Emotion–attention interactions in fear conditioning: Moderation by executive load, neuroticism, and awareness

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Despite increasing evidence suggesting interactive effects of emotion and attention on perceptual processing, it still remains unclear how their interplay influences affective learning, such as fear conditioning. In the present study, a conditioning procedure using threat-related conditioned stimuli (CSs) was implemented while executive load and attentional focus were manipulated. The modulation effects of neuroticism and contingency awareness were also examined. Results showed that fear conditioning depended on the available executive resources even with threat-related CSs. In addition, although individuals with high neuroticism showed an enhanced conditioning effect overall, this facilitation effect still depended on the availability of executive resources. Finally, the impact of attentional focus was most evident among individuals with high neuroticism who were aware of the contingency. Overall, the present study demonstrates interactive effects of emotion and attention in fear conditioning, while illuminating mechanisms of individual differences and clarifying the controversial role of contingency awareness in fear conditioning.

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1. Introduction

The emotional properties of stimuli, along with internal attentional processes, influence the way we perceive and remember things. Emotional content is often prioritized in perceptual and mnemonic processes (Anderson & Phelps, 2001; Dolan, 2002; Dolcos, Denkova, & Dolcos, 2012; Tabert et al., 2001), but its processing is also susceptible to cognitive influences, such as attention (Lim, Padmala, & Pessoa, 2008; Pessoa, Padmala, & Morland, 2005). Despite increasing evidence pointing to the reciprocal and interactive effects of emotion and attention on cognitive processing, it is still unclear how their interplay influences affective learning, such as fear conditioning. Given the importance of fear conditioning for a wide range of life outcomes, including the development of mental disorders, clarification of the mechanisms involved in fear conditioning is critical. The present study investigated how emotion–attention interactions influence fear conditioning, while taking into consideration individual differences in neuroticism and the awareness of the association between conditioned (CS) and unconditioned (US) stimuli (contingency awareness).

An important question in the recent emotion–cognition literature is whether attentional resources are required for processing emotional information (Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Vuilleumier, Armony, Driver, & Dolan, 2001). The “traditional view” (Vuilleumier et al., 2001) proposes that processing of emotional, especially threatening, information is prioritized through bottom-up mechanisms (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003) and occurs automatically, unaffected by the availability of attentional resources (Morris, Öhman, & Dolan, 1999). In contrast, the “competing view” (Pessoa et al., 2002) proposes that emotional stimuli compete for neural representation with all other stimuli, and hence processing emotional information requires top-down attention. These two opposing views were recently reconciled in studies (Lim et al., 2008; Pessoa et al., 2005; Shafer et al., 2012) demonstrating that the processing of emotional information is both prioritized and susceptible to attentional modulation. For example, using a dual task with emotional distraction, Shafer et al. (2012) showed that emotional stimuli elicited slower responses irrespective of the manipulation of processing demands, and that the impact of emotion on task performance was largest when most attentional resources were available.

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Although these studies (Lim et al., 2008; Pessoa et al., 2005; Shafer et al., 2012) clarified how interactions between stimulus-driven/bottom-up and goal-directed/top-down attention may influence the processing of emotional information, their joint influence on affective learning, particularly in fear conditioning, is still unclear. Previous investigations showed that manipulations of executive demands can influence fear conditioning, such that high executive load can prevent conditioning from occurring (Carrillo, Gabrieli, & Disterhoff, 2000; Carter, Høftøtter, Tsujiya, & Koch, 2003). Although this suggests that the availability of attentional resources influences fear conditioning, at least when intrinsically neutral CSs are used, it is not clear whether this is also the case when the CSs have intrinsic emotional value. Given their evolutionary value, emotional stimuli could facilitate conditioning independently of top-down attentional demands, by superior engagement of bottom-up processing.

