparisons indicated that corrugator activity increased during *passive viewing* of unpleasant pictures (v. pl: p=0.001; v. neu: p=0.014; Valence, F[2,58]=8.84, p=0.001, η^2_p=0.222), but that

no such modulation occurred during the Easy or Difficult tasks (*F*s<1.16). This effect is illustrated in Figure 2-2.

Across all task conditions, corrugator activity increased with increasing exposure to unpleasant and neutral pictures over the 60 s block (Valence x Time: $F[4,116]=6.34$, $p=0.010$, $\eta^2_p=0.142$), such that activity was greatest at the end of the picture series compared to the middle (*p*s<0.073) and beginning (*p*s<0.016). No other significant interactions were revealed.

Defensive Reactivity after Picture Viewing

Corrugator muscle tension *after* unpleasant picture blocks was significantly greater than activity after neutral ($p=0.007$) and pleasant blocks ($p<0.001$; Valence, $F[2,58]=5.04$, $p=0.01$, $\eta^2_p=0.148$), suggesting that defensive reactivity elicited during picture viewing was maintained during the inter-block interval. Again, while the overall interaction did not reach significance ($F[4,116]=1.70$, $p=0.173$), this increase in corrugator activity was only significant after the passive viewing condition (Valence, $F[2,58]=7.81$, $p=0.002$, $\eta^2_p=0.201$; unp v. neu & pl, *p*s<0.008).

Neither startle magnitude nor average heart rate was significantly modulated by task condition or preceding picture valence during the inter-block interval. After picture viewing, the number of skin conductance responses was greater during both the Easy ($p=0.019$) and Difficult ($p=0.007$) tasks, compared to the No Task condition, independent of preceding picture valence (task main effect*:* $F[2,56]=15.84$, $p<0.001$, $\eta^2_p=0.361$). Skin conductance reactivity was not affected by picture valence during the inter-block interval ($F<1$).

Discussion

Experiment 1 examined the influence of a secondary task on defensive reactivity during sustained emotional processing. When participants performed a task concurrently with picture

viewing, defensive reactivity was generally sustained—as evidenced by potentiated startle, increased electrodermal activity, and decreased heart rate during unpleasant pictures—which is consistent with the hypothesis that motivated attention persists, even when resources are limited. In contrast, although corrugator muscle tension increased during passive viewing of unpleasant picture series, when participants performed a secondary task, emotional modulation was no longer significant.

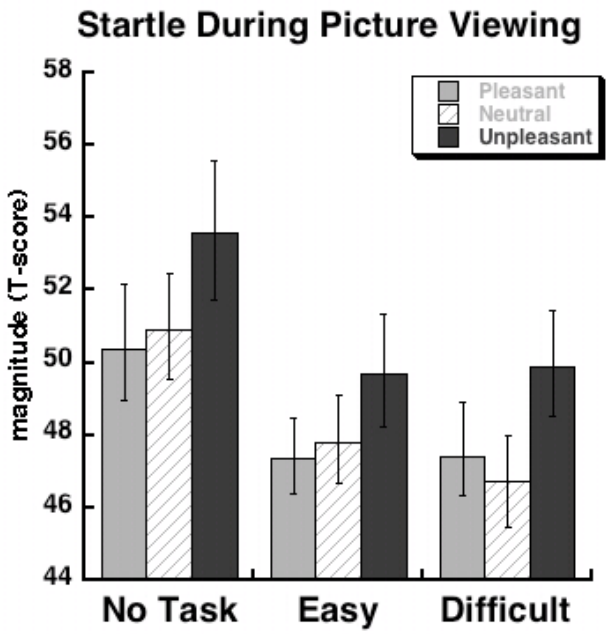
Decreased task accuracy and slower reaction times were associated with the Difficult n-back task, compared to the Easy tracking task. Likewise, average heart rate and SCRs increased as task demands increased, reflecting greater metabolic load. Importantly, however, despite this increased autonomic activity, these measures were nonetheless similarly modulated by emotional picture content during the passive viewing, Easy, and Difficult conditions. Thus, task difficulty did not affect the degree of defensive reactivity prompted by unpleasant stimuli.

Experiment 1 also examined the effects of sustained picture presentation on defensive reactivity during and after picture viewing. Consistent with previous work, corrugator muscle tension increased with increasing exposure to unpleasant pictures, and this reactivity persisted in the inter-block interval that followed. This suggests that at least the facial action component of affective reactivity was maintained. However, evidence of emotional arousal in startle, heart rate, and skin conductance was limited to the picture period only, and was not sustained after picture exposure.

A) Passive Viewing Condition

B) Task Conditions

Figure 2-1. Design of the passive viewing (no task) and task conditions. A) In the passive viewing condition, one trial was comprised of 20, 3 s pictures of the same emotional valence (unpleasant, neutral, unpleasant), that constituted a 60 s picture block. The picture block was followed by a 60 s inter-block interval, in which no pictures were presented. B) The task conditions followed the same trial structure; the fixation cross was replaced by a single-digit number that changed every 750ms (three times during each picture).



