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Review

Cardiac defense: From attention to action☆

Jaime Vila*, Pedro Guerra, Miguel Ángel Muñoz, Cynthia Vico, Maria Isabel Viedma-del Jesús, Luís Carlos Delgado, Pandelis Perakakis, Elisabeth Kley, José Luís Mata, Sonia Rodríguez

University of Granada, Spain

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Abstract

The concept of defense relates to the idea that organisms react physiologically to the presence of danger or threat in order to protect themselves from potential injury or death. This article reviews the literature on cardiac defense, a specific defense reaction that has a long tradition in psychophysiological research. The review begins with a brief analysis of the two traditional approaches to understand this autonomic response: the cognitive – linked to Pavlov, Sokolov, and Graham's work on sensory reflexes – and the motivational — linked to Cannon and Selye's work on the concepts of activation and stress. Then, the classic model of cardiac defense and its basic assumptions concerning differentiation from other cardiac reflexes – namely orienting and startle – are presented. A critical analysis of these assumptions follows centered on evidence from a systematic research of the cardiac response to intense acoustic stimulation. Finally, an integrative model of cardiac defense is presented which emphasizes the dynamic nature of this defense reaction – characterized by a complex pattern of heart rate changes with accelerative and decelerative components, with sympathethic and parasympathetic influences, and with both attentional and motivational significance – providing a new framework in which the two opposite traditional approaches can be reconciled.

Keywords: Cardiac defense; Attention; Emotion; Stress; Individual differences

1. Introduction

Organisms react physiologically to the presence of danger or threat in order to protect themselves from potential injury or death. Typical defense responses reported in the experimental and clinical literature include freezing, startle, fainting, and the fight–flight response. These various responses can be categorized into two general forms of defense (Lang et al., 2000): immobility and active defense. The protective function of both types of reactions is evident. However, if too intense or prolonged, this defensive reactivity may constitute a serious risk for both mental and physical health. For many researchers and clinicians, excessive physiological reactivity is the main mechanism linking defense to stress and illness (Dienstbier, 1989; Lovallo and Gerin, 2003; Turner, 1994).

Fear and anxiety are the typical emotional reactions to the presence of danger and threat and are, therefore, closely linked to the concept of defense. Recent advances in the neurophysiology of fear and anxiety come primarily from research with animals using defense reactions such as freezing, startle, and escape-attack behaviors (Davis, 1992; LeDoux, 2000; Blanchard and Blanchard, 1989; Fanselow, 1994). Paradigms frequently used to study the neural circuit of fear (fear conditioning, fear sensitization, and fear potentiation) always include nociceptive or intense stimulation, eliciting unconditioned defense reactions, in order to investigate the neural pathways underlying the fear response. Research with humans has also made frequent use of intense or aversive stimulation in order to study fear modulation of specific protective reflexes such as eye-blink startle or postural freezing (Lang et al., 2000; Azevedo et al., 2005; Ruiz-Padial and Vila, 2007).

Pathological fear and anxiety are also closely related to defense. Perhaps, the most dramatic evidence of the relevance of defense in the development of pathological fear and anxiety

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* Corresponding author. Facultad de Psicología, Universidad de Granada, Campus La Cartuja s/n. 18071 Granada, Spain. Tel.: +34 958 243753; fax: +34 958 243749.
E-mail address: jvila@ugr.es (J. Vila).

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comes from clinical studies on post-traumatic stress disorder as a consequence of extreme, life-threatening, traumatic events (Schauer et al., 2005). However, in these cases, as in any natural setting where a real danger emerges, it is difficult to talk of the defense reaction as a single entity. Rather, a dynamic sequence or cascade of defense reactions, from heightened attention to response mobilization, seems to take place depending primarily on the type and severity of the danger, its spatial and temporal proximity, and the success or failure of the initial defense responses to cope with it (Fanselow, 1994; Lang et al., 1997a; McNaughton and Corr, 2004).

In this paper, we will focus on a specific defense reaction which has a long tradition in psychophysiological research: cardiac defense. We will begin with a brief review of the two opposite traditional approaches to understand this autonomic response: the cognitive and the motivational. Then we will present the classic model of cardiac defense and its basic assumptions concerning differentiation from other cardiac reflexes, namely orienting and startle. A critical analysis of these assumptions will follow centered on evidence from a systematic research of the cardiac response to intense acoustic stimulation. It will be shown that this response is characterized by a complex pattern of heart rate changes with accelerative and decelerative components, with sympathetic and parasympathetic mediating mechanisms, and with cognitive and motivational significance. Finally, an integrative model will be presented which emphasizes the dynamic nature of this defense reaction and provides a new framework in which the two opposite traditional approaches can be reconciled.

2. Traditional approaches to cardiac defense

The historical antecedents of the defense concept are rooted in the work of Pavlov (1927) and Cannon (1929). By the end of the nineteenth and beginning of the twentieth century, Pavlov and other Russian reflexologists (see Konorski, 1967) used the term *defense reflex* to refer to protective physiological responses elicited by noxious stimulation, such as hand withdrawal to an electric shock, eye blink to a puff of air, or vomit to bad food. Some years later, Cannon used the same term to refer to the *fight or flight response*, a sympathetically-mediated cardiovascular response to emergency situations aimed at providing energy to facilitate adaptive behaviors such as attack or escape. By the middle of the last century, and following Cannon's ideas, Selye (1956) introduced the concept of *stress* and used the term *alarm response* to refer to the first stage of the physiological response to threatening (stressful) situations.

Research on the defense response has been extensive throughout the twentieth century. Several approaches can be identified. However, the two major psychophysiological approaches to defense, both emphasizing the cardiovascular components, are the cognitive and the motivational ones. The *cognitive approach*, built on Pavlov's (1927) distinction between orienting (*'what is it?'*) and defense reflexes, assumes that cardiac changes in response to environmental stimuli reflect attentional and perceptual mechanisms aimed at facilitating or inhibiting stimulus processing (Graham and Clifton, 1966; Graham, 1992). The orienting reflex (a deceleration of the heart rate to moderate or novel stimulation) facilitates attention and perception of the stimulus, whereas the defense response (an acceleration of the heart rate to intense or aversive stimulation) reduces attention and perception as a form of protection against the threatening stimulus.

In this context, the defense-orienting distinction proposed by Graham and Clifton (1966) is equivalent to the same distinction proposed by Sokolov (1963) a few years earlier based on vascular responses: concomitant vasoconstriction in the forehead and hands for defense, and reciprocal vasodilation-vasoconstriction in the forehead and hands for orienting. It is also equivalent to the intake-rejection distinction proposed by John and Beatrice Lacey (Lacey et al., 1963; Lacey and Lacey, 1974). The intake-rejection hypothesis assumes that the direction of heart rate changes reflects the organism's intention to attend or reject environmental stimuli. Cardiac deceleration is associated with the intention to attend to external stimuli and fulfils the function of improving both the organism's receptivity to afferent stimulation and its readiness to make effective responses (Jennings, 1986a; Lacey, 1972). On the other hand, cardiac acceleration is associated with the intention to reject sensory input either because the external stimulus is unpleasant or because the task requires internal cognitive elaboration (Jennings, 1986b; Lacey and Lacey, 1974).