Another aspect of top-down attention that can influence fear conditioning is the focus of attention, i.e., whether attention is explicitly oriented to the CS or not (Anderson et al., 2003; Pessoa et al., 2005; Vuilleumier et al., 2001). Studies have shown that amygdala activation for fear-relevant stimuli is modulated not only by attentional resources but also by the focus of attention (Pessoa et al., 2005). While executive load is associated with available attentional resources, attentional focus relates to selecting representations that are relevant to the goal of the current task, at the entry level of information processing (Bradley, 2009; Knudsen, 2007). Findings are mixed regarding the processing of task-irrelevant emotional stimuli outside the focus of attention. Certain studies have identified attenuated responses to emotional stimuli when they were irrelevant for the ongoing task (i.e., outside the focus of attention) (Van Dillen, Lakens, & Van Den Bos, 2011; Zhou & Liu, 2013), whereas others have found no such modulation (Vuilleumier et al., 2001). Despite the importance of attentional focus in emotional processing (Pessoa et al., 2005) and its implication for the automaticity of fear conditioning with fear-relevant CSs, the impact of attentional focus on fear conditioning has not been investigated. Thus, the first goal of this study was to clarify whether fear conditioning with threat-related CSs is largely automatic (given its evolutionary value), or is influenced by different aspects of top-down attention, such as executive load and attentional focus.

Personality traits, such as neuroticism, may further influence fear conditioning by affecting the overall dynamics of emotion–attention interactions (Hur et al., 2015). For instance, in the emotional Stroop task, individuals with high neuroticism show longer response times to naming the color of threat compared to neutral words, suggesting that their attention is biased towards threat-related information (Canli, 2008; Fox, Russo, Bowles, & Dutton, 2001). This idea is also supported by brain imaging evidence showing that among individuals with high neuroticism, there is an altered balance of activity within the amygdala–prefrontal circuitry consistent with a bias toward threat-related responses (Cremers et al., 2010; Haas, Oumura, Constable, & Canli, 2007). Given that activity in amygdala–prefrontal circuitry is thought to be critically involved in fear conditioning (Sotres-Bayon, Bush, & LeDoux, 2004), it is likely that fear conditioning is moderated by individual differences in neuroticism.

Although there are a number of studies showing that trait anxiety (a construct related to neuroticism) influences the magnitude of fear conditioning (Indovina, Robbins, Núñez-Elizalde, Dunn, & Bishop, 2011; Lee, Lim, Lee, Kim, & Choi, 2009), these studies did not investigate how such modulations may depend on top-down attention (e.g., executive load, attentional focus). Furthermore, although trait anxiety and neuroticism are related, they are hardly identical; compared to trait anxiety, neuroticism is a broader construct that refers to a disposition to experience unpleasant affective states, including but not limited to anxiety (Luteijn & Bouman, 1988). It is often conceptualized as ‘emotional instability’ (Meites, Lovallo, & Pishkin, 1980), ‘vulnerability’ (Hassanyeh, Eccleston, & Davison, 1981), and ‘negative emotionality’ (Watson & Clark, 1984) and is considered a risk factor for a broader range of psychopathology (Muris, de Jong, & Engelen, 2004; Ormel, Rosmalen, & Farmer, 2004; Tackett et al., 2013). Thus, investigating the impact of neuroticism on fear conditioning has its own merits. Importantly, attention bias literature suggests that individuals with high trait neuroticism are driven to negative information (e.g., threat), even when their attention is directed away from it (Canli, 2008; Derryberry & Reed, 1994). Thus, it is possible that individuals with high neuroticism may show an enhanced conditioning effect even when their attention is distracted away from the fear-relevant CS. Hence, the second goal of this study was to clarify the influence of neuroticism on fear conditioning, by looking at its interaction with different aspects of top-down attentional processing (e.g., executive load and attentional bias).

