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The dynamics of cardiac defense: From attention to action

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Abstract

The attentional and motivational significance of cardiac defense is examined in two studies. In Study 1, cardiac defense was evoked by an intense acoustic stimulus in the context of either a visual search or a memory search task using letters as stimuli. Results showed a potentiation of the long latency acceleration of cardiac defense in the visual search task. In Study 2, participants performed the same visual search task using pleasant, neutral, and unpleasant pictures as stimuli. Results showed a further potentiation of the long latency acceleration of cardiac defense when the visual search task was performed with unpleasant, compared to pleasant or neutral pictures. These results indicate that cardiac defense has both attentional and motivational contributions, where the attentional significance is related to increased sensory processing, whereas the motivational significance is associated with preparation for active defense.

Descriptors: Cardiac defense, Visual attention, Aversive motivation, Habituation

Two major psychophysiological approaches to cardiac defense can be identified: the cognitive and the motivational. The *cognitive approach*, built on Pavlov's (1927) and Sokolov's (1963) distinction between *orienting* and *defense* reflexes, assumes that cardiac responses to environmental stimuli reflect cognitive mechanisms aimed at facilitating or inhibiting stimulus processing (Graham, 1992; Graham & Clifton, 1966). The *motivational approach*, built on Cannon's (1929) and Selye's (1956) concepts of the *fight–flight* and the *stress* response, assumes that cardiac changes reflect metabolic mechanisms aimed at providing the body with the necessary energy for adaptive behaviors (Obrist, 1981). These two approaches have been difficult to reconcile in the past. From the cognitive perspective, the functional significance of cardiac defense was understood as an attentional mechanism contrary to cardiac *orienting*. From the motivational perspective, the functional significance of cardiac defense was understood as a response mobilization mechanism contrary to cardiac *relaxation*.

A different approach to cardiac defense has been proposed in recent years, based on a naturalistic perspective of defense derived largely from animal research (Blanchard & Blanchard, 1988; Bracha, 2004; Facchinetti, Imbiriba, Azevedo, Vargas, & Volchan, 2006; Fanselow, 1994; Lang, Bradley, & Cuthbert, 1997; Marx, Forsyth, Gallup, Fusé, & Lexington, 2008). The new approach views defense as a dynamic sequence or cascade of reactions, from *attentive freezing* to active defense (*flight* and *fight*), which takes place depending primarily on proximity of the source of danger and availability of an escape route. Lang and colleagues (see Lang et al., 1997; Lang, Davis, & Öhman, 2000) were the first to propose an adaptation of the animal cascade model of defense to explain human psychophysiological reactions to threatening stimuli. They suggested that the increase in arousal induced in the laboratory as stimuli become more aversive may be analogous to the increase in arousal induced in natural settings by increased proximity of a predator. Thus, the initial stages would be characterized by a progressive increase of physiological indices of attention, including increased heart-rate deceleration, but, as the arousal intensifies and the threat becomes more imminent, the heart rate reverses the direction of change "*from a vigilance related fear bradycardia to action mobilization and cardiac acceleration*" (Lang et al., 2000, p. 150).

A similar approach to cardiac defense was proposed by Vila and colleagues after a series of studies on attentional modulation of the heart rate response to intense auditory stimulation (Fernández & Vila, 1989; Pérez, Fernández, Vila, & Turpin 2000; Vila, Pérez, Fernández, Pegalajar, & Sánchez, 1997). Previous research (Eves & Gruzelier, 1984; Turpin & Siddle, 1978; Vila, Fernández, & Godoy, 1992) had repeatedly demonstrated a

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complex pattern of heart rate response to an unexpected intense noise that comprises two accelerative/decelerative components in alternating order. The attentional modulation of this response pattern was investigated by Vila and colleagues by manipulating the direction of attention (external versus internal) in line with the intake-rejection hypothesis (Lacey & Lacey, 1974). Results revealed a positive relationship between cardiac defense and attentional processes of sensory intake. No relation with attentional processes of sensory rejection was found. Based on these findings, it was proposed (Vila et al., 1997; Vila, Guerra, Muñoz, Vico, Viedma-del Jesús, et al., 2007) that the pattern of heart rate changes in response to unexpected intense aversive stimuli reflects the succession of two defensive phases: an attentional protective phase linked to the short latency acceleration/deceleration and a motivational protective phase linked to the long latency acceleration/deceleration.

This interpretation of cardiac defense is contrary to the classic cognitive model of defense ('shut down sensory processing,' 'rejection of the stimulus') but is consistent with recent models of attention developed within cognitive neuroscience (Posner, 1994). Posner's attentional model assumes the existence of three anatomical and functional attentional networks: the alertness network (involved in maintaining an appropriate vigilance state), the anterior attentional network (involved in executive control), and the posterior attentional network (involved in selection of information from sensory input). In his model, Posner (1994) proposed an excitatory relationship between the alerting and posterior attentional networks and an inhibitory relationship between the alerting and anterior attentional networks (see Callejas, Lupiáñez, & Tudela, 2004; Cohen, Semple, Gross, Holcomb, Dowling, & Nordahl, 1998; Fan, McCandliss, Sommer, Raz, & Posner, 2002). Accordingly, if cardiac defense elicited by an intense noise represents activation of the alerting system, the response would tend to be potentiated by the simultaneous performance of a posterior attentional task (e.g., visual search) and inhibited by the performance of an anterior attentional task (e.g., memory search).