The *motivational approach*, built on Cannon's and Selye's ideas on the fight–flight and the stress response, assumes that the cardiac changes in response to environmental demands reflect metabolic mechanisms aimed at providing the body with the energy necessary to support behavioral adjustments (Obrist, 1981). If the appropriate behavior is to be passive and quiet, then the response will be a heart rate deceleration. If the appropriate behavior is to be active, either physically or psychologically, then the cardiac response will be a heart rate acceleration. This approach has mainly used emotionally or cognitively challenging tasks to study cardiac defense, such as pressing a key as fast as possible to avoid shocks, or doing a complex cognitive task. The term *mental stress* was introduced in this context to refer to tasks that require *mental effort* rather than *physical effort* (Steptoe and Vögele, 1991). Similarly, the term *social stress* was introduced in this context to refer to tasks that involve a threat to the social self, such as public speaking (Kirschbaum et al., 1993).

Research within the field of stress has experienced a tremendous thrust in the last decades favored by the influence of the cognitive-transactional model (Lazarus and Folkman, 1984) and the increasing amount of evidence suggesting that the way individuals assess and cope with a given situation is as important as the actual physical challenge (Miller et al., 2007). Although there are a variety of terminologies to describe individual differences in coping styles, a distinction that parallels the active-passive tasks mentioned above is the proactive-reactive coping styles proposed by several researchers (Frankenhaeuser, 1986; Koolhaas et al., 1999). The proactive style is characterized by active attempts to counteract the threatening situation and includes, as typical responses, active avoidance and aggression. The reactive style is characterized by passive coping strategies such as immobility and withdrawal. While the first one is

associated with high sympathetic reactivity and low glucocorticoid secretion, the second one is associated with low sympathetic reactivity and high glucocorticoid secretion.

The cognitive and the motivational approaches to cardiac defense have been difficult to reconcile in the past. From the cognitive perspective, the functional significance of cardiac defense was better understood as an attentional mechanism opposite to cardiac orienting. From the motivational perspective, the functional significance of cardiac defense was better understood as a response mobilization mechanism opposite to cardiac relaxation. Investigation into both perspectives has given rise to several debates which have not been satisfactorily resolved one way or the other (see Coles et al., 1984). While attentional involvement may be evident at certain stages of certain tasks, but not in others (Jennings, 1986a), motivational involvement may also be evident at certain stages of certain tasks or with respect to certain motor muscles, but no to others (Brunia and Damen, 1985).

3. The classic model on cardiac defense

The most elaborate theoretical model on cardiac defense was developed within the cognitive tradition. Based on the seminal work of Sokolov (1963) and Lacey and Lacey (1958), Graham and Clifton (1966) proposed a classification of cardiac reflexes that had a great impact in the field of psychophysiology. The classification was later extended and refined by Frances Graham (1979, 1992); (see also Graham and Hackley 1991) who proposed four basic reflexes elicited by stimuli as a function of their intensity and their transient/sustained characteristics: the transient detection reflex, the orienting reflex, the startle reflex, and the defense reflex.

Low intensity transient stimuli were said to elicit the transient detection reflex, whereas low intensity sustained stimuli elicit orienting. High intensity transient stimuli were said to elicit the startle reflex, whereas high intensity sustained stimuli elicit defense. The differentiation between the four reflexes was also based on response direction and habituation rate. The transient detection and orienting reflexes were both characterized by a heart rate deceleration. They differed in the response latency and its habituation rate, the orienting reflex having longer latency and faster habituation rate than the transient detection reflex. On the other hand, the startle and defense reflexes were both characterized by a heart rate acceleration. They differed also in response latency and habituation, the defense reflex having longer response latency and showing slower habituation rate. The four reflexes were further differentiated according to their functional significance. The transient detection and orienting reflexes were said to increase sensory input helping to detect and process, respectively, novel moderate stimuli. The startle and defense reflexes were said to decrease sensory input helping to clear and shut down, respectively, the sensory processing of intense aversive stimuli.

The classic model of cardiac defense, therefore, assumes the following characteristics: (a) The response is a heart rate acceleration; (b) the eliciting stimulus can be of any sensory modality but must be of high intensity; (c) the response shows slow habituation with repeated stimulation; (d) its functional significance is a decrease in sensory processing as a form of protection against aversive stimulation; and (e) its physiological mediation is exclusively sympathetic activation.

Graham's model has been the topic of much research (see Dawson et al., 1999; Kimmel et al., 1979; Lang et al., 1997b; Siddle, 1983). However, it has also been the subject of continuous debate and reformulation (Barry and Maltzman, 1985; Cook and Turpin, 1997; Graham and Hackley, 1991; Graham, 1997; Öhman et al., 2000; Turpin et al., 1999; Vossel and Zimmer, 1992). The research and the debate have been mainly focused on the orienting reflex. The defense reflex has received less attention on its own, being usually compared to the orienting reflex more on a theoretical than an empirical basis. The transient detection reflex has been the least investigated while interest in the startle reflex has increased over the years mainly focused on its motor components, in particular the eyeblink response (Dawson et al., 1999; Graham and Hackley, 1991; Lang, 1995; Vrana et al., 1988).

The idea that orienting is the opposite of defense, and that cardiac deceleration is indicative of orienting and cardiac acceleration indicative of defense, is still widely repeated in books and journals dealing with psychophysiological reflexes (see Andreassi, 2007; Barry, 2006; Cacioppo et al., 2000; Sokolov et al., 2002). However, since the early 1940s there have been several reports challenging the view not only that the heart rate response to intense stimulation is an acceleration, but also that the response shows slow habituation and is exclusively mediated by sympathetic activation. Bond, a student of Cannon, published in 1943 an article entitled *Sympathetic and vagal interaction in emotional responses of the heart rate* describing in dogs and cats a response pattern to intense startling noises with accelerative and decelerative components and with sympathetic and vagal mediation. Bond (1943, page 89) reported a *remarkably constant response* to a noise made by a pistol shot or by hitting a table top with an iron rod several times in less than 2 s. The response was *repeatedly demonstrable for the individual* and consisted of an increasing heart rate that began *within one-fifth of a second or less* and progressed to a maximum *reached in 3 to 4 s*. This increase was *maintained for 4 to 6 s* followed by a sudden fall toward baseline level, *sometimes crossing it*. The fall *lasted about 10 s* and was succeeded by either *a flattening at this level or a significant rise*, on a slope more gradual than that of the initial rise, which reached a peak, variable in height, *at 20 to 40 s for cats* and *45 to 60 s for dogs*. From this time onward undulations in the rate were common. *All evidence of the response usually disappeared within 2 to 3 min*.