Another critical factor that needs to be considered in the context of fear conditioning is the participant’s awareness of the CS–US association (i.e., contingency awareness). Previous investigations yielded mixed results regarding the role of contingency awareness in fear conditioning (Lovibond, 1992). Although certain evidence suggests that contingency awareness may be necessary for fear conditioning to occur (Hamm & Vaitl, 1996), other studies have shown that conditioning can be achieved independently of contingency awareness, provided that the CSs are fear-relevant (Morris, Öhman, & Dolan, 1998; Öhman & Soares, 1998). A potential explanation for the discrepant results may be the inability to separate the contribution of contingency awareness from the attentional engagement to the CSs. Although there is evidence in support of such dissociations (Bechara et al., 1995; Knight, Waters, & Bandettini, 2009), evidence regarding their possible interactive effects on fear conditioning (Foa & Kozak, 1986) is lacking. Hence, the third goal of this study was to clarify the interactive effect of contingency awareness and attentional focus on fear conditioning, while taking individual differences into consideration.

The present study addressed these issues by using classical conditioning with threat-relevant stimuli (pictures of snakes and spiders) embedded in an N-back working memory (WM) task, in conjunction with skin conductance response (SCR) recordings. Based on the extant literature, we made the following predictions. Regarding the influence of attentional resources availability on conditioning with fear-relevant CSs, we made the following conditional predictions. If conditioning with fear-relevant CSs is independent of the availability of attentional resources (Öhman & Soares, 1998; Soares & Öhman, 1993), then we expected that conditioning effects would occur regardless of the concurrent executive load. If, on the other hand, conditioning with fear-relevant CSs depends on the availability of attentional resources (Carrillo et al., 2000; Carter et al., 2003), then we expected that fear conditioning would occur under low but not under high executive load. Similarly, we made the following conditional predictions regarding the influence of attentional focus on conditioning with fear-relevant CSs. If conditioning with fear-relevant CSs is independent of attentional orienting to the CS, then we expected that conditioning effects would occur regardless of the attentional focus. If, on the other hand, conditioning with fear-relevant CSs requires attentional orienting to the CS, then we expected that fear conditioning would occur only when attention was devoted to the CS but not when attention was distracted away from the CS. Next, based on previous evidence regarding the link between high neuroticism and a bias toward threat-related responses (Canli, 2008), we expected that individuals with high neuroticism would show an overall enhanced conditioning effect, which would be evident...
even when their attention is distracted away from the CS. Finally, based on evidence pointing to a dissociable and possibly interactive role of contingency awareness and attention orienting, along with the individual differences in attentional orienting to threat-related CSs, we expected that the impact of attentional orienting would be most evident among individuals with high levels of neuroticism who are also aware of the contingency.

2. Methods

2.1. Participants

Ninety-seven university students (53.6% female), between ages of 18 and 24 ($M = 20.0$, $SD = 1.4$) and having normal or corrected-to-normal vision, including normal color vision, participated in the study. All participants provided informed consent and received partial credit toward a research participation requirement in exchange for their participation.

2.2. Questionnaire

The Negative Temperament subscale of the General Temperament Survey (GTS) (Watson & Clark, 1993) was used to assess neuroticism. Participants were instructed to decide whether statements mostly described them and to rate each item as true/false. The Negative Temperament subscale includes 28 items such as “I sometimes get all worked up as I think about things that happened during the day”. Prior research attests to the reliability and validity of this measure (Watson & Clark, 1993). Internal consistency in our sample was good ($\alpha = 0.83$).

2.3. Apparatus, stimuli, and design

Mild electric shocks (US) were controlled by an electrical stimulator (Biopac Systems, Inc., Goleta, CA) and delivered via two Ag/AgCl disposable snap electrodes pre-gelled with isotonic electrolyte and attached to the inside wrist of the non-dominant hand. Stimulus delivery and physiological data acquisition were controlled by two computers using E-Prime (Psychology Software Tools, Inc., Pittsburgh, PA) and AcqKnowledge software (Biopac Systems, Inc., Goleta, CA). Physiological channels were recorded using the Biopac MP150 system at a sample rate of 250 Hz (i.e., 250 sampling/second). Skin conductance (SC) measures were recorded using two 11-mm inner diameter Ag/AgCl disposable snap electrodes pre-gelled with isotonic electrolyte. Two electrodes were placed in parallel on the middle phalanx of the index and middle fingers of the non-dominant hand.