The objective of the two studies reported here was to test the attentional and motivational significance of cardiac defense. Study 1 was designed to replicate the potentiation of the second accelerative component of cardiac defense by external attention. We selected two similar but opposite attentional tasks with respect to the direction of attention: Sternberg's visual search task (external attention) and Sternberg's memory search task (internal attention). The present study was also intended to confirm whether the attentional modulation depends on the direction of attention and not on task demands, as partially demonstrated by Pérez et al. (2000).

Study 2 was designed to test the motivational significance of cardiac defense by adding emotional content to the visual search task in Study 1. Instead of searching for letters, participants had to search for unpleasant, neutral, or pleasant pictures while the cardiac defense response was being evoked. Previous studies (Ruiz-Padial, Mata, Rodríguez, Fernández, & Vila 2005; Sánchez, Guerra, Muñoz, Mata, Bradley, Lang, & Vila, 2009; Sánchez, Ruiz-Padial, Pérez, Fernández, Cobos, & Vila, 2002) using the startle probe paradigm (Lang, 1995) demonstrated the potentiation of cardiac defense by the visualization of unpleasant and fearful pictures presented a few seconds before the defense stimulus. Based on these data, it was hypothesized that adding an aversive content to the visual search task would further potentiate cardiac defense.

STUDY 1

Method

Participants

Participants were 80 student volunteers (40 women) with ages ranging between 17 and 39 years. None of the participants had auditory or visual deficits or cardiovascular problems and none were under pharmacological or psychological treatment. They received course credit for their participation, after signing an informed consent form approved by the local ethics review board.

Design

Participants of each gender were randomly assigned to one of four experimental groups derived from the 2 × 2 factorial design used in the study, with 2 attentional tasks (visual search and memory search) each one with 2 levels of task difficulty (easy and difficult).

Physiological Test

The physiological test consisted of three presentations of an intense white noise of 105 dB, 500-ms duration, and instantaneous rise time, capable of eliciting the cardiac defense response (Ramírez, Sánchez, Fernández, Lipp, & Vila, 2005), in the following sequence: (a) 10 min of rest period, (b) three presentations of the white noise with an inter-stimulus interval of 100 s, and (c) a final period of 60 s with no stimulation. Each presentation of the white noise was followed by the initiation of the corresponding attentional task performed during 80 s. The noise was generated by a Coulbourn audio system (Coulbourn Instruments, L.L.C., Allentown, PA) (modules S81-02, S84-04, S82-24, and S22-18) and presented binaurally through earphones (Telephonic TDH Model- 49, Telephonic Corporation, Farmingdale, NY), calibrating the intensity of the sound by using a sound pressure meter (Bruel & Kjaer, model 2235, Naerum, Denmark) and artificial ear (Bruel & Kjaer, model 4153).

Behavioral Tasks

The tasks were programmed using MEL software (Schneider, 1988) and presented on a Pentium computer using a 35-cm (14-inch) CRT monitor located approximately 50 cm from the participant's eyes.

Memory search. We used a variant of Sternberg's Memory Search Task (Sternberg, 1966), identical to that used by Pérez et al. (2000). Participants had to memorize a set of letters and then indicate whether a target letter belonged to the memorized set. Each trial consisted of the following sequence: (1) A fixation point (*) was presented in the center of the screen for 500 ms, and was followed by (2) an array of horizontally displayed capital letters (2 or 7, depending on the level of difficulty) with a duration of 2500 ms; after which (3) an array of masks (#) was presented in the positions previously occupied by the letters for 500 ms. Finally, (4) a target letter was shown in the center of the screen until the participant emitted the response. Participants were instructed to respond, as fast and accurately as possible, by pressing with the index finger of the right hand a key with a green circle on it (key 'B') if the target letter belonged to the array, and another key with a yellow circle on it (key 'N') if the target letter did not belong to the array. A new trial started 5 sec after the onset of the previous trial. A total of 16 trials (lasting 80 sec) were performed following the defense noise. Letters and trials were randomly selected so that half of the time (50%) the target belonged to the array.

Visual search. We used a variant of Sternberg's Visual Search Task (Sternberg, 1969). Participants had to search for a target letter (always the letter 'A') and detect whether it was present in an array of letters randomly distributed over the computer screen. In each trial: (1) A fixation point (*) in the center of the screen was presented for 500 ms, and was followed by (2) the target letter ('A') also in the center of the monitor with a duration of 2500 ms; (3) a mask (#), occupying the same position of the target letter, was presented for 500 ms, and was followed by (4) the onset of an array of 4 or 12 capital letters (depending on the level of difficulty), which were scattered around the monitor and presented until the participant emitted the response. As in the Memory Search condition above, participants were instructed to respond, as fast and accurately as possible, by pressing with the index finger of the right hand a key with a green circle on it (key 'B') if the target letter belonged to the array, and another key with a yellow circle on it (key 'N') if the target letter did not belong to the array. In all other respects, both tasks were identical.