AUTONOMIC REACTIVITY DURING PICTURE VIEWING

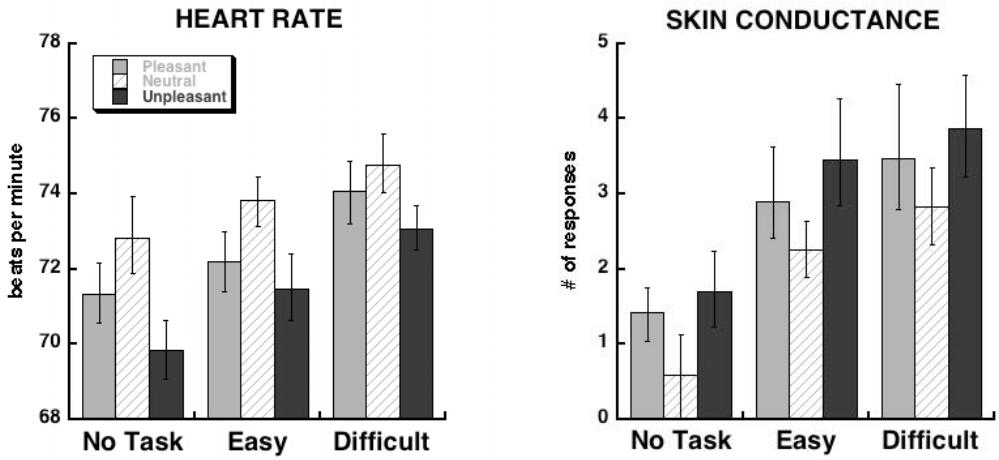


Figure 2-2. Experiment 1: Startle and autonomic reactivity. Startle magnitude (top), average heart rate (bottom left), and number of skin conductance responses (bottom right) elicited by pleasant, neutral, and unpleasant picture series during a passive viewing condition, as well as performance of easy and difficult concurrent tasks. Error bars represent 95% confidence intervals.

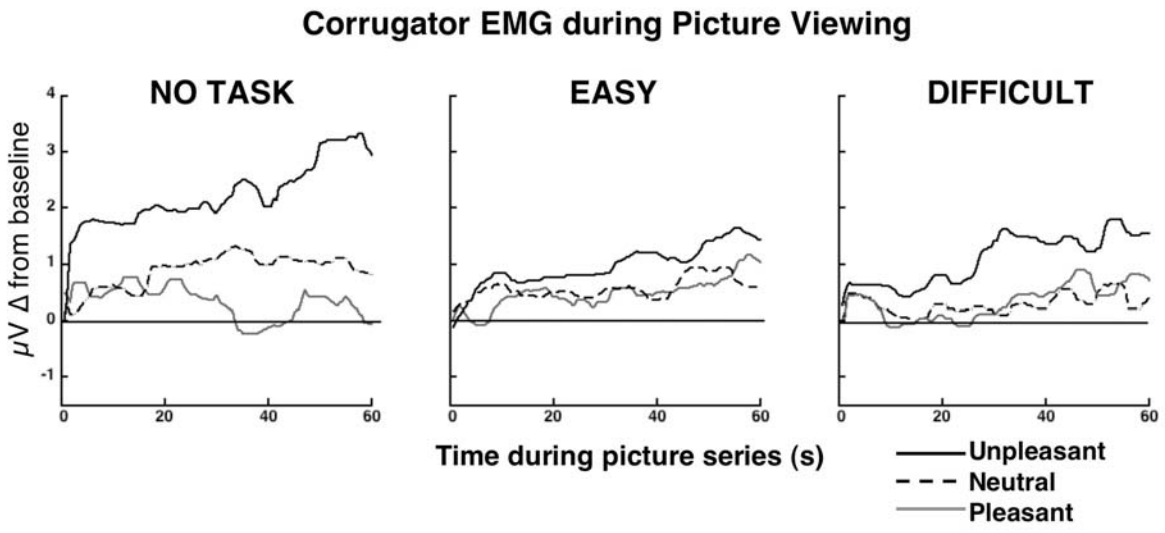


Figure 2-3. Experiment 1: Corrugator EMG. Waveforms represent change in corrugator electromyographic activity (microvolts) relative to a 1 s baseline prior to the onset of each 60 s unpleasant, pleasant, and neutral picture series, during passive viewing, and easy and difficult concurrent tasks.

Table 2-1. Experiment 1: Mean *(SD)* activity in physiological measures during picture viewing, by picture content and task condition.