The design of the experiment involved differential conditioning with one fear-relevant stimulus (the conditioned stimulus, CS+) that was followed by the shock (US), whereas another fear-relevant stimulus (the CS−) was never followed by a shock. Three different stimulus categories were used including pictures of spiders, snakes, and mushrooms. Pictures were selected from the International Affective Picture Rating System (Lang, Bradley, & Cuthbert, 1999). Four different pictures were selected from IAPS for each of the two fear-relevant stimulus categories (i.e., spiders, snakes) that served as CS+ and CS−, respectively. By using fear-relevant stimuli as both CS+ and CS−, salience and significance of the stimuli, as well as physical properties of the stimuli (e.g. complexity), were controlled; CS+ and CS− did not differ in their SAM valence ($t(6) = 0.57$, $p > 0.5$) or arousal ratings ($t(6) = 1.05$, $p > 0.3$). More details are provided in Appendix A. Five different pictures were selected from IAPS for the other category using fear-irrelevant stimuli (i.e., mushrooms), to serve as the neutral control stimulus (N−). The stimulus category (i.e., spiders, snakes) that served as CS+ and CS− was counterbalanced across participants in each conditioning task. Each picture was presented 8 times during the task, while randomly colored in yellow or blue hue for an even ratio. Luminance values of the tinted pictures were not significantly different across stimulus categories [$F(2,6) = 0.49$, $p > 0.6$].

2.4. Experimental procedures

The participants were tested individually. First, they were told that their physiological responses would be measured while performing a cognitive task, and that there would be a mild level of electrical stimulation occasionally through the two sensors connected to their wrist. Participants were instructed to ignore the electrical shock and focus on the task. After the consenting procedure, the electrode sites were washed with distilled water before the electrodes were attached. The experimenter then adjusted the intensity of the electrical stimulation to establish a level that the participant described as “uncomfortable but not painful”. After the set-up was completed, both verbal and screen instructions for the task were provided, and a short practice task (during which there was no physiological recording or electric stimulation) was administered.

The conditioning task commenced with a 10 s fixation for stabilization and was followed by 104 trials. Each trial consisted of a target presented for 1500 milliseconds, followed by a fixation cross for 10 s (i.e., inter-trial interval). As a target, fear-relevant pictures (i.e., spiders, snakes) and fear irrelevant pictures (i.e., mushrooms) were presented in a pseudo-randomized order and randomly colored in yellow or blue hues. The conditioning task consisted of the following three phases: habituation (one block), acquisition (three blocks), and extinction (four blocks). Each block consisted of 13 trials and contained four presentations of CS+, four presentations of CS−, and five presentations of N−. Within each block, CS+ and CS− order was quasi-randomized such that the same stimulus category type (i.e., spiders, snakes, mushrooms) or color type (i.e., yellow, blue) was never presented on more than two consecutive trials. During acquisition, each CS+ was followed by a 200 ms US immediately after stimulus offset. No electrical stimulation (US) was provided during the habituation and extinction phases.

Participants completed one of the four different tasks in which executive load and attentional focus were systematically manipulated during all three phases of the conditioning experiment (i.e., habituation, acquisition, and extinction). Attentional focus was manipulated by changing the instruction to indicate the color of the picture (i.e., blue or yellow) vs. the content of the picture (i.e., animal or non-animal). Executive load was manipulated by varying the task difficulty (i.e., 0-back vs. 2-back task). In the 0-back task, participants had to indicate either the color or the content of the current trial. In a 2-back task, participants had to indicate whether the color (or content) of the picture in the present trial was the same as the one presented two trials before (see Fig. 1). Responses were made by pressing left or right arrow buttons. The following four conditions were administered: (1) CONTENT 0-back, (2) COLOR 0-back, (3) CONTENT 2-back, and (4) COLOR 2-back. Participants were randomly assigned to one of the four conditions. In every condition, participants were asked to respond as quickly and accurately as possible. Table 1 illustrates the specific instructions provided for each condition.