Dependent Variables

Cardiac defense. Electrocardiogram was recorded using a Grass polygraph (model Rps 7c), with a 7P4 preamplifier, and standard Beckman electrodes at lead III (left arm and left foot with ground electrode in right foot). A band-pass filter of 10–35 Hz and a sampling rate of 1000 Hz were used. Weighted averaged sec-by-sec heart rate was obtained from the R-R intervals analyzed using the VPM program (Cook, 1999). The 80 heart rate values after onset of each auditory stimulus were then expressed as difference scores with respect to baseline level (15 s before each trial). To facilitate the statistical analysis, we followed the same procedure used in previous studies: for each participant, the 80 sec-by-sec heart rate values in each trial were reduced to 10 heart rate values corresponding to the medians of 10 progressively longer intervals: two of 3 s, two of 5 s, three of 7 s, and three of 13 s (Vila et al., 1992). This procedure allows reduction of the cardiac response without altering the response form.

Behavioral measures. Reaction time (in milliseconds) and number of correct, incorrect, and missed responses were recorded for each behavioral task.

Subjective measures. Participants completed a post-experimental questionnaire with three rating scales to assess the intensity and unpleasantness of the first noise and the difficulty of the task on a scale from 0 (not at all) to 100 (extremely).

Procedure

Each participant attended a single laboratory session that lasted approximately 60 min. Upon arrival, the participant was invited to sit in an armchair and then received information about the experimental session and signed the informed consent form. A brief interview followed to establish that selection criteria were met. The electrodes, filled with electrolyte paste, were attached after cleaning the skin at attachment sites. The computer monitor and keyboard were placed in front of the participant, who then read the instructions for performing the attentional task. A practice session with the specific task corresponding to the participant's group was carried out to confirm that the task was correctly understood. The physiological recording was then checked, the earphones were placed, and the participant was left alone in the room. After the test, the experimenter removed the earphones and electrodes, and the participant completed the post-experiment questionnaire. Finally, the participant was debriefed and given the credit for his/her participation.

Statistical Analysis

Cardiac defense was analyzed by means of a 2 × 2 (× 3 × 10) analysis of variance (ANOVA) with two between-group factors, Task (memory search vs. visual search) and Difficulty (easy vs. difficult) and two repeated measures factors, Trials (the three noise presentations) and Time (the 10 heart rate medians). The Greenhouse-Geisser epsilon correction was applied to the repeated measures factors. The behavioral and subjective data were analyzed by means of 2 × 2 ANOVAS, with Task and Difficulty as the two between-group factors.

Results

Cardiac Defense

The 2 × 2 (× 3 × 10) ANOVA yielded significant main effects of Task, $F(1,76) = 6.15$, $p < .02$, Trials, $F(2,152) = 27.37$, $p < .0001$, and Time, $F(9,684) = 12.81$, $p < .0001$, and two significant interaction effects: Trials × Time, $F(18,1368) = 22.15$, $p < .0001$, and Task × Trials × Time, $F(18,1368) = 2.93$, $p < .002$. No significant main or interaction effect was found for Difficulty. Figure 1 plots the triple Task × Trials × Time interaction. Both tasks showed the expected cardiac defense response pattern in the first trial and the rapid habituation of the long-latency acceleration/deceleration in the second and third trials. In addition, larger accelerative responses were observed with the visual search task than with the memory search task, evident in the long-latency acceleration of trial 1.

Follow-up analyses of the three-way interaction revealed significant differences between the two tasks in trials 1 and 3. The significant differences in trial 1 appeared in medians 4 ($p < .02$), 5 ($p < .005$), 6 ($p < .001$), and 7 ($p < .003$), corresponding to the long-latency acceleration. The significant differences in trial 3 appeared in median 1 ($p < .005$), corresponding to the short-latency acceleration. In both trial 1 and trial 3, a larger accelerative response was observed with the visual search task than with the memory search task.

Behavioral Data

Table 1 presents the means and standard deviations for the behavioral data as a function of Task and Difficulty. The 2 × 2 ANOVAs for reaction time and number of correct and missed responses only revealed a significant effect of Difficulty (reaction time: $F(1,76) = 53.33$, $p < .0001$; correct responses: $F(1,76) = 6.06$, $p < .02$; missed responses: $F(1,76) = 4.77$, $p < .04$). Participants in the easy condition had a shorter reaction time, higher number of correct responses, and lower number of missed responses in comparison to participants in the difficult condition.

The 2 × 2 ANOVA for incorrect responses yielded significant effects of Task, $F(1,76) = 42.71$, $p < .0001$, Difficulty, $F(1,76) = 24.77$, $p < .0001$, and Task × Difficulty, $F(1,76) = 19.16$, $p < .0001$. Follow-up analysis of the Task × Difficulty interaction revealed significant differences between the easy and difficult conditions only in the memory search task ($p < .0001$) and between both tasks in the difficult condition ($p < .0001$). No differences were found between the easy and difficult condition in the