Measure	No Task	Easy Task	Difficult Task
Startle magnitude (T-score)			
Unpleasant	52.4 *(6.4)*	49.1 (4.6)	49.3 *(4.9))*
Neutral	50.6 *(5.1)*	47.0 (3.7)	46.4 *(4.4))*
Pleasant	49.8 *(5.6)*	46.9 (3.1)	47.1 *(3.7)*
Skin conductance (# of responses)			
Unpleasant	1.70 *(2.76)*	3.51 (4.51)	3.87 *(4.02)*
Neutral	1.63 *(2.40)*	2.27 (3.14)	2.83 *(3.04)*
Pleasant	1.43 *(2.66)*	2.93 (4.16)	3.47 *(4.65)*
Heart Rate (BPM)			
Unpleasant	69.8 *(10.9)*	71.5 *(11.4)*	73.5 *(10.8)*
Neutral	72.8 *(11.4)*	73.8 *(11.2)*	75.5 *(11.1)*
Pleasant	71.3 *(11.0)*	72.2 *(11.5)*	74.5 *(12.1)*
Corrugator EMG (μV)			
Unpleasant	2.21 *(3.76)*	0.93 *(1.80)*	1.07 *(2.00)*
Neutral	0.86 *(1.68)*	0.57 *(1.52)*	0.30 *(2.79)*
Pleasant	0.05 *(1.97)*	0.48 *(1.99)*	0.34 *(1.57)*

Mean *(SD)* activity collapsed across each 60 s picture block, within each task condition. Values reflect startle reflex magnitude (in T-score units), electrodermal activity (number of skin conductance responses greater than 0.05 μS), average heart rate (beats per minute), and change in corrugator electromyographic activity relative to a baseline 1 s prior to each picture block.

CHAPTER 3
EXPERIMENT TWO

Although the findings of the first experiment appear straightforward, on reflection, a question arises concerning the consistent presentation of a passive viewing condition prior to the task conditions. That is, could the passive viewing experience have trained participants to focus on the picture stimuli, and thus reduced the subsequent distracting effects of the secondary task? In the following experiment, we therefore examined whether defensive reactivity under conditions of distraction would change when a passive viewing condition did not precede task performance.

Additionally, in a secondary analysis, we explored the assumption that individuals endorsing an anxious temperament style would show a greater response to unpleasant picture stimuli than less anxious participants (e.g., Smith et al., 2005).

Methods

Participants

Fifty-one (25 male, 26 female) introductory psychology students at the University of Florida received course credit for their participation in this study, which was approved by the University of Florida Department of Psychology Institutional Review Board. Written informed consent was obtained from each participant prior to the start of the experiment.

Materials, Design, and Procedure

Using a procedure identical to that of Experiment 1, with the same emotional picture stimuli, participants viewed blocks of unpleasant, neutral, and pleasant pictures during passive viewing and task conditions. The design differed only in that one group of participants (n=26) was exposed first to the passive viewing condition, followed by the tasks; the second group (n=25) always began with the task conditions, followed by passive viewing.

As in the first experiment, startle reflex magnitude, heart rate, skin conductance, and corrugator EMG activity were recorded. Data acquisition was identical to that of Experiment 1, except that the startle probe was delivered via the soundcard of the stimulus presentation PC. The stimulus properties of the probe (50ms, 95dB, instantaneous rise time) were unchanged from the first experiment.

After the psychophysiogical session, participants completed a brief (155-item) version of the Multidimensional Personality Questionnaire (MPQ; Patrick, Curtin, & Tellegen, 2002), a self-report measure assessing temperament and affect constructs across 11 trait scales constituting three orthoganal factors: Positive Emotionality, Negative Emotionality, and Constraint. Of import to the current study, Negative Emotionality is linked to the negative affect dimension of mood, which is conceptualized as a susceptibility to negative affective states (Tellegen, 1985; Watson, 2000; Watson, Wiese, Vaidya, & Tellegen, 1999) and has been implicated in the development of anxiety and mood disorders (Clark & Watson, 1999; MPQ in specific: Krueger, McGue, & Iacono, 2001; Lilienfeld, 1997).

Data Reduction and Primary Analysis

Data reduction followed the same procedure as outlined for Experiment 1. Because the degree of defensive reactivity did not differ significantly between the Easy and Difficult task conditions in the first experiment, the analysis was simplified and physiological activity was averaged over the Easy and Difficult conditions to create a single "Task" condition.[1] Activity in each of the physiological measures was then calculated for each 60-second picture block and subsequent inter-block interval, for the Task and passive viewing condition separately. Activity

[1]In the current experiment, 2(Task: Easy, Difficult) x 3(Valence) x 3(Time) ANOVAs conducted for each physiological measure revealed that this 2-level task factor did not significantly interact with the effects of picture content or time within the picture series (all Fs <2.3, all ps >0.20).

within each picture block was also averaged into 20-sec time windows, constituting estimates of activity at early, middle, and late points across a picture series.

As in the first experiment, to assess effects during picture viewing, a 2(Task: no task, task) x 3(Valence: pleasant, neutral, unpleasant) x 3(Time: early, middle, late) within-subjects design was employed. Planned follow-up comparisons examined the effect of picture valence within each condition, following a significant main effect of Valence. After picture viewing, a 2(Task) x 3(Valence) design was employed. Greenhouse-Geisser corrected *p*-values are reported.