Right after the fear conditioning experiment, contingency awareness was measured by asking participants whether they were able to predict the electrical stimulation with one category of pictures (Snakes, Spiders, or Mushrooms) and, if so, whether they correctly identified the picture category that was paired with mild electrical stimulation.
Fig. 1. Task Design. The conditioning procedure was implemented during four different cognitive task conditions, in which Executive Load (i.e., 0-back vs. 2-back) and Attentional Focus (i.e., content vs. color) were systematically manipulated. In each condition, one of the two fear-relevant stimulus categories (i.e., spiders or snakes) was used as CS+ and CS− respectively (counterbalanced). Fear-irrelevant stimulus category (i.e., mushrooms) was used as the N−.

Table 1
Instructions for the four experimental conditions.

<table>
<thead>
<tr>
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<th>Attention is on CONTENT</th>
<th>Attention is on COLOR</th>
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<tbody>
<tr>
<td>Low executive load (0-back)</td>
<td>CONTENT 0-back task: Indicate the CONTENT of the current picture [i.e., Animal or Non-animal], while ignoring the color.</td>
<td>COLOR 0-back task: Indicate the COLOR of the current picture [i.e., yellow or blue], while ignoring the content.</td>
</tr>
<tr>
<td>High executive load (2-back)</td>
<td>CONTENT 2-back task: Indicate whether the current CONTENT is the same as the one presented 2-trials back (i.e., same or different), while ignoring the color.</td>
<td>COLOR 2-back task: Indicate whether the current COLOR is the same as the one presented 2-trials back (i.e., same or different), while ignoring the content.</td>
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2.5. Data reduction and statistical analysis

2.5.1. Skin conductance response analyses

Skin conductance responses (SCRs) were calculated by subtracting the mean baseline level (2 s before stimulus onset) from the maximum SC level recorded within a 1–4 s latency window following the onset of each stimulus (Öhman & Soares, 1998; Prokasy & Kumpfer, 1973; Vansteenwegen, Crombez, Baeyens, & Eelen, 1998). Before statistical analyses, the SCR data underwent a range correction (i.e., dividing the SCR by the subject's range in tonic level) (Lykken, 1972) to reduce variation not related to psychological processes (Öhman & Soares, 1998; Yates, Aswhin, & Fox, 2010). This procedure significantly enhanced the normality of the data distribution and resulted in normality measures (skewness and kurtosis) adequate for common psychometric purposes as presented in Appendix D. We tested whether subsequent transformation (either square-root or log transformation) gave us a better psychometrics, but it did not. Thus, no further transformations to the data were applied.

2.5.2. Statistical analyses

To investigate modulation effects of different factors (Executive Load, Attentional Focus, Neuroticism and Contingency Awareness) on conditioning, SCR data were evaluated by full-factorial analyses of variance (ANOVAs). Although the experiment included three different types of stimuli (CS+, CS−, and N−), based on a priori hypotheses, a planned contrast for CS type (i.e., CS+ vs. CS−) was conducted throughout the analysis to assess conditioning effects—i.e., the differences between mean responding to CS+ and CS−. Separate analyses were conducted for: (1) SCR before US was introduced (during habituation phase) and (2) SCRs after US was removed (during extinction phase). Since a 100% reinforcement schedule was used for acquisition (during which US was paired with CS+), the CS+ vs. CS− comparison during acquisition phase is not considered here. Responses to CS type (CS+, CS−) were averaged for each block of the experimental phase.