Similar findings have been reported in humans (Eves and Gruzelier, 1984; Turpin, 1986; Turpin and Siddle, 1978, 1983; Vila and Beech, 1978). Turpin and Siddle (1978) were the first to report a complex pattern of heart rate changes to intense auditory stimulation with two distinct accelerative components, one acceleration of short latency (peak around second 4) and a second acceleration of long latency (peak around second 35). This response pattern showed rapid habituation, the second acceleration almost disappearing after the first stimulus presentation. Subsequent research has confirmed Bond's and Turpin and

Siddle's findings and advanced knowledge about the characteristics of the eliciting stimulus and the response pattern. In general, the findings do not fit well with the classic model. However, in spite of this criticism, no much independent research has been conducted to identify the specific features of the heart rate response to an aversive physical stimulus such as an intense noise or an electric shock. Both types of stimulation are by far the most frequently used in both animal and human studies on aversive reactivity, habituation, and conditioning. Intense acoustic stimulation is indeed the preferred unconditioned stimulus used in human conditioning studies (Öhman et al., 2000). It is also one of the most common aversive stimulation in natural settings, its negative effects on health and psychopathology being well documented in the scientific literature (Kryter, 1970; Napalkov, 1963; Schell and Lieberman, 1981; Vera et al., 1994; Watson and Rayner, 1920).

4. A systematic search on cardiac defense

In the following sections we will summarize a series of studies on the heart rate component of the defense response in humans using as basic paradigm the presentation of an unexpected intense noise under different stimulus and task conditions. Instructions typically inform participants that they would hear brief intense noises but no indication of the exact moment of their presentation is given. The main dependent variable was always the beat-by-beat heart rate response recorded from the electrocardiogram. The studies were designed to test the following issues: (a) descriptive pattern of the response; (b) individual differences; (c) characteristics of the eliciting stimulus; (d) habituation; (e) sympathetic versus parasympathetic mediation; and (f) attentional versus emotional significance.

4.1. Descriptive pattern of the response

Fig. 1 illustrates the beat-by-beat heart rate response of an individual to three presentations of an intense noise of 109 dB intensity, 500 ms duration, and instantaneous rise time, with an inter-stimulus interval of about 100 s, after a resting period of 10 min. The response to the first stimulus reproduces quite clearly the response pattern described by Bond (1943) in cats and dogs. The two accelerative components, one of short and the other of long latency, are evident in this representation, as well as the presence of a decelerative component after the first acceleration. The rapid habituation of the second acceleration is also clearly observed.

When the response is averaged across a group of participants during 80 s after the first stimulus and expressed in terms of second-by-second HR changes with respect to a baseline of 15 s, the response pattern shows two accelerative and two decelerative components in alternating order (see Fig. 2 left panel): acceleration–deceleration–acceleration–deceleration. The first acceleration reaches its peak around second 3 and the second acceleration around second 35, the first acceleration being shorter than the second acceleration. Both accelerations are larger in amplitude than the two decelerations. Fig. 2 (right panel) also shows a simplified representation of the averaged response based on 10 points corresponding to the medians of 10 progressively longer intervals: 2 of 3 s, 2 of 5 s, 3 of 7 s, and 3 of 13 s. This simplified representation facilitates statistical analysis without altering the topographic characteristic of the response.

The above response pattern was first described by Fernández (1986a) and consistently confirmed afterwards (Vila and Fernández, 1989, Vila et al., 1992, 1997). Previous reports (Turpin and Siddle, 1978; Vila and Beech, 1978), however, had described the first and second deceleration as returns towards baseline rather than true decelerations. Several factors can explain this initial discrepancy in the description of the response. Some of these factors are (a) the use of other stimuli preceding the first noise, (b) insufficient recording period after the second acceleration, and (c) individual differences. In Vila and Beech (1978) study, for instance, where no true decelerations were observed, the intense noise was presented in the context of a conditioning study where the noise (the unconditioned stimulus) followed a visual signal (the conditioned stimulus). Another methodological limitation was to present the following conditioning trial after an interval shorter than 60 s, therefore, not allowing full development of the response pattern. Individual differences may also contribute to discrepancies in the description of the response, as commented below.

4.2. Individual differences

Research has shown important individual differences in the response pattern (Cloete, 1979; Eves and Gruzelier, 1984, 1987; Fernández, 1986b; Fernández and Vila, 1989a; Jung-Stalmann, 2003; Knott and Bulmer, 1984; Richards and Eves, 1991; Vila and Beech, 1978; Vila et al., 1992). Eves and Gruzelier (1984) classified people as accelerators and decelerator according to the presence or absence of the second acceleration. Fernández and Vila (1989a) confirmed this classification in a group of 120 participants (32 males and 88 females) using cluster analysis. However, two groups showing the second acceleration and two groups not showing the second acceleration were also identified (see Fig. 3). Of the two groups showing the second acceleration, one group displayed the response pattern described in Fig. 2,

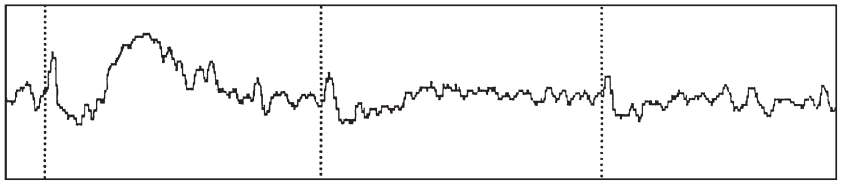

Fig. 1. Beat-by-beat heart rate recording in one participant during three presentations of an intense noise (vertical lines).

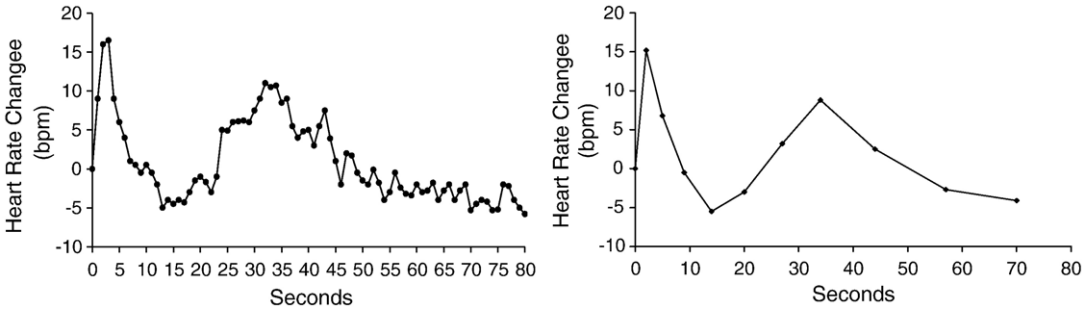

Fig. 2. Average second-by-second heart rate response of 15 participants to the first presentation of an intense noise (left), and the same data expressed in terms of the medians of 10 intervals (right).

with its four accelerative–decelerative components (cluster 1). The second group did not show the deceleration after the initial acceleration, the overall pattern being a single prolonged acceleration (cluster 2). Of the other two groups not showing the second acceleration, one group showed a return towards baseline after the first acceleration (cluster 3). The other group showed a prolonged deceleration after the initial acceleration (cluster 4).