Exploratory Analysis of Individual Differences

A simple median split was performed on the subset of individuals who completed the MPQ (n=40), resulting in two groups: those reporting higher levels of negative emotionality compared to a normative adult sample (mean*[SD] T*-score: 63.2*[6.5];* 11 females, 8 males) and those endorsing lower levels of negative emotionality compared to the same normative sample (mean*[SD] T*-score: 48.0*[3.9]*; 9 females, 12 males). Repeated-measures ANOVAs were performed on the mean activity within each physiological measure during the 60 s picture block, examining the within-subjects Task (no task, task) and picture Valence (pleasant, neutral, unpleasant) factors, with Group (lower, higher) as a between-subjects factor.

Results

Defensive Reactivity during Picture Viewing

Table 3-1 summarizes the mean activity observed within all physiological measures during picture viewing, within each level of the Valence and Task factors.

Startle magnitude

Overall, unpleasant pictures elicited increased startle magnitude compared to neutral (p=0.001) and pleasant (p<0.001) pictures (Valence, $F[2,94]=9.03$, $p<0.001$, $\eta^2_p=0.161$) and this modulation was not affected by the secondary task (Task x Valence: $F<1$). Follow-up

comparisons revealed significant startle potentiation in both the passive viewing and the task condition, as illustrated in Figure 3-1 (Fs[2,100]<4.47, ps<0.03, η^2_p<0.087; unp v. neu & pl: ps<0.034). Overall startle magnitude did not differ between the two conditions (Task, F<1).

Skin conductance responses

A greater number of SCRs was elicited during task performance compared to passive picture viewing, overall (F[1,50]=32.48, p<0.001, η^2_p=0.394). Despite this increase, more SCRs were elicited by unpleasant, compared to neutral (p=0.006) and pleasant (p=0.02), picture blocks (Valence, F[2,100]=9.19, p<0.001, η^2_p=0.155). Follow-up tests confirmed significant valence modulation within both conditions, as illustrated in Figure 3-1 (Fs[2,100]<6.06, ps<0.006, η^2_ps<0.11; unp v. neu & pl: ps<0.03).

The number of skin conductance responses decreased over time across the 60-sec picture block, overall (Time, F[2,100]=3.87, p=0.032, η^2_p=0.072; early v. middle, late ps<0.001). However, time did not significantly interact with picture content or task condition (Fs<1).

Average heart rate

Overall, average heart rate increased during task performance compared to passive picture viewing (Task, F[1,50]=22.78, p<0.001, η^2_p=0.072). Across task conditions, heart rate decreased during unpleasant compared to pleasant (p=0.001) picture blocks, and was lower during both emotional picture blocks compared to neutral (ps<0.002; Valence, F[2,100]=11.77, p=0.004, η^2_p=0.191). This valence effect was not dependent on task condition (Task x Valence, F<1). Follow-up tests confirmed that valence modulation was similar between the No Task and Task conditions, as illustrated in Figure 3-1 (Fs[2,100]<20.0, ps<0.001, η^2_ps<0.287; unp & pl v. neu: ps<0.01). Time did not significantly interact with picture valence or task condition (Fs<1).

Corrugator EMG

Compared to neutral picture blocks, corrugator tension significantly increased during unpleasant (p=0.05), and decreased during pleasant picture viewing (p=0.35*;* Valence, F[2,76]=5.12, p<0.012, η^2_p=0.119), however, corrugator activity was no longer modulated by emotional picture valence when participants performed a secondary task (Task x Valence, F[2,76]=5.48, p=0.011, η^2_p=0.126). As seen in Figure 3-2, follow-up comparisons confirmed that corrugator activity was significantly modulated by picture content during the passive viewing condition only (No Task: F[2,76]=8.46, p=0.001, η^2_p=0.183, unp v. neu, pl: p<0.015; Task: F[2,76]<1). Across picture contents, overall corrugator activity was similar during the task and passive viewing conditions (Task, F<1.3).

Corrugator tension increased with increasing exposure to unpleasant and neutral pictures, overall (Valence x Time, F[4,152]=4.71, p=0.005, η^2_p=0.110). Specifically, tension was greatest at the end of the picture series compared to the middle (ps<0.05) and beginning (ps<0.010). No other significant interactions were revealed (Fs<1.33).

Defensive Reactivity after Picture Viewing

A linear trend suggested that, overall, relative corrugator *relaxation* persisted after viewing pleasant pictures (*linear trend:* F[1,40]=5.5, p=0.024), however, the potentiation specific to unpleasant pictures that was present during picture viewing was not maintained during the inter-block interval (F<1).

A greater number of SCRs was elicited when participants performed a task during inter-block intervals, compared to no task (F[1,50]=7.22, p=0.01, η^2_p=0.126). Similarly, overall corrugator tension tended to be greater during task performance, compared to no task

(F[1,40]=3.24, p=0.079, η^2_p=0.075). No other effects of task condition or picture content were revealed after picture viewing (Fs<2.28, ps>0.11).