For the habituation phase, a 2 (CS type: CS+ vs. CS−) × 2 (Executive Load: 0-back vs. 2-back) × 2 (Attentional Focus: CONTENT vs. COLOR) × Neuroticism ANOVA was conducted to test whether there were any differences in SCR to the CS+ and the CS− or modulation effects by the manipulated factors prior to acquisition phase (during which US was introduced). CS type was entered as a within-subject variable. Executive Load and Attentional Focus were dichotomous variables entered as between-subject variables. Neuroticism was a continuous variable entered as a covariate, which allowed us to study its interactive effects with other variables without removing its variance (Miller & Chapman, 2001). For the extinction phase, the analyses included an additional within-subject factor (i.e., Block), since this phase consisted of more than one block. An awareness factor was also included in this analysis since awareness is one of the outcomes from the learning phase (i.e., acquisition) and can influence extinction phase activities. Hence, a 2 (CS type: CS+ vs. CS−) × 4 (Block: b1 vs. b2 vs. b3 vs. b4) × 2 (Load: 0-back vs. 2-back) × 2 (Attentional Focus: CONTENT vs. COLOR) × 2 (Awareness: Aware vs. Unaware) × Neuroticism ANOVA was conducted to investigate main effects and interactions between the experimental factors during this phase. If the sphericity assumption was violated, a Greenhouse–Geisser correction was used to adjust for it. An alpha level of 0.05 was used to determine statistical significance.

3. Results

3.1. Sample characteristics

Neuroticism scores showed a wide range (0–23), and skewness ($= 0.09$) was adequate for common psychometric purposes. Neither participants' neuroticism scores [$F(3.90) = 0.31, p > 0.8$] nor gender ratio [$F(3.93) = 0.73, p > 0.5$] differed across conditions. Given that neuroticism was a continuous variable and participants were not selected based on its scores, we used correlations to follow-up on significant effects involving neuroticism in the main ANOVA. Percent (%) Awareness in each condition, descriptive statistics, and
3.2. Skin conductance response analyses

Analysis of SCR during the habituation phase confirmed the equivalence of CS+ and CS− [F(1,86) = 0.02, p > 0.8] and no influence of the targeted factors (i.e., Executive Load, Attentional Focus, and Neuroticism) prior to the acquisition phase. Analysis of SCR during the extinction phase showed a phasic decrease in SCRs and a trend for a conditioning effect. A main effect of block was found [F(3234) = 7.59, p < 0.001] and post-hoc tests revealed a significant SCR decrease from block 1 to 2 [F(1.78) = 11.38, p < 0.001] and from block 2 to 3 [F(1.78) = 4.24, p = 0.043]. The block factor did not interact with the other independent variables. A trend for a conditioning effect, that is, the increased SCRs for CS+ compared to CS−, was identified [F(1,78) = 3.16, p = 0.074], suggesting interacting effects between the experimental conditions. Results of analyses considering the targeted factors are detailed in turn below. For simplicity, in the sections below any factors that interacted with ‘CS type’ will be described as a moderator of the conditioning effect (CS+ minus CS−), even though the ANOVAs included CS type (CS+, CS−) as a factor. Descriptive statistics for SCRs are reported in Appendix C.

3.2.1. Fear conditioning effect only apparent under low executive load

Executive Load influenced the conditioning effect [F(1,78) = 4.30, p = 0.041]. As shown in Fig. 2, a difference in SCR (CS+ vs. CS−) was observed under low executive load [t(48) = 1.99, p = 0.052], but no such effect was observed under high executive load [t(47) = 1.52, p = 0.136]. This suggests that cognitive resource availability influences the conditioning effect, even when intrinsically emotional stimuli are employed. On the other hand, Attentional Focus did not influence fear conditioning by itself [F(1,78) = 2.23, p = 0.139] or did it interact with Executive Load [F(1,78) = 2.97, p = 0.089]. As presented below, however, there was evidence of Attentional Focus interacting with Contingency Awareness and Neuroticism to influence fear conditioning.

3.2.2. Increased conditioning effect linked to high neuroticism

Consistent with our prediction, Neuroticism modulated the conditioning effect [F(1,78) = 6.03, p = 0.016]; higher neuroticism scores were associated with greater conditioning effects [r = 0.25, p = 0.014]

Furthermore, the effect of Neuroticism was moderated by Executive Load [F(1,78) = 5.12, p = 0.026]. Neuroticism was associated with an increased conditioning effect under low executive load [r = 0.43, p = 0.003], but not under high executive load [r = −0.02, p > 0.8]; the associations between neuroticism and conditioning effects are illustrated in Fig. 3. The nature of this interaction is illustrated further in the panels on the right side of Fig. 3 (in which neuroticism is treated dichotomously: low vs. high, based on a median split). As can be seen in Fig. 3, the impact of executive load was evident only among individuals with elevated levels of neuroticism.