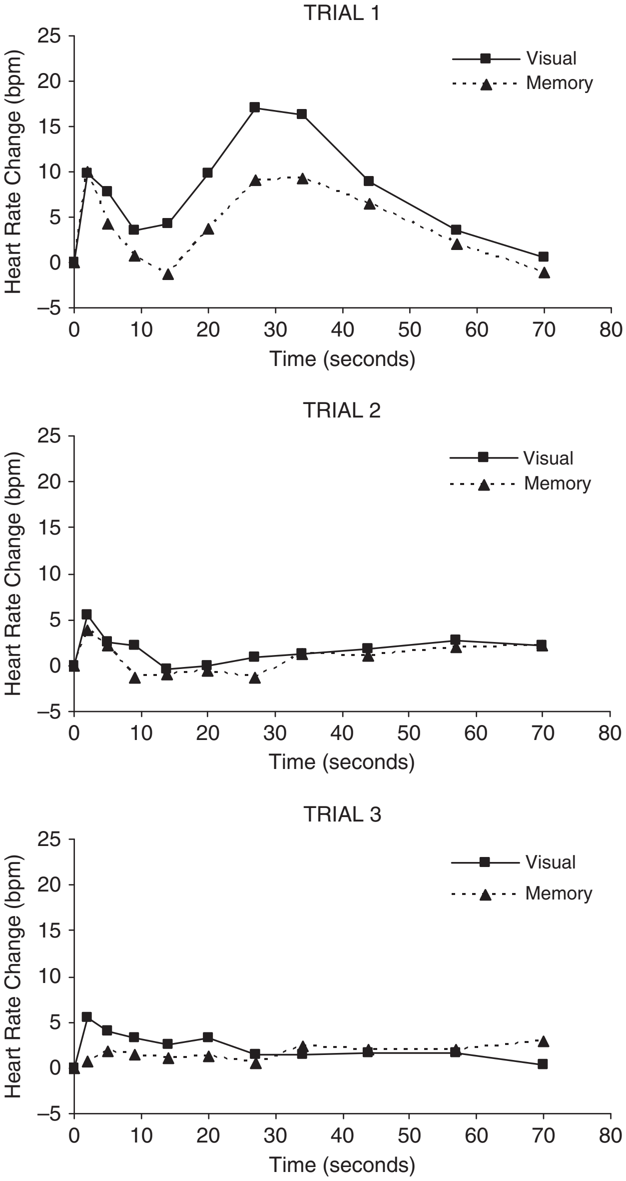

Figure 1. Cardiac Defense elicited when participants were performing the Memory Search Task versus the Visual Search Task in trials 1 (top), 2 (middle), and 3 (bottom).

visual search task ($p > .65$) or between the two tasks in the easy condition ($p > .11$).

Subjective Data

Table 1 also shows the means and standard deviations for the subjective data as a function of Task and Difficulty. The 2 × 2 ANOVA for the rating of the difficulty of the task yielded significant effects of Task, $F(1,76) = 14.04$, $p < .0001$, Difficulty, $F(1,76) = 24.36$, $p < .0001$, and Task × Difficulty interaction, $F(1,76) = 15.87$, $p < .0001$. Follow-up analysis of the Task × Difficulty interaction revealed significant differences between the easy and difficult conditions only in the memory search task ($p < .0001$) and between the two tasks in the difficult condition ($p < .0001$). No differences were found between the easy and difficult condition in the visual search task ($p > .5$) or between the two tasks in the easy condition ($p > .8$).

Table 1. *Mean and (Standard Deviation) of the Behavioral and Subjective Data as a Function of Task (Visual Search vs. Memory Search) and Difficulty (Easy vs. Difficult)*

	Visual search		Memory search	
	Easy ($N = 20$)	Difficult ($N = 20$)	Easy ($N = 20$)	Difficult ($N = 20$)
Behavioral data				
Reaction time	679 (118)	916 (137)	708 (102)	881 (140)
Correct responses	45.25 (7.5)	42.85 (4.8)	43.65 (8.7)	38.85 (4.1)
Incorrect responses	1.25 (1.8)	1.5 (1.9)	2.15 (1.7)	6.05 (2.1)
Missed responses	1.60 (5.8)	3.65 (4.9)	0.70 (1.3)	2.80 (3.6)
Subjective data				
Task difficulty	22.5 (18.9)	26.5 (20.3)	21.5 (16.6)	59.0 (19.2)
Noise intensity	86.7 (8.1)	81.2 (13.2)	79.3 (11.3)	81.5 (16.7)
Noise unpleasantness	93.4 (7.1)	84.0 (17.3)	90.5 (8.8)	87.9 (7.5)

Finally, the 2 × 2 ANOVAs for the rating of the intensity and unpleasantness of the noise revealed only a significant main effect of Difficulty in the rating of unpleasantness, $F(1,76) = 5.97$, $p < .02$. Participants in the easy condition of both tasks rated the noise as more unpleasant than participants in the difficult condition. No other significant effects were found.

Discussion

As predicted, the amplitude of the second accelerative component of cardiac defense, elicited in the first defense trial, was larger when participants were simultaneously performing the visual search task than when they were performing the memory search task. Although not predicted, due to the expected rapid habituation of the response, a larger amplitude of the first accelerative component was also observed when participants were performing the visual versus memory search task in the third defense trial. These results are consistent with previous findings supporting the association of cardiac defense with attentional factors related to external rather than internal attention (Fernández & Vila, 1989; Pérez et al., 2000; Vila et al., 1997). Unlike previous studies, however, the present study used a visual search task for external attention that was matched, in terms of perceptual stimuli and motor responses, with the internal attention task under comparison, thereby providing stronger support for the attentional interpretation of results.