The long-term stability of these different response patterns was demonstrated in a study where 8 participants showing the second acceleration (clusters 1 and 2) and 8 participants not showing the second acceleration (clusters 3 and 4) were tested under identical conditions in two sessions separated by 12 months (Fernández, 1986b). Long-term stability coefficients (product moment correlation and interclass reliability coefficients) were compared with short-term stability coefficients (the same coefficients obtained within a single session). In all cases, between-session coefficients were significantly higher than within-session coefficients, confirming the *remarkably constant response* reported by Bond (1943).

These differential response patterns have been found associated with various biological and psychological factors: (a) menstrual cycle (Vila and Beech, 1978); (b) gender (Vila et al., 1992); (c) personality traits (Cloete, 1979; Jung-Stalmann, 2003; Richards and Eves, 1991); (d) excessive worry (Delgado, 2006); and (e) pathological anxiety (Kley, 2004; Viedma, 2005). In particular, the second accelerative component has been found to be augmented in phobic women during the pre-mentrual phase, in men as compared to women, in people with high scores in worry and emotional instability, and in patients diagnosed of anxiety disorder. An interesting finding is the difference observed within the two accelerative patterns (clusters 1 and 2): people with excessive worry and patients with generalized anxiety disorder tend to show cluster 2 rather than cluster 1, whereas people with subclinical anxiety and patients with specific phobias tend to show cluster 1 rather than cluster 2.

4.3. Characteristics of the eliciting stimulus

Four stimulus parameters have been studied: sensory modality, intensity, duration, and rise time. Auditory, visual, and electrocutaneous stimuli, matched in subjective intensity, were examined in one study (Vila et al., 1992) and found that only the auditory and electrocutaneous modalities elicited the cardiac response pattern described in Fig. 2. The visual modality did not show any response pattern. This study also showed that *intensity* is not the only factor eliciting the response. At high intensity (109 dB for the auditory modality) the accelerative components are larger. At moderate intensity (79 dB for the auditory modality) the accelerative components are smaller but the full pattern is still present. Two other studies examined the duration and rise time of the eliciting stimulus (Ramírez et al., 2005). *Duration* of the stimulus (white noise of 105 dB and instantaneous rise time, manipulated at 5 stimulus durations: 50, 100, 250, 500, and 1000 ms) affects the amplitude of the first and second accelerative components (see Fig. 4 left panel): the first acceleration increases linearly as a function of duration (from 50 to 500 ms), whereas the

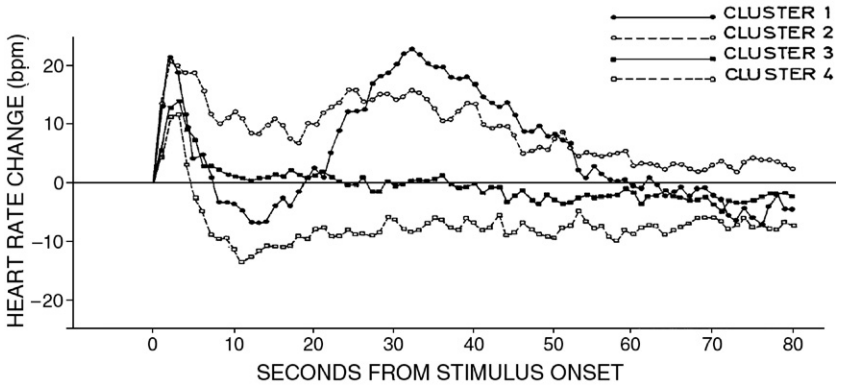

Fig. 3. Individual differences in the response pattern to the first presentation of an intense noise.

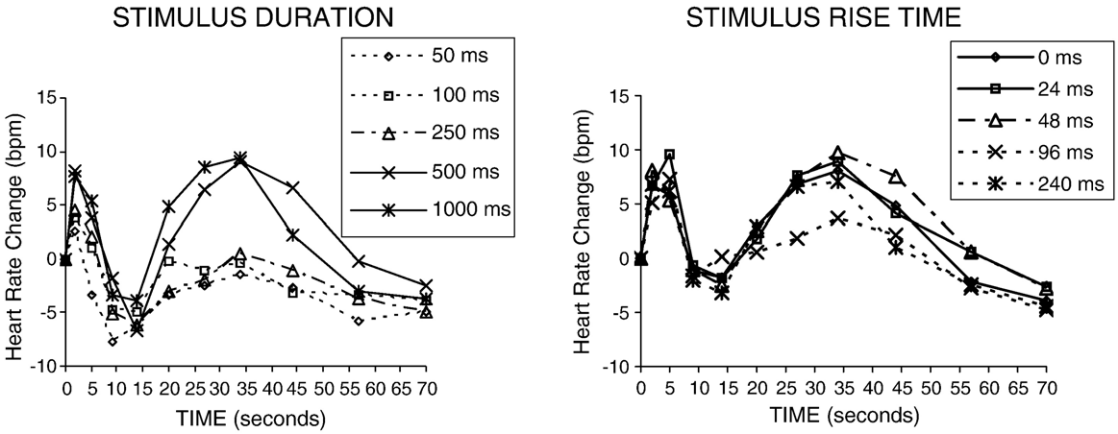

Fig. 4. Cardiac defense as a function of stimulus duration (left panel) and stimulus rise time (right panel).

full response pattern, with the second acceleration/deceleration, was present only in the two longest durations (500 and 1000 ms). Finally, *rise time* of the stimulus (white noise of 105 dB and 1000 ms duration, manipulated at 5 different rise times: 0, 24, 48, 96, and 240 ms) had no effect on any of the cardiac components. The full pattern was observed in all rise time conditions (see Fig. 4 right panel). In these two studies, the startle reflex was also examined by recording the eye blink response. It was found that, contrary to cardiac defense, duration of the stimulus did not affect the magnitude of the startle reflex, whereas rise time did. As expected, the magnitude of the startle reflex was highest at the shortest rise times (0 and 24 ms) but, after that point, the magnitude decreased linearly until almost disappears at the longest rise time (240 ms). The finding that cardiac defense is not affected by rise time (the full response pattern is observed even at 240 ms rise time), while eye-blink startle is, suggests that startle is not a necessary component of cardiac defense.