Individual Differences in Negative Emotionality

For startle magnitude, a significant Group x Valence interaction (F[2,76]=7.33, p=0.002, η^2_p=0.049) suggested that, across task conditions, participants endorsing higher negative emotionality showed a different pattern of startle reactivity compared to the lower group (p=0.001). Further examination of this effect revealed that only the higher group showed significant startle potentiation during unpleasant, compared to neutral and pleasant picture blocks, whereas the lower group showed no effect of emotional valence, as illustrated in Figure 3-3 (Valence within higher group: F[2,37]=19.0, p<0.001, η^2_p=0.51; lower group: F[2,37]<1). These group differences were not affected by task condition (3-way interaction, F[2,76]<1).

With respect to corrugator activity, a Group x Task x Valence interaction suggested that task-dependent emotional modulation of the facial frowning response differed between the two temperament groups (F[2,62]=4.55, p=0.02, η^2_p=0.142). While each group showed increased corrugator tension during passive viewing of unpleasant, compared to neutral, picture blocks (ps<0.049), the higher negative emotionality group showed significant corrugator muscle *relaxation* during passive viewing of pleasant pictures, compared to neutral pictures (p=0.013; Valence effect within No Task: F[2,37]=19.0, p<0.001), whereas the lower group did not show this effect (F<1).

There were no significant Group effects in heart rate or electrodermal measures, and no group differences were uncovered in any measure post-picture viewing (all Fs < 1).

Discussion

Replicating the results of the first experiment, unpleasant pictures prompted heightened autonomic and somatic reactivity (startle potentiation, decreased heart rate, increased SCRs) despite distraction by a concurrent, non-emotional task. As in Experiment 1, facial frowning increased during passive viewing of unpleasant picture blocks, but when a concurrent task was added, this activity was no longer greater than that elicited by neutral or pleasant contents. None of the above effects varied with Task/No Task order.

Also replicating results of the first experiment, general autonomic activity (average heart rate and SCRs) increased during task performance compared to passive picture viewing alone, independently of emotional picture content, reflecting the greater metabolic load demanded by the task condition.

Defensive reactivity associated with unpleasant content was generally limited to the duration of the picture block, such that analyses of reactivity during inter-block intervals revealed no sustained effects of unpleasant picture content.

Analyses of individual differences revealed that participants endorsing higher levels of temperamental negative affect demonstrated greater startle potentiation during unpleasant picture series, across the passive viewing and task conditions, compared to those reporting lower levels of this construct. The two groups showed similar defensive reactivity to unpleasant pictures with respect to heart rate, electrodermal activity, and facial frowning.