The difficulty of the task did not have any effect on cardiac defense, also confirming previous findings (Pérez et al., 2000). The behavioral data (reaction time and number of correct and missed responses) confirmed the effectiveness of the manipulation of the task demand. In general, participants seemed to have emphasized accuracy (few incorrect and missed responses) over speed, yielding the clearest statistical results for reaction time. However, the number of incorrect responses and the retrospective ratings did not confirm the effectiveness of the difficulty manipulation in the visual search task. Hence, conclusions concerning the effect of difficulty on the visual search task should be drawn with caution. Finally, an unexpected finding was the effect of task difficulty on the subjective rating of the noise. The rating of unpleasantness was lower for difficult versus easy tasks, which may be due to reduced attentional resources to process the quality of the noise under higher task demands.

STUDY 2

Method

Participants

Participants were 60 student volunteers (30 women) between 18 and 30 years of age. None of the participants had auditory or visual deficits or cardiovascular problems, and none were under pharmacological or psychological treatment. They received course credit for their participation.

Design

All participants performed a visual search task that was identical to the easy task in Study 1 except that the letters were replaced with emotional pictures. The task was superimposed on the evocation of cardiac defense in three successive trials. Each defense noise presentation was followed by performance of the visual search task with one of three different picture valences: pleasant, neutral, or unpleasant. The order of picture valence along the three defense trials was counterbalanced according to a Latin square design. Participants were randomly distributed among the different orders, balancing the gender of participants (10 men and 10 women per order of picture valence).

Physiological Test and Material

The physiological test was identical to that used in Study 1. A set of 17 pleasant pictures (erotic couples), 17 neutral pictures (household objects), and 17 unpleasant pictures (mutilated bodies) were selected from the *International Affective Picture System* (IAPS; Lang, Bradley, & Cuthbert, 2005) using the Spanish norms (Moltó, Montañés, Poy, Segarra, Pastor, et al., 1999). The three sets significantly differed in *valence* (pleasant: $M = 7.39$, $SD = .39$; neutral: $M = 5.11$, $SD = .28$; unpleasant: $M = 1.82$, $SD = .36$). Pleasant and unpleasant pictures did not significantly differ in *arousal* (pleasant: $M = 6.37$, $SD = .67$; unpleasant: $M = 6.87$, $SD = 1.0$), whereas neutral pictures were significantly lower in *arousal* ($M = 3.05$, $SD = .57$). IAPS codes for each picture are given in Footnote 1.[1]

The emotional pictures were presented on a 48-cm (19-in) CRT monitor using Visual Basic software. The presentation sequence in each visual search trial was the same as in Study 1: (a) fixation square of 15 × 15 cm in the center of the monitor, presented for 500 ms; (b) the target picture, with same size of fixation square in the center of the monitor, for 2500 ms; (c) symbol # in the center of the monitor for 500 ms; and (d) an array of 4 pictures of identical target size scattered around the monitor and presented until the participant emitted the response. Participants had to respond whether the target picture was in the array. A total of 16 trials with the same target picture and the same affective valence (pleasant, neutral, or unpleasant) of the pictures presented in the arrays were performed after each defense noise. The 17 pictures belonging to the same valence category were randomly distributed along the 16 trials, with the restriction that (a) none of the 4 pictures in the same array was repeated, and (b) the target picture appeared in the array with a 50% probability.

Dependent Variables

Cardiac defense. Cardiac defense was defined as in Study 1.

Behavioral and subjective measures. The same measures as in Study 1 were used, except that the difficulty of the task was not rated. In addition, nine pictures (the three targets plus two randomly selected pictures in each emotional category) were rated using the Self-Assessment Manikin *valence* and *arousal* scales (Lang et al., 2005). These final measures were included to confirm the *a priori* selection of the pictures.

Procedure

We used the same procedure as Study 1 except that, after the physiological test and the subjective ratings of the noise, the participants assessed the emotional pictures. The assessment procedure was as follows: (a) the participant was given instructions on using the Self-Assessment Manikin scales; (b) each picture was projected on the wall in front of the participant for 15 s using a Kodak 9000 Ektapro slide projector; and (c) the participant rated the *valence* and *arousal* of the picture on the two Self-Assessment Manikin scales printed on a sheet of paper (one for each picture). Four random orders of picture presentation were used.

Statistical Analysis

Cardiac defense was analyzed by means of a 3 (× 3 × 10) ANOVA with one between-group factor, Order of trials (the three groups with different order of picture valence), and two repeated-measures factors, Picture Valence (pleasant, neutral, and unpleasant) and Time (the 10 heart rate medians). Behavioral data were analyzed by means of 3 (× 3) ANOVAs with one between-group factor (Order of trials) and one repeated-measures factor (Picture Valence). The Greenhouse-Geisser epsilon correction was applied to the repeated-measures factors. Subjective assessment of the intensity and unpleasantness of the first noise was analyzed by means of ANOVAs with a single between-group factor (e.g., Picture Valence in trial 1). Analysis of the valence and arousal ratings of the nine pictures were analyzed by means of ANOVAs with a single repeated measures factor (e.g., Picture Valence).