4.4. Habituation

In the studies mentioned above, repetition of the acoustic stimulus resulted in rapid habituation of the response pattern. The second acceleration/deceleration almost disappeared after the first stimulus presentation. This has been a consistent finding in studies where the intense noise was repeated several times with inter-stimulus intervals between 100 and 120 s. In these studies, the first acceleration/deceleration also showed habituation, but the habituation trend was less pronounced. Dishabituation or recovery of the response pattern has been reported after repetition of the same procedure several weeks and months later (Fernández, 1986b). There have also been reports of recovery during dual tasks where the intense noise is presented along a secondary cognitive task (Turpin, 1986).

Two recent studies have examined the habituation and dishabituation of the response within a single session manipulating the time interval between the stimuli (Mata, 2006) and the acoustic quality and meaning of the evoking stimulus (Guerra, 2007). In the first study, an intense white noise (105 dB, 500 ms duration, and instantaneous rise time) was presented three times maintaining constant the time interval between the first and third presentation (30 min) and manipulating the moment of the second stimulus presentation. This was done in such a way as to increase and decrease symmetrically the time interval in minutes between the three presentations: 2.5/27.5, 7.5/22.5, 12.5/17.5,

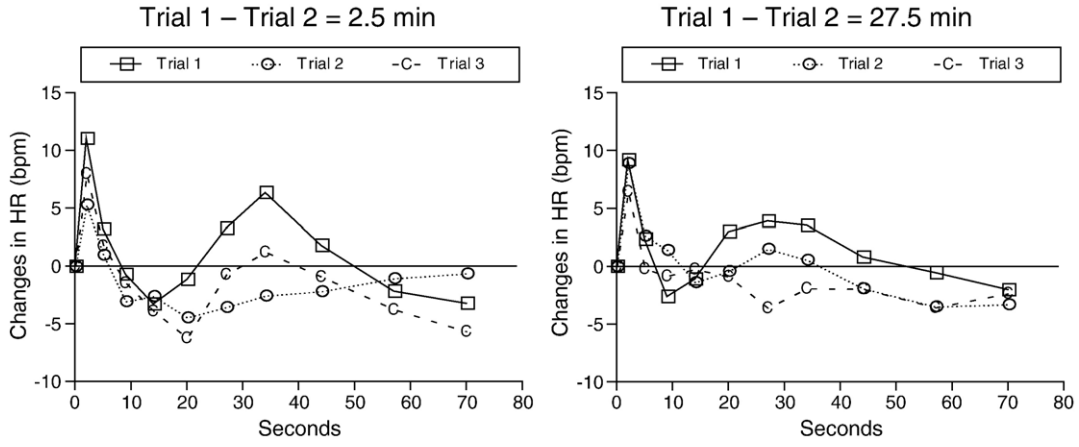

Fig. 5. Habituation and dishabituation of cardiac defense as a function of inter-trial interval (ITI). Left panel: short ITI between trials 1 and 2 (2.5 min) and long ITI (27.5 min) between trials 2 and 3. Right panel: long ITI between trials 1 and 2 (27.5 min) and short ITI (2.5 min) between trials 2 and 3.

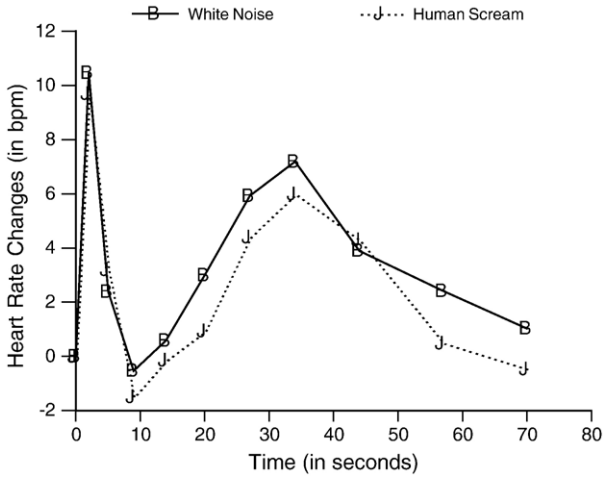

Fig. 6. Dishabituation of cardiac defense as a function of changing the acoustic quality and meaning of the eliciting stimulus: from human scream to white noise.

17.5/12.5, 22.5/7.5, and 27.5/2.5. As can be observed in Fig. 5, habituation of the response is delayed as a function of increasing the time interval between the first and second stimulus. Similarly, dishabituation of the response is facilitated by increasing the time interval between the second and third stimulus.

In the second study, a white noise and a human scream, matched in intensity and duration (95 dB and 2 s duration) were presented three times in the following sequence: 10 min rest period followed by three presentations of either the white noise or the human scream with an inter-stimulus interval of 120 s. Immediately after the last presentation, the same sequence was repeated with the other stimulus. Results are presented in Fig. 6. As can be seen, the response pattern fully recovered after habituation when the stimulus changed from human scream to white noise.

4.5. Sympathetic versus parasympathetic mediation

The physiological mechanisms underlying cardiac defense have been studied using indirect indexes of sympathetic (Pulse Transit Time and Stroke Volume) and parasympathetic (Respiratory Sinus Arrhythmia and the Baroreceptor Reflex) mediation mechanisms together with pharmacological blockade (Fernández and Vila, 1989b; Reyes del Paso et al., 1993; Reyes del Paso et al., 1994).

Pulse Transit Time, the time interval between the peak of the R-wave of the electrocardiogram and the peak of the pulse wave in the finger or in any other peripheral location, has been considered an indirect measure of ventricular contractibility and, therefore, an index of beta-adrenergic influences on the heart. A shortening of this time is interpreted as an increase in sympathetic activation. Fernández and Vila (1989b) reported an initial decrease in sympathetic activation coinciding with the first acceleration of cardiac defense followed by a sustained increase with reaches its maximum amplitude coinciding with the peak of the second acceleration. From there on, the sympathetic activation decreased in parallel with the decrease in heart rate. Identical results were obtained measuring Stroke Volume through impedance cardiography, another index of ventricular contractibility (Reyes del Paso et al., 1994). In addition, in this study, it was found that the pattern of sympathetic activation disappeared under pharmacological blockade (metoprolol), confirming the sympathetic origin of the second acceleration and second deceleration.

Respiratory Sinus Arrhythmia (RSA), the cyclical changes in heart rate coinciding with each respiratory cycle, has been proposed as a non-invasive index of vagal control, since the arrhythmia is due exclusively to vagal inhibition during inspiration. Analysis of the RSA during the evocation of cardiac defense shows a clear reduction of vagal control coinciding with the first acceleration, followed by a great increase coinciding with the first deceleration (Reyes del Paso et al., 1993). From there on, the RSA shows a smaller decrease during the second acceleration and a final increase during the second deceleration. Thus, the RSA moves in opposite directions to the heart rate changes suggesting a clear involvement of parasympathetic control during the defense response. Similar results were obtained when simultaneously recording heart rate and systolic blood pressure in order to asses the implications of the baroreflex in the elicitation of the response (Reyes del Paso et al., 1994). The baroreflex is a homeostatic mechanisms, mediated by the vagus, which is manifested by successive increases in blood pressure that are accompanied by successive decreases in heart rate, or viceversa. As in RSA, the heart rate and the systolic blood pressure moved in opposite directions during the evocation of the defense response suggesting again a clear involvement of the vagus.