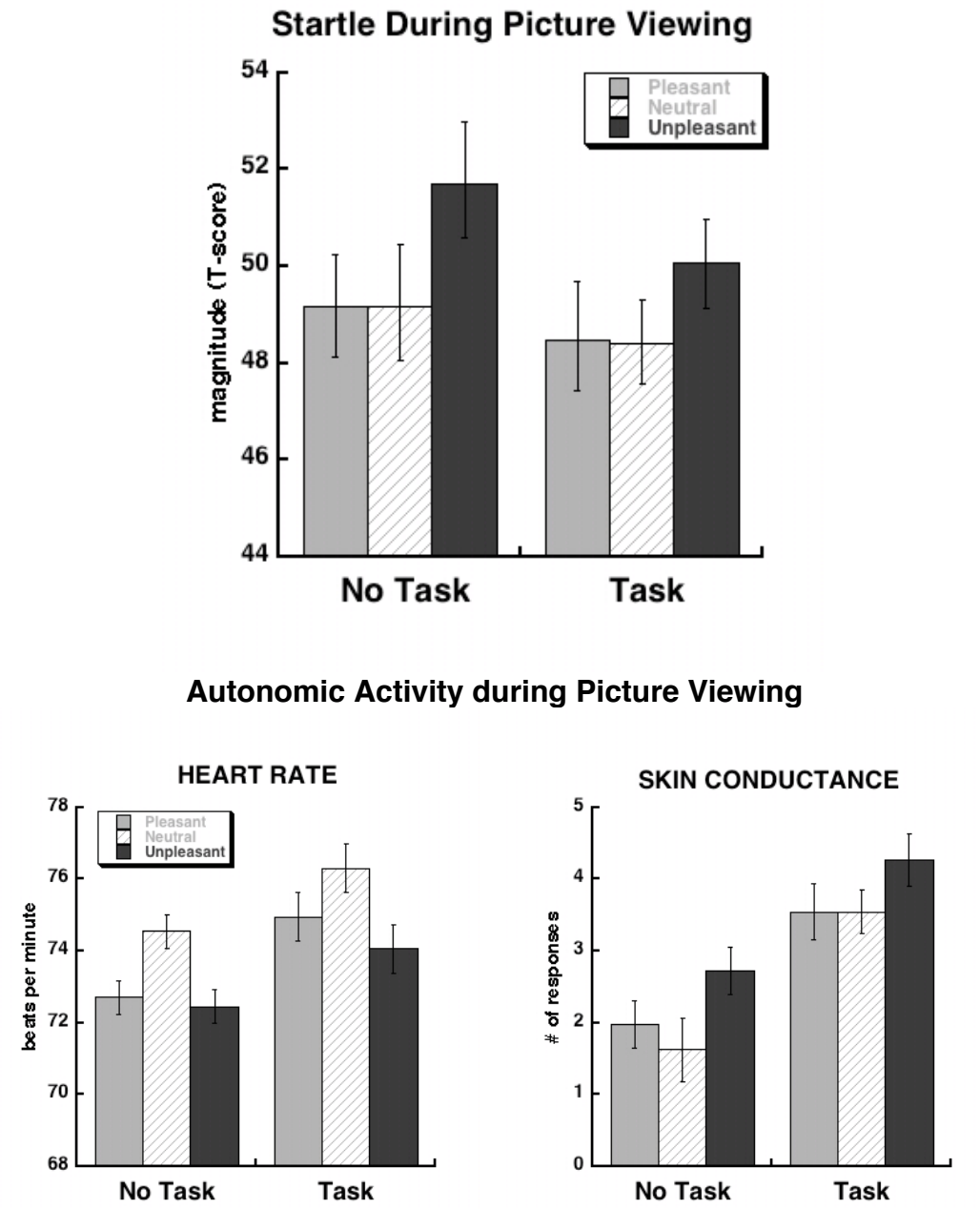


Figure 3-1. Experiment 2: Startle and autonomic measures. Startle magnitude (top), average heart rate (bottom left), and number of skin conductance responses (bottom right) elicited by pleasant, neutral, and unpleasant picture series during passive viewing and concurrent task performance. Error bars represent 95% confidence intervals.

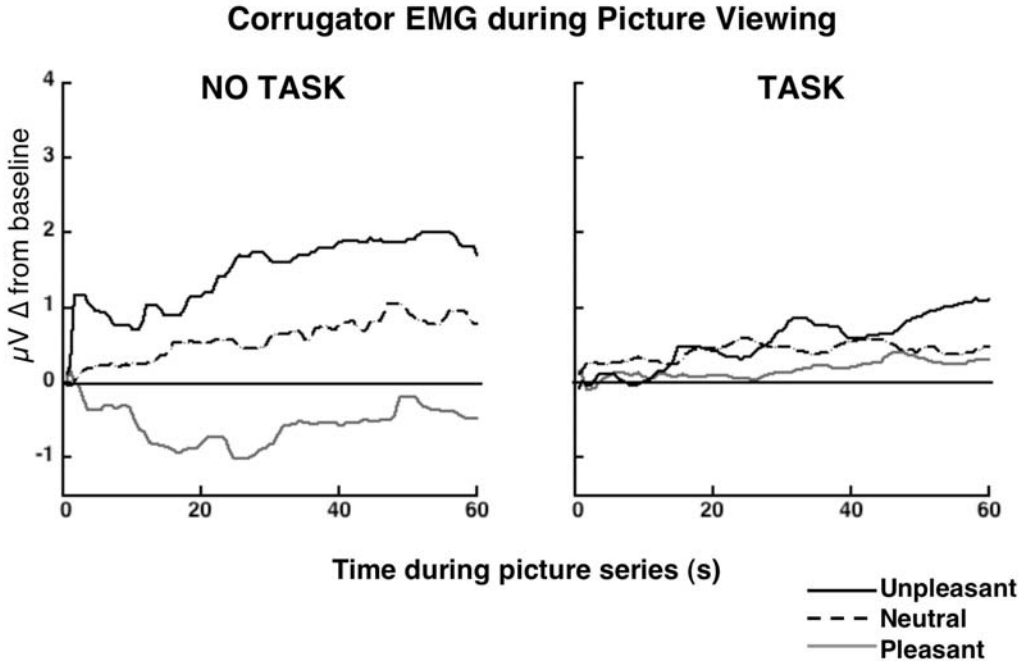


Figure 3-2. Experiment 2: Corrugator EMG. Waveforms representing change in corrugator electromyographic activity (microvolts) relative to a 1 s baseline prior to the onset of each 60 s unpleasant, pleasant, and neutral picture series, while participants passively viewed the pictures, or performed a concurrent task.