Results

Cardiac Defense

The 3 (× 3 × 10) ANOVA yielded significant main effects of Picture Valence, $F(2,114) = 4.94$, $p < .009$, and Time, $F(9, 513) = 18.68$, $p < .0001$, and three significant interaction effects: Picture Valence × Time, $F(18,1026) = 2.44$, $p < .01$, Picture Valence × Order, $F(4,114) = 16.83$, $p < .0001$, and Picture Valence × Time × Order, $F(36, 1026) = 13.13$, $p < .0001$. Figure 2 plots the triple interaction. As can be seen, a potentiated cardiac defense response is observed in the first trial, when participants were performing the visual search task with unpleasant pictures. In the second and third trial, the response pattern is markedly reduced, reflecting the rapid habituation of the long-latency acceleration/deceleration.

Follow-up analysis of the three-way interaction revealed significant differences between the three picture valences in trials 1 and 2. The significant differences in trial 1 appeared in medians 4 ($p < .006$), 5 ($p < .03$), 6 ($p < .04$), and 7 ($p < .05$), corresponding to the long-latency acceleration. In all cases, pair-wise comparisons indicated that the cardiac acceleration was significantly

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[1] Codes of IAPS pictures used in study 2. Pleasant pictures: 4651 (target), 4800, 4599, 4611, 4653, 4810, 4608, 4609, 4650, 4660, 4607, 4659, 4652, 4606, 4680, 4690, 4664. Neutral pictures: 7010 (target), 7000, 7009, 7025, 7030, 7034, 7035, 7040, 7050, 7060, 7080, 7090, 7150, 7190, 7235, 7233, 7002. Unpleasant pictures: 3010 (target), 3010, 3120, 3130, 3100, 3140, 3060, 3053, 3160, 3170, 3071, 3102, 3051, 3400, 3220, 3230, 3180.

higher for the unpleasant picture content than for the neutral (medians 4, 5, 6, and 7) and pleasant (medians 4, 5, and 7) picture contents. In trial 2, pair-wise comparisons also indicated a higher average heart rate response for the unpleasant versus neutral picture content. No other comparisons were significant.

Behavioral Data

Table 2 presents the mean and standard deviation of the behavioral data as a function of Picture Valence. The 3 (× 3) Order of trials × Picture Valence ANOVAs yielded significant main effects of Picture Valence for reaction time, $F(2,114) = 19.33$, $p < .0001$, correct responses, $F(2,114) = 3.32$, $p < .05$, and missed responses, $F(2,114) = 5.87$, $p < .008$, and significant Order × Picture Valence interactions for reaction time, $F(4,114) = 11.39$, $p < .0001$, correct responses, $F(4,114) = 5.35$, $p < .002$, incorrect responses, $F(4,114) = 3.91$, $p < .005$, and missed responses, $F(4,114) = 4.48$, $p < .005$. Pair-wise comparisons for the main effect of Picture Valence revealed: (a) significant slower reaction time for pleasant and unpleasant pictures than for neutral pictures (both $ps < .0001$), (b) significant lower number of correct responses for pleasant and unpleasant pictures than for neutral ones (both $ps < .05$), and (c) significant higher number of missed responses for pleasant and unpleasant pictures than for neutral ones (both $ps < .02$). No significant difference was found between pleasant and unpleasant picture valence in any variable. On the other hand, pair-wise comparisons between picture valences in the first trial revealed significant differences in reaction time only between pleasant and neutral and between unpleasant and neutral content (both $ps < .0001$), with no significant difference between pleasant and unpleasant content ($p > .75$). Differences did not reach statistical significance in the remaining trials or in the trials for correct, incorrect, and missed responses.