In general, these findings suggest a parasympathetic dominance during the first acceleration/deceleration and a sympathetic-parasympathetic reciprocal interaction, with sympathetic dominance, during the second acceleration/deceleration.

4.6. Attentional versus motivational significance

4.6.1. Attentional involvement

The classic model of cardiac defense to intense sensory stimulation assumes an attentional interpretation of the heart rate changes. The organism protects itself against the aversive

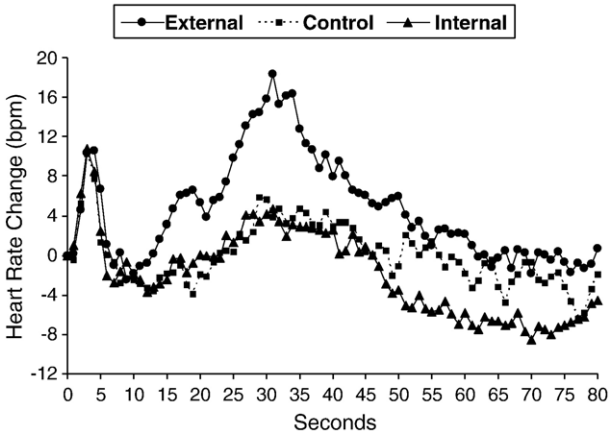

Fig. 7. Modulation of cardiac defense by directing attention towards external cues.

stimulus by reducing external sensory processing ('closing sensory input', 'stimulus rejection'). Accordingly, cardiac defense should correlate positively with indexes of sensory rejection (internal attention) and negatively with indexes of sensory intake (external attention), to use Lacey's terminology. Several studies have addressed this issue and have consistently found the opposite prediction: a positive relationship of cardiac defense with attentional processes of sensory intake (external attention).

In one of these studies (Vila et al., 1997), the evocation of the defense response was superimposed on a secondary task in which the direction of the attentional mechanism (external versus internal) was manipulated. Participants had either to press a telegraph key tracking an external light that came on and went off every half second during the 80 s in which the cardiac response was evoked (external attention), or to press the same key in coincidence not with the light but with the perception of their heart beats (internal attention). Fig. 7 shows the results of this study. There is a clear potentiation of the second accelerative component of the response when participants were performing the externally-directed attention task. This modulatory effect of external attention is consistent with a significant relationship found in a previous study (Fernández and Vila, 1989c) between the presence of the second accelerative component and greater cardiac reactivity in a simple reaction time task (external attention), but not in a mental arithmetic task (internal attention).

Two other studies have examined the direction of attention, together with the amount of mental workload, using visual and memory search tasks at different levels of task difficulty (Pérez et al., 2000; Ramírez, 2003; see Vila et al., 2003). In the visual search task, participants had to detect a letter within a currently presented set of letters (external attention). In the memory search task, participants had to recognize a letter as belonging or not to a previously-memorized set of letters (internal attention). In addition, two levels of task difficulty were manipulated. Results of both studies again show a potentiation of the second accelerative component of the response in the external attention condition, with no effect of task difficulty.

4.6.2. Motivational involvement: emotion

The motivational approach to cardiac defense assumes an energetic interpretation of the heart rate changes. The organism protects itself by preparing for active defense such as fight or flight. Accordingly, cardiac defense should be a heart rate acceleration which becomes potentiated when participants are under negative emotional states triggered by danger or threat signals. Several studies have addressed this issue using Lang's startle probe paradigm (Lang, 1995). This paradigm examines the modulation of the eye-blink startle response by viewing affective pictures selected from the IAPS ('International Affective Picture System').

The IAPS consists of a large set of colour pictures evaluated in three emotional dimensions: valence (pleasant–unpleasant), arousal (relaxed–activated), and dominance (dominant–submissive). The startle probe paradigm superimposes acoustic probes while people view emotional pictures. One of the most consistent findings using the startle probe paradigm is the potentiation of the eye-blink response when people are viewing fearful or unpleasant pictures and the inhibition of the eye-blink response when people are viewing pleasant ones, as compared to neutral pictures (Bradley, 2000; Lang, 1995; Lang et al., 1990, 2000). This opposite effect has been explained as due to the congruence versus incongruence between the motivational system engaged by the perceptual stimuli and the type of reflex being elicited (*motivational priming hypothesis*): unpleasant pictures that engage the aversive motivational system potentiate defensive reflexes whereas pleasant pictures that engage the appetitive motivational system inhibit them (Lang, 1995).

In our studies, we have examined the effect of viewing unpleasant and phobic pictures on both cardiac defense and eye-blink startle by using acoustic stimuli of long duration (500 or 1000 ms) and short rise time (instantaneous) in order to elicit both reflexes. In the first study (Sánchez et al., 2002), we used three pleasant, three neutral, and three unpleasant pictures counterbalancing the order of presentation. The acoustic stimulus was presented at mid-point of the six-second viewing period for each picture. Results not only show a clear potentiation of cardiac defense to the first noise when participants were viewing the unpleasant picture, but also a profound modification of the pattern of the response: the first deceleration disappeared and the two accelerations seemed to join into a single larger and longer acceleration (see Fig. 8). This effect was only observed in the first trial. No differences were found between the pleasant and neutral pictures, both showing a general attenuation of the response pattern. As regards the eye-blink results, they reproduced the expected findings: augmentation during the unpleasant pictures and reduction during the pleasant ones, as compared to the neutral pictures. This effect was greater in the second and third trial than in the first trial, suggesting the presence of a sensitization effect along the defense trials.

A second study examined the effect on cardiac defense and eye-blink startle of viewing phobic and non-phobic pictures. We expected an even greater potentiation of cardiac defense under these conditions. Three groups of participants were examined: (a) a group of animal phobic but not blood phobic participants;

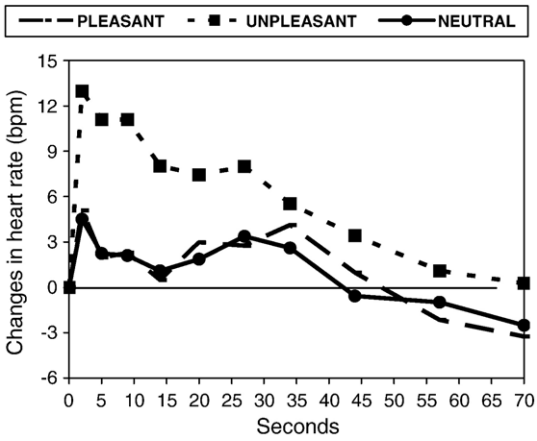

Fig. 8. Modulation of cardiac defense by viewing unpleasant pictures.