3.2.3. Interactive effects of attentional focus, contingency awareness, and neuroticism on conditioning

Consistent with our prediction, there was a significant interaction between Attentional Focus and Contingency Awareness [F(1,78) = 4.11, p = 0.046]. Furthermore, a significant Attentional Focus × Contingency Awareness × Neuroticism interaction was identified [F(1,78) = 4.10, p = 0.047]. Separate analyses conducted within each of the four conditions (i.e., COLOR-Aware, COLOR-Unaware, CONTENT-Aware, CONTENT-Unaware) showed a significant effect of neuroticism on conditioning only when participants were answering to the color of the pictures and were also aware of the contingency (COLOR-Aware condition) [F(1,17) = 6.24, p = 0.03]. Neuroticism was associated with an increased conditioning effect only in the COLOR-Aware condition [r = 0.52, p = 0.023]. Neuroticism was not associated with an increased conditioning effect in any of the other conditions (i.e., CONTENT-Aware, CONTENT-Unaware, COLOR-Unaware); the associations between neuroticism and conditioning effects, presented separately for each of the four conditions, are illustrated in Fig. 4. The nature of the three-way interaction is illustrated further in the panels on the right side of Fig. 4 (in which neuroticism is treated dichotomously: low vs. high, based on a median split). As can be seen in Fig. 4, the impact of attentional focus (CONTENT vs. COLOR) was most evident among individuals with high levels of neuroticism who were also aware of the contingency.

4. Discussion

This study yielded three main findings, which are discussed in turn below.

4.1. Fear conditioning effect only apparent under low executive load

The present study demonstrates that fear conditioning with emotional CSs is modulated by the availability of executive processing resources. These results are consistent with previous behavioral and brain imaging evidence showing diminished impact of emotion under high attentional load (Pessoa et al., 2005; Shafar et al., 2012) and with conditioning studies showing reduced conditioning effects for intrinsically neutral CSs under high executive load (Carrillo et al., 2000; Carter et al., 2003). The present results suggest that, separate from the influence of bottom-up/stimulus-driven processing of threat-related CSs, top-down/executive attention independently influences fear conditioning. Consistent with these findings, fMRI studies demonstrated a critical role of the prefrontal cortex in fear conditioning (Rosenkranz, Moore, & Grace, 2003). It is also possible that executive control attention is required to process and create cognitive representations of the event in the memory system (Carrillo et al., 2000).

4.2. Increased conditioning effect linked to high neuroticism

The present results show that, although neuroticism facilitates fear conditioning, possibly via bottom-up/stimulus-driven attention biases, it is still influenced by the availability of executive
processing resources. Consistent with previous findings (Eysenck, 1979), individuals with high neuroticism showed stronger conditioning effects than those with low neuroticism. Attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007) and recent brain imaging evidence suggest a link between trait anxiety and both increased amygdala response and decreased ventral prefrontal cortex response to phasic fear cues (Indovina et al., 2011). Given that activity in the amygdala-prefrontal circuitry is thought to be critically involved in fear conditioning (Sotres-Bayon et al., 2004), it is conceivable that high neuroticism might facilitate fear conditioning through automatic attention biases towards threat-related information.

It is important to note, however, that consistent with recent findings that attentional bias to negative stimuli is limited to situations when the executive load is low (Bishop, Jenkins, & Lawrence, 2007; Fox, Yates, & Ashwin, 2012), the influence of neuroticism on fear conditioning was observed only under low executive load, thus demonstrating that the impact of neuroticism depends on the availability of executive processing resources.