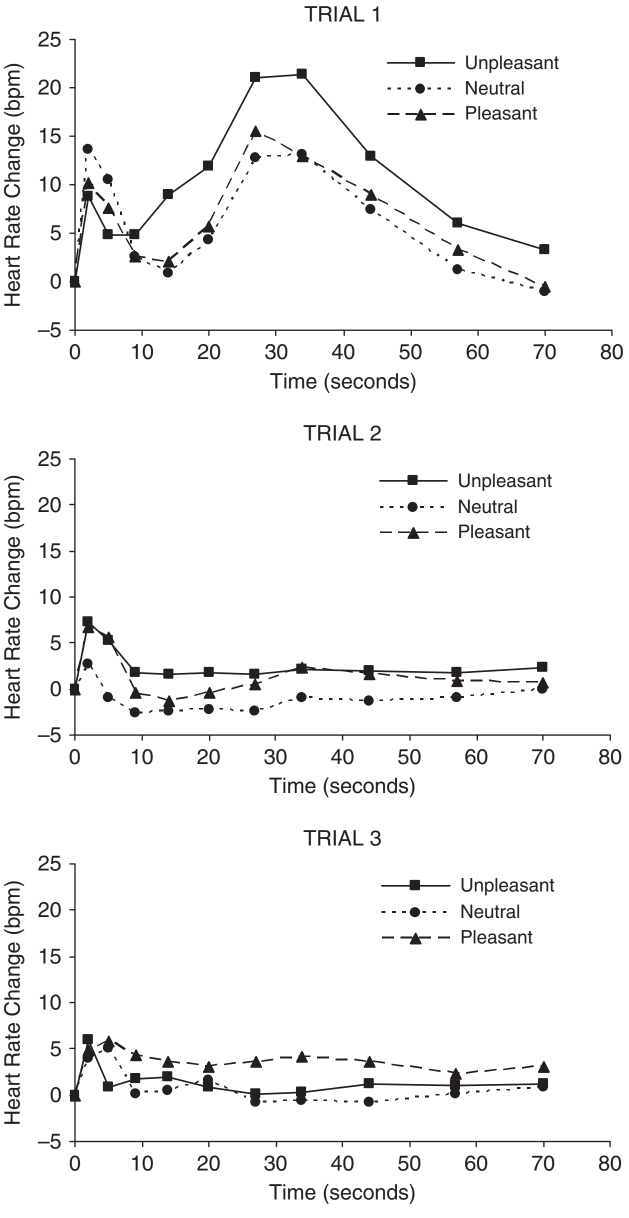

Figure 2. Cardiac Defense elicited when participants were performing the Visual Search Task in trials 1 (top), 2 (middle), and 3 (bottom) as a function of Picture Valence.

Subjective Data

Table 2 also presents the mean and standard deviation of the subjective data as a function of Picture Valence. The ANOVAs for the subjective ratings of the intensity and unpleasantness of the first noise revealed no significant effects of Picture Valence (intensity: $F(2,57) = .97$, $p > .38$; unpleasantness: $F(2,57) = 1.59$, $p > .2$).

Ratings of *valence* and *arousal* of the nine selected pictures confirmed the selection criteria for *valence*. As expected, pleasant, neutral, and unpleasant pictures differed significantly in *valence*, $F(2,118) = 217.58$, $p < .0001$), with significant differences among the three picture contents (all $ps < .0001$). However, contrary to expectations, the three categories of pictures also differed in *arousal*, $F(2,118) = 108.33$, $p < .0001$, with significant differences among the three picture contents (all $ps < .0001$). Pleasant and unpleasant pictures were not expected to differ in *arousal*, according to the IAPS selection criteria. However, whereas the ratings of unpleasant and neutral pictures were consistent with IAPS norms, the pleasant pictures were rated by our participants as somewhat less pleasant and arousing than in the original reference study.

Discussion

As predicted, the addition of an aversive emotional content to the visual search task resulted in larger amplitudes of the second accelerative component of cardiac defense in the first defense trial. No significant differences in cardiac defense were observed in this trial when pictures were pleasant or neutral. Although not predicted, due to the expected rapid habituation of the response, a larger accelerative pattern was also observed in the second trial when the visual search task was performed with unpleasant versus neutral pictures.

The observed potentiation of cardiac defense when participants were performing the task with unpleasant pictures, and the lack of differences when participants were performing the task with pleasant and neutral pictures, is consistent with previous findings by our group (Ruiz-Padial et al., 2005; Sánchez et al., 2002, 2009). Sánchez et al. (2002) tested the emotional modulation of cardiac defense by using the startle probe paradigm. They reported that visualization of unpleasant pictures presented a few seconds before the defense noise resulted in a cardiac defense response characterized by a single large and prolonged acceleration. Visualization of pleasant and neutral pictures attenuated the typical response pattern, with no differences be-

Table 2. *Mean and (Standard Deviation) of the Behavioral and Subjective Data as a function of Picture Valence (Pleasant, Neutral, and Unpleasant)*

	Picture valence		
	Pleasant	Neutral	Unpleasant
Behavioral data			
Reaction time ($N = 60$)	890 (176)	747 (181)	863 (196)
Correct responses ($N = 60$)	14.3 (2.4)	15.0 (1.6)	14.3 (2.1)
Incorrect responses ($N = 60$)	0.4 (0.7)	0.4 (0.7)	0.4 (0.8)
Missed responses ($N = 60$)	1.3 (1.9)	0.6 (1.4)	1.5 (1.9)
Subjective data			
Noise intensity ($N = 20$)	87.1 (10.8)	91.5 (11.2)	87.3 (11.9)
Noise unpleasantness ($N = 20$)	88.2 (16.1)	93.8 (7.9)	86.0 (16.8)
Rating of Picture Valence ($N = 60$)	6.6 (1.5)	5.2 (1.1)	1.9 (1.1)
Rating of Picture Arousal ($N = 60$)	5.7 (1.9)	2.6 (1.6)	6.8 (2.1)

tween these categories. A similar aversive potentiation of cardiac defense was reported, using the startle probe paradigm, when fearful participants were viewing fearful versus fear-irrelevant pictures (Sánchez et al., 2009), as also observed using masked and unmasked picture presentation (Ruiz-Padial et al., 2005).