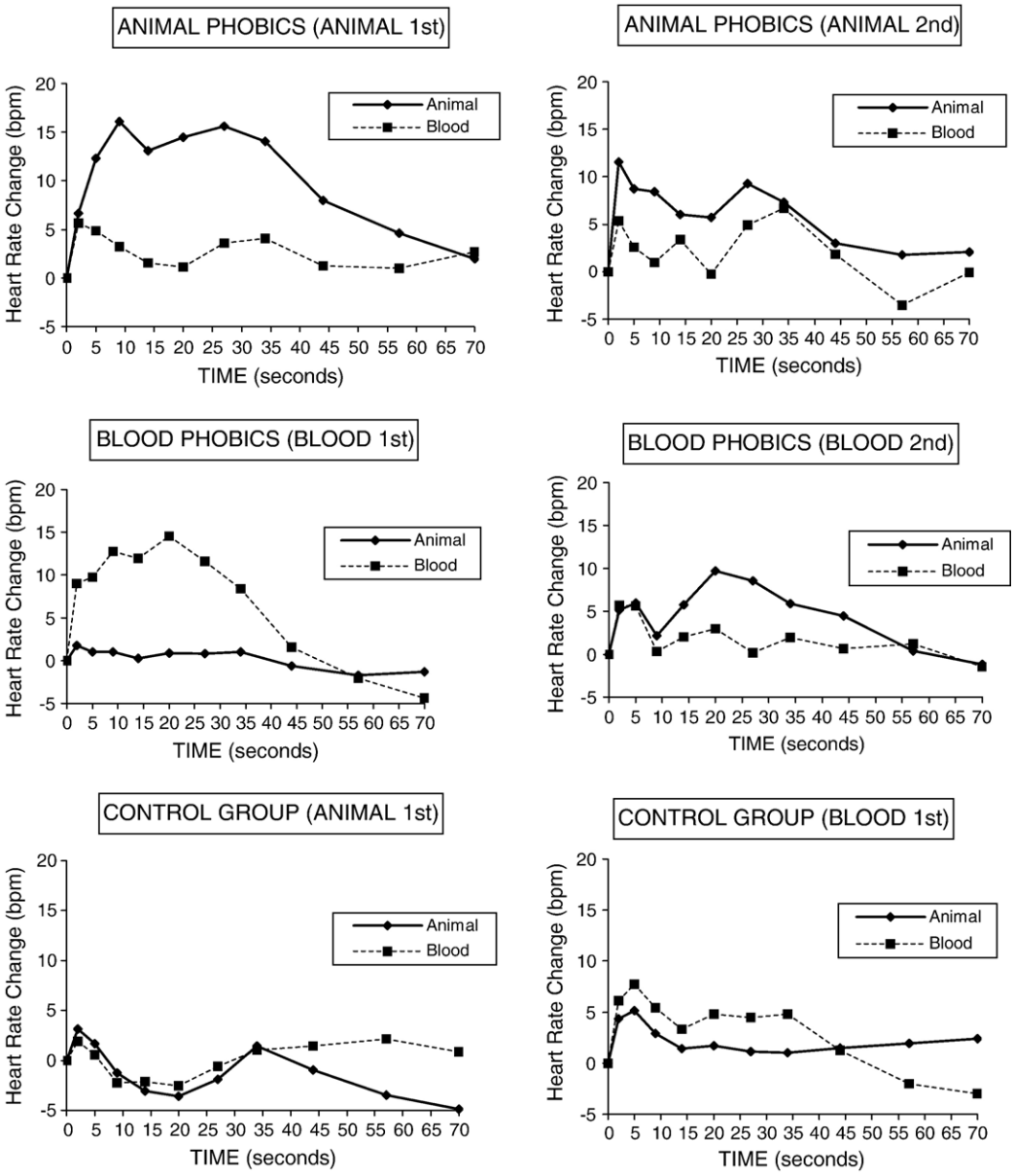

Fig. 9. Modulation of cardiac defense by viewing phobic pictures. Response patterns of animal phobics (top panels), blood phobics (middle panel) and controls (bottom panels) while viewing an animal and a blood picture controlling order of presentation: phobic picture first (left panels) or phobic picture second (right panels).

(b) a group of blood phobic but not animal phobic participants; and (c) a group of participants with no fear of animals or blood. All participants had two defense trials: one while viewing a picture of the phobic animal and the other viewing a picture of blood, in counterbalanced order. Results, again, show a clear potentiation of the accelerative components of the response when phobic participants were viewing their phobic object, as compared to their non-phobic objects, or to both objects in non-phobic participants (see Fig. 9). As could be expected, the effect was greater when the phobic picture was presented first and the non-phobic picture second (Fig. 9 left panels), due to the potentiation effect on the phobic picture (trial 1) and the habituation effect on the non-phobic one (trial 2). In the reverse order (non-phobic picture first and phobic picture second), the differences diminished due to the absence of potentiation on the non-phobic picture (trial 1) and reduced habituation on the phobic one (trial 2) (Fig. 9 right panels). As regards eye-blink startle, the results again reproduced the expected findings: greater amplitude when phobic participants were viewing their phobic picture as compared to their non-phobic picture and to both pictures in non-phobic participants. However, in this case, the time course of the potentiation was the opposite of cardiac defense: the effect was greater when the non-phobic picture was presented first and the phobic picture second due to the expected effect of sensitization on eye-blink startle.

A third study has examined this priming effect under conscious and non-conscious presentation of the phobic pictures by using a backward masking procedure (Ruiz-Padial et al., 2005; Ruiz-Padial and Vila, 2007). Both masked and unmasked presentation groups showed potentiation of the cardiac defense response when

viewing their phobic picture, as compared to the non-phobic one, reproducing the same time course of the potentiation as in the previous study: greater difference when the phobic picture was presented first and the non-phobic picture second. The masked presentation group showed the same effect although diminished in amplitude. As regards eye-blink startle, both groups showed again startle potentiation while viewing the phobic picture, the time course of the potentiation being reverse due to the expected sensitization effect: greater difference when the phobic picture was presented second and the non-phobic picture first.