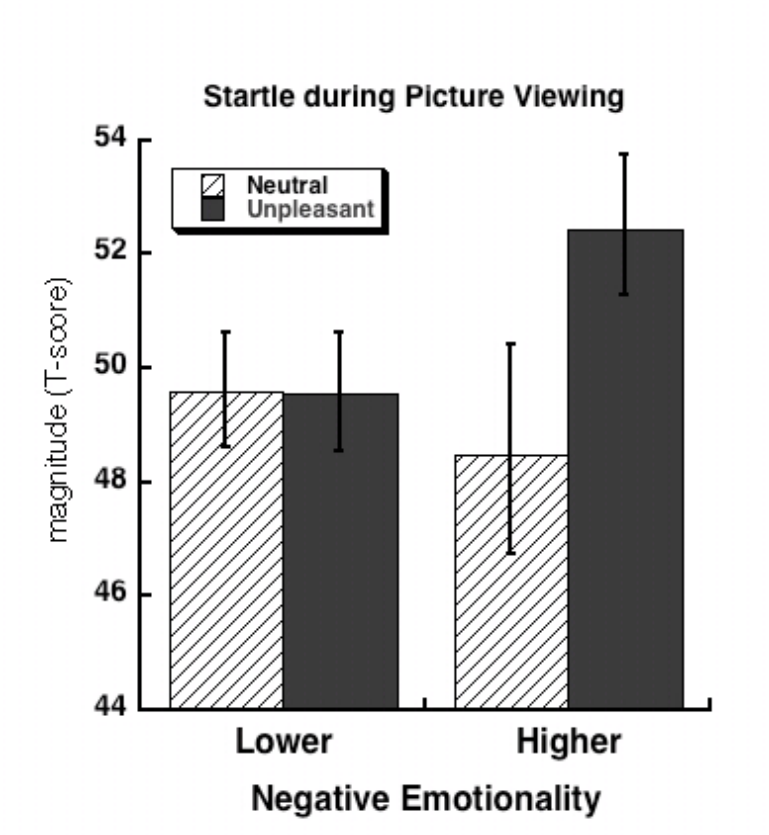


Figure 3-3. Individual differences in negative emotionality. Mean startle magnitude during exposure to series of neutral and unpleasant picture series, collapsed across passive viewing and task conditions, for those who score lower (n=20) and higher (n=20) in temperamental negative affect (Negative Emotionality), based on their responses on the MPQ-155 after the experiment.

Table 3-1. Experiment 2: Mean *(SD)* reactivity to unpleasant, neutral, and pleasant pictures, during passive viewing and task performance.

Measure	No Task	Task
Startle magnitude (T-score)		
Unpleasant	51.7 *(6.08)*	50.1 *(3.59)*
Neutral	49.2 *(5.80)*	48.4 *(3.22)*
Pleasant	49.1 *(5.04)*	48.5 *(4.38)*
Skin conductance (# of responses)		
Unpleasant	1.98 *(2.85*	4.27 *(3.45)*
Neutral	1.63 *(2.40)*	3.62 *(3.05)*
Pleasant	2.73 *(3.52)*	3.55 *(3.17)*
Heart Rate (BPM)		
Unpleasant	72.5 *(9.81*)	74.1 *(9.43)*
Neutral	74.5 *(10.1)*	76.3 *(9.89)*
Pleasant	72.7 *(9.21)*	74.9 *(9.41)*
Corrugator EMG (μV)		
Unpleasant	1.41 *(2.81)*	0.53 *(2.47)*
Neutral	0.57 *(1.77)*	0.42 *(1.01)*
Pleasant	-0.5 *(2.85)*	0.16 *(1.79)*

Mean *(SD)* activity collapsed across each 60 s picture series, within each task condition. Values reflect startle reflex magnitude (T-score units: $\text{mean}_{\text{within-subject}}$ =50), electrodermal activity (number of skin conductance responses greater than 0.05 μS), average heart rate (beats per minute), and change in corrugator electromyographic activity relative to a baseline 1 s prior to each picture block.

CHAPTER 4
GENERAL DISCUSSION

Defensive Reactivity during Concurrent Task Performance

These experiments demonstrate that even when attentional resources are reduced by a concurrent task, unpleasant emotional content nevertheless prompts heightened autonomic and somatic reactivity. In conjunction with EEG and neuroimaging research (Erk, et al., 2006; Hajcak, et al., 2007; Lane, et al., 1999), these data lend support to the hypothesis that motivationally relevant cues capture attention and facilitate emotional responding.

Specifically, startle reflex magnitude was potentiated during unpleasant picture series, whether viewed passively or under conditions of distraction, and was further enhanced in individuals reporting higher temperamental negative affect. This finding highlights the fundamental role of the startle response in marking organisms' defensive motivational states, and is consistent with the wide body of research describing its common neural circuitry among animals and humans (see, Davis & Lang, 2003). From an evolutionary perspective, the fact that startle reflex potentiation persists despite distraction reflects an adaptive ability to detect potential threat and mobilize for defensive action, even when attention is focused elsewhere.

While heart rate and electrodermal activity increased overall during task performance, reflecting the greater metabolic load demanded by additional information processing (e.g., Kalamas, Gruber & Rypma, 1999; Veltman & Gaillard, 1998), defensive reactivity was still apparent despite this overall increase. Thus, these findings reflect additive effects of task demand and emotional content that are consistent with the important role of autonomic activation in both general attentional orienting and specific defensive motivational reactivity (Lang, Bradley, & Cuthbert, 1997).