Potentiation of cardiac defense by viewing of unpleasant pictures parallels the eye-blink startle reflex potentiation consistently demonstrated in the context of the startle probe paradigm (see Bradley & Lang, 2007). Lang and colleagues (1997, 2000) consider this phenomenon as due to the congruence between the motivational system engaged by the perceptual stimuli (aversive) and the type of reflex being elicited (defensive). This explanation, known as the *motivational priming hypothesis*, also predicts inhibition of defensive reflexes by viewing pleasant pictures, due to the incongruence between the motivational system engaged by the pictures (appetitive) and the type of reflex being elicited (defensive). Both predictions have consistently been confirmed for the eye-blink startle reflex when pleasant and unpleasant pictures are compared to neutral ones.

The present data and those published by Sánchez et al. (2002) support the predicted potentiation of cardiac defense by unpleasant pictures, in line with the *motivational priming hypothesis*, but they do not support its inhibition by pleasant versus neutral pictures. This finding may reflect a fundamental difference between cardiac and motor reflexes, or it may result from an ineffective manipulation of the appetitive motivational system by our pleasant pictures. Participants rated pleasant pictures as less pleasant and arousing than the IAPS reference population, supporting the second alternative. However, the first alternative is also supported by the behavioral data showing similar reaction times, correct responses, and missed responses for pleasant and unpleasant pictures compared to neutral pictures, indicating that the appetitive system was effectively manipulated.

Implications for the Attention-Motivation Model of Cardiac Defense

The results of our two studies provide new evidence to support an interpretation of cardiac defense in terms of both attentional and motivational significance. The attentional significance would be related to directing attention towards the processing of external cues, and the motivational significance towards activation of the aversive motivational system. However, the attention-motivation model of cardiac defense proposed by Vila and colleagues (2007) suggests that the complex pattern of heart rate changes in response to unexpected intense acoustic or electrocutaneous stimuli represents the succession of two protective phases: an attentional protective phase linked to the short latency acceleration/deceleration—aimed at interrupting ongoing activity and heightening attention to the potential external danger—and a motivational protective phase linked to the long latency acceleration/deceleration—aimed at motor preparation for active defense and recovery if no real danger occurs. Several questions arise concerning the present data.

External attention and the short latency acceleration/deceleration. A first question concerns the effect of the visual search task on the long latency component, rather than the short latency one, the cardiac component presumably linked to the attentional phase. It should be noted that the visual search task used in our study did not only affect the long latency acceleration/deceleration. In both studies, significant differences in response pattern started in median 4, which, in the memory search task of Study 1 and in the pleasant and neutral picture conditions of Study 2, corresponded to the end of the short latency deceleration. Hence, the external attention task had a relatively generalized effect on cardiac defense, reducing the short latency deceleration and bringing forward the long latency acceleration. Vila and colleagues (1997) attributed this effect to the congruence between the type of attentional demands required by the defense stimulus (external) and the type of attentional demands required by the visual search task (also external). The shared attentional demands between stimulus and response would facilitate earlier completion of the attentional phase and a higher allocation of resources to the subsequent motivational phase.

Aversive motivation and the long latency acceleration/deceleration. A second question concerns the effect of viewing unpleasant pictures—in the context of the startle probe paradigm—on the short latency component of cardiac defense, rather than the long latency one (Ruiz-Padial et al., 2005; Sánchez et al., 2002, 2009), the component presumably linked to the motivational phase. A methodological difference between the startle probe paradigm and the visual search task may explain this effect. Visualization of unpleasant pictures starts *before* presentation of the defense stimulus in the startle probe paradigm, whereas the unpleasant pictures are presented *after* the defense stimulus in the visual search task. When unpleasant pictures are presented before the defense stimulus, the typical cardiac defense response pattern changes from a complex pattern with two accelerative/decelerative components to a single large and prolonged acceleration. One interpretation is that the attentional protective phase (linked to short latency acceleration/deceleration) has been pre-activated by the preceding threatening signals, temporally anticipating the motivational protective phase (long latency acceleration/deceleration) in preparation for active defense (Vila et al., 2007). In the visual search task, the threatening signals do not precede the defense stimulus and, therefore, no pre-activation of the attentional phase is expected.

The space-time dimension in the cascade model and cardiac defense. A final theoretical question concerns the translation of the cascade model of defense, based primarily on increased spatial proximity of a distant visual cue (the approaching predator), to cardiac defense, based on a time sequence of cardiac responses to a fixed and close acoustic cue (the sudden unexpected intense noise). It can be argued that such intense noise represents the imminent presence of the danger (the predator) and that the timing of the short and long latency components of cardiac defense do not fit well with the necessity for fast action in self defense. Indeed, the long latency component—which starts around 15 s after stimulus onset and reaches its maximum amplitude around 30 s—may be considered too slow for an effective response mobilization (flight or fight). However, if the short latency component is considered analogous to the freezing response (attentive immobility), the absence of response mobilization during several seconds would play the adaptive function of passive defense against an unknown danger: reduced detectability accompanied by increased attention towards the source of the potential danger (Marx et al., 2008). The physiological mechanism underlying the short latency component of cardiac defense, mediated exclusively by vagal influences (Reyes del Paso, Godoy, & Vila, 1993), would support this interpretation.

In summary, the data presented here confirm the description and interpretation of cardiac defense as a dynamic sequence of accelerative and decelerative components with both attentional and motivational significance: the attentional significance would be related to directing attention to external cues and the motivational significance to a metabolic preparation of the organism for active defense.

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