4.7. Summary of findings

The studies reported above do not support a description of cardiac defense as a sympathetically mediated heart rate acceleration that is unspecific regarding the sensory modality of the eliciting stimulus, shows slow habituation, and helps to decrease sensory processing. Firstly, the response is a complex pattern that, depending on the context and the individual, shows different accelerative and decelerative components along the 80 s after stimulus onset. In unselected group of people and with no secondary task overimposed, the average response pattern is characterized by two accelerative and two decelerative components in alternating order: acceleration–deceleration–acceleration–deceleration. Secondly, the response pattern is elicited by unexpected intense acoustic or electrocutaneous stimulation, but not by visual stimulation. Stimulus duration is a crucial factor for its elicitation – not shorter than 500 ms-while rise time is not – rise times that eliminate motor startle can still elicit the full cardiac response pattern. Third, the response shows fast habituation with stimulus repetition. The second acceleration and second deceleration are the response components showing the fastest habituation. However, habituation can be delayed by increasing the time interval between the stimulus repetitions both within and between sessions. Similarly, dishabituation can be facilitated by changing the sensory quality and meaning of the stimulus (from natural to artificial noise). Fourth, the underlying physiological mechanism of this response pattern includes both sympathetic and parasympathetic influences. The first acceleration/deceleration is controlled by parasympathetic influences: inhibition during the first acceleration and activation during the subsequent deceleration. The second acceleration/deceleration is controlled by sympathetic and parasympathetic influences working reciprocally: sympathetic activation accompanied by parasympathetic inhibition during the second acceleration and sympathetic inhibition accompanied by parasympathetic activation during the second deceleration. And fifth, the functional significance of the response includes both attentional and motivational factors, the attentional factors being related to external attention, increasing rather than decreasing sensory processing.

5. An attentional-motivational model of cardiac defense

5.1. The defense cascade

The description of cardiac defense to intense acoustic and electrocutaneous stimulation as a response pattern with both accelerative and decelerative components, with both sympathetic and parasympathetic influences, and with both attentional and motivational significance highlights the dynamic character of the defense reaction, obvious in natural settings. As has been emphasized by animal researchers (Blanchard and Blanchard, 1989; Fanselow, 1994), in natural settings such as the imminence of a predator, the defense reaction is not a single response that could be conceptualized either as attentional or motivational. Rather, the defense reaction follows a dynamic sequence or cascade of responses with initial phases in which aversively motivated attentional factors predominate, aimed at detection and analysis of the potential danger, and later phases in which aversively motivated actions predominate, aimed at active defense, such as escape or attack. Thus, depending on the type and severity of the danger, its spatial and temporal proximity, and the success or failure of the initial phases to cope with it, different components of the defense reaction may take place successively.

The complex pattern of heart rate changes that characterizes cardiac defense can be better understood within this naturalistic perspective. The pattern of heart rate changes observed in response to unexpected intense aversive stimuli, with two accelerative/decelerative components, seems to reflect the succession of two defensive phases: an attentional protective phase linked to the short latency acceleration/deceleration, aimed at interruption of the ongoing activity and analysis of the potential danger, and a motivational protective phase linked to the long latency acceleration/deceleration, aimed at preparation for active defense. Thus, the pattern of cardiac defense, with the two accelerative/decelerative components, would represent the transition from attention to action preparation: (a) first acceleration/deceleration: interruption of ongoing activity and heightened attention to external cues; and (b) second acceleration/deceleration: preparation for active defense and recovery if no real danger occurs.

5.2. Change in the defense cascade

This sequential process, however, can be altered if the eliciting stimulus is primed by preceding threatening signals or if the individual is already in a pre-existing aversive emotional state. The data reported above on individual differences and emotional modulation support this view. The topographical change in the response pattern when the aversive stimulus is primed by viewing phobic and unpleasant pictures (transformed into a single large acceleration with no deceleration after the initial acceleration) suggests that the attentional phase might have already been activated by the preceding threatening signals, and that the motivational phase in preparation for protective actions have been advanced in time to better match successful adaptation. The same interpretation applies to individuals who show a single large acceleration with no initial deceleration in response to unexpected intense aversive stimuli. This response pattern has been observed in patients with generalized anxiety disorders (Viedma, 2005) as well as in non clinical population with high scores in excessive worry (Delgado, 2006). A pre-existing state of anticipatory anxiety and worry may act in the

same way as the preceding threatening pictures, i.e. priming the defense stimulus and advancing the motivational phase.

This attentional-motivational model not only allows integration of the two traditional approaches to cardiac defense. It also helps to clarify contradictory descriptions concerning its response pattern. As mentioned before, the classic model describes cardiac defense as a single accelerative response exclusively mediated by the sympathetic branch of the autonomic nervous system. This description seems to fit with the data on cardiac defense when the intense aversive stimulus is primed by anticipatory threatening signals or pre-existing anxiety states. Under such conditions the response pattern becomes a single large and long acceleration. Thus, depending on whether the defensive stimulus is emotionally primed or unprimed, cardiac defense will be described as a single sympathetically mediated acceleration or as a complex pattern of accelerations and decelerations mediated by both sympathetic and parasympathetic influences.

The attentional-motivational model of cardiac defense can also explain the other two response patterns observed in some individuals. It has been consistently reported that there are people who show either a prolonged deceleration after the initial acceleration or just a return to baseline (Bond, 1943; Eves and Gruzelier, 1984). The prolonged deceleration can be due to reduced sympathetic activation and sustained vagal control during the response. Defensive bradycardia has been reported associated with freezing (Azevedo et al., 2005; Facchinetti et al., 2006) and with perception of unpleasant pictures (Bradley, 2000). The reactive or passive coping style, described in the stress literature (Frankenhaeuser, 1986; Koolhaas et al., 1999), is also characterized by immobility accompanied by low sympathetic activation. It can be argued that people responding to intense stimulation with a prolonged bradycardia after the initial acceleration respond defensively with a response pattern that resembles the reactive or passive coping style, whereas those who respond with the two accelerative patterns resemble the proactive or active coping one. People responding with a return to baseline would be individuals with a reduced defense reaction.

5.3. Neural model of fear

The observed potentiation of cardiac defense when participants were viewing unpleasant and phobic pictures supports the *motivational priming hypothesis* proposed by Lang and colleagues to explain the potentiation of defense reflexes (Lang, 1995; Lang et al., 2000). It also supports the neural model of fear proposed by neuroscientists such as Davis (1992) and LeDoux (2000). According to the *motivational priming hypothesis*, aversive pictures that engage the defensive motivational system potentiate protective reflexes. The studies reported above have shown that such a potentiation is not limited to motor reflexes such as eye-blink startle. It also extends to autonomic reflexes such as cardiac defense. This extension is consistent with the neural circuit underlying the fear potentiation phenomenon. The fear circuit has the central nucleus of the amygdala as the key structure receiving inputs from the sensory thalamus and various cortical structures, and projecting on subcortical and brainstem areas that directly mediate specific defensive and fear reactions such as freezing (central gray), startle (nucleus reticularis pontis caudalis), facial expressions (facial motor nucleus), and autonomic responses (lateral hypothalamus).

This hierarchical organization of the fear neural circuit, with common modulatory structures and different local pathways for different defense reactions, can explain the similarities and differences observed between cardiac defense and eye-blink startle. Both reflexes can be elicited by intense acoustic stimulation and both show similar affective potentiation. However, the parametric characteristics of the eliciting stimuli and the time course of the response are different. The whole pattern of cardiac defense requires an eliciting stimulus of long duration but no specific rise time. In contrast, eye-blink startle can be elicited with