In contrast, facial frowning elicited by unpleasant content was eliminated during task performance. Under voluntary control compared to autonomic reactivity, facial expressivity may reflect a response to the primary task to which attention is directed--in this case, the number stimuli. Post-hoc analyses revealed that raw corrugator activity increased during task performance in Experiment 2[1], suggesting an increase in tension due to concentration on the foreground task, which may have masked effects of emotional content, in contrast to the additive effect shown in the autonomic measures. From an evolutionary perspective, as facial expressivity serves a social-communicative function, rather than directly facilitating attention or defensive mobilization (Tassinary & Cacioppo, 2000), it is likely to be more susceptible to attentional interference than cardiac and electrodermal reflexes.

When examining the above effects, it must be considered that the number tasks were not sufficiently difficult and that defensive activity could be reduced by greater task demands. Accuracy rates were over 80% during the Difficult n-back condition; thus, the task may have only partially consumed attentional resources, leaving sufficient a sufficient amount "left over" to process emotional stimuli (Lavie, 1997; 1995). Indeed, Schupp et al. (2007) and Erthal et al. (2005) reported that interference by very difficult (e.g., 60% accuracy) tasks limited attentional resources to the point at which emotional modulation of ERPs and reaction times, respectively, were eliminated. Future investigations assessing autonomic and somatic reactivity should systematically increase the attentional load demanded by the foreground task, (i.e. by varying the "size" of the n-back component in the present design).

[1] Corrugator EMG, uncorrected for pre-picture baseline activity, was averaged across valence within each task condition, and Friedman's tests were conducted to account for the non-normal distribution of raw EMG values. Corrugator activity was significantly greater overall, during task performance, compared to passive viewing, in Experiment 2 ($\chi^2[1,51]=7.08$, $p=0.008$). This effect was not significant in Experiment 1 ($\chi^2[2,32]=0.813$, $p=0.67$).

Sustained Emotional Processing

Analyses of sustained emotional processing effects revealed that corrugator activity prompted by passively viewed unpleasant content increased as additional unpleasant pictures were presented in the series. Furthermore, this activity persisted *after* picture offset in the first experiment, supporting previous studies' findings that prolonged unpleasant exposure leads to sensitization and a sustained unpleasant affective state (Bradley et al., 1996; Smith et al., 2005). Our results were not completely congruent with these data, however, since no sustained effects of defensive response mobilization (startle magnitude, skin conductance responses) were observed, whereas previous investigations reported maintenance of this activity.

Individual Differences in Negative Emotionality

Finally, our analyses of individual differences revealed that, compared to those reporting lower negative emotionality, individuals endorsing a greater predisposition to negative affect exhibited greater startle reflex potentiation during unpleasant pictures, across passive viewing and task conditions. This group difference may reflect the presence of a greater negative emotional state ("mood") in those reporting a predisposition to such reactivity. Unlike autonomic measures that are activated by both task engagement and affective arousal, the startle reflex may be a more sensitive measure of individual differences, given its primary role in defensive activation. Thus, these results add to existing evidence that individual differences in affective state are detected during prolonged emotional processing (Smith et al., 2005), and again highlight the role of startle potentiation in marking states of defensive mobilization. In light of research suggesting differences in affective physiology between anxiety disorder groups (Lang, McTeague, & Cuthbert, 2006), it is possible that such effects may relate to differential processing of aversive cues. Thus, the current paradigm could be implemented in future clinical

investigations directly examining differences in defensive reactivity and attentional engagement across the anxiety disorder spectrum.

Conclusion

In sum, despite ongoing attentional interference, unpleasant emotional content elicits startle potentiation, decreased heart rate, and increased electrodermal activity consistent with states of defensive motivation, supporting the hypothesis that humans' attentional systems are primed to detect, process, and mobilize responses to motivationally relevant cues. The research presented here supports the view that motivated attention is an automatic process, and suggests that further investigations should more closely examine how individual differences in such attention allocation may relate to clinical anxiety disorders.

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BIOGRAPHICAL SKETCH

My interests in anxiety disorders and the neurophysiology of emotion began during my undergraduate study at the University of North Carolina at Chapel Hill. As a research assistant in an anxiety laboratory, I aided with a project examining video-feedback as a clinical tool in the behavioral treatment of social phobia. My interests in biopsychology and neuroscience continued to develop throughout my coursework, leading me to initiate independent work on a neuroimaging project investigating the relationship between facial emotion perception and fusiform gyrus volume in first-episode schizophrenia, which I adopted as my undergraduate honors thesis. This unique, collaborative experience across the fields of clinical psychology, psychiatry, and neuroscience directed my interests toward the field of emotion neuroscience. After matriculating with highest honors in psychology, this led me to pursue post-baccalaureate training at the NIMH Center for the Study of Emotion and Attention, where I assisted with and conducted psychophysiological and EEG projects that further developed my skills in experimental methods. Since transitioning to a graduate student role in the clinical and health psychology doctoral program, I have become integrally involved in the translational research mission of the NIMH-CSEA, and have had the opportunity to present sections of this thesis at college-wide and professional conferences. While my research interests surrounding emotion, anxiety, and neurophysiology are broad, I continually seek to inform the assessment and treatment of clinical anxiety through basic science investigation.