4.3. Interactive effects of attentional focus, contingency awareness, and neuroticism on conditioning

In contrast to executive load, which had a noticeable impact on conditioning independent of all other variables, the impact of attentional focus was dependent on neuroticism and contingency awareness. Specifically, individuals with high neuroticism showed an enhanced conditioning effect even when their attention was distracted away from the CS, as long as they were aware of the CS–US contingency. The present finding not only supports the interpretation that neuroticism facilitates fear conditioning, possibly via bottom-up/stimulus-driven attention biases, but also clarify previous mixed findings regarding the role of contingency awareness in fear conditioning (Lovibond, 1992).

A potential explanation for these findings may be related to the differential influence of distinct components of top-down attention on emotion processing (Lavie, Hirst, de Fockert, & Viding, 2004; Petersen & Posner, 2012). Lavie et al. (2004) proposed a dissociable impact of perceptual versus executive load on task-irrelevant distractor processing, and suggested that these aspects of processing are involved in different stages of attention (early vs. late, respectively), linked to separate brain networks (Petersen & Posner, 2012). Similarly, attentional focus has to do with the early selection stage of information processing, closely related to the biased processing of goal-relevant information, whereas executive load is associated with a later stage of attention control (Knudsen, 2007). When attentional bias to task-irrelevant, salient information (e.g., fear-relevant stimuli) occurs, it is more likely to influence the early stage of information processing that is concerned with attentional focus, rather than executive control (Knudsen, 2007). Consistent with this evidence, the current finding shows that the facilitated conditioning effect by neuroticism was most evident when attention was distracted away from the CS. This suggests that neuroticism leads to enhanced fear conditioning potentially via biased attentional processing of emotional information.

The current finding is also consistent with previous studies proposing dissociable effects of attention and contingency awareness on associative learning (Field & Moore, 2005; Nissen...
Fig. 4. Interactive effect of Attentional Focus, Contingency Awareness, and Neuroticism (NT) on the Conditioning effect.
Left panels: The modulating effect of neuroticism on conditioning was only evident when participants were attending to the color of the pictures and were also aware of the contingency (COLOR-Aware condition). Y-axis = mean SCR for CS+ minus CS−; X-axis = NT scores. *p<0.05; **p<0.01.
Right panels: The effect of awareness was only evident when participants were attending to the color of the pictures and were high in neuroticism. Bars refer to 1 standard error of the mean.

& Bullemer, 1987), and with lesion studies identifying a double dissociation between the roles of amygdala and hippocampus in fear conditioning (Bechara et al., 1995). Bechara et al. results point to amygdala involvement in biasing attention toward fear cues, and to hippocampal involvement in the acquisition of contingency awareness, both of which are shown to have a critical role in fear conditioning. Although interactions between these mechanisms are expected in healthy individuals, our findings are consistent with a dissociation of their contributions and further suggest an interactive effect of attention and contingency awareness in fear conditioning. More specifically, our results suggest that biased orienting attention to the CS (augmented by neuroticism), combined with contingency awareness, leads to a facilitated conditioning effect. Such complex interactions of attention orienting, contingency awareness, and neuroticism explain the possible mechanisms by which individual differences in fear conditioning may occur.

5. Conclusion

The present findings demonstrate that fear conditioning is influenced by interactions between bottom-up and top-down processing, as well as by individual differences in neuroticism. First, fear conditioning was modulated by the availability of executive resources, even though potentially prioritized CSs were used. Second, although neuroticism promotes fear conditioning, its influence is still dependent on available executive processing resources. Finally, individuals with high neuroticism showed an enhanced conditioning effect even when their attention was distracted away from the CS, as long as they were aware of the CS-US contingency, thus clarifying the role of contingency awareness in conditioning and identifying a potential mechanism by which neuroticism facilitates fear conditioning. These findings have critical implications for understanding the development of psychological disorders that are linked to fear learning (e.g., panic disorder, PTSD), and for enhancing the clinical interventions for treating them.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biopsycho.2015.10.007.

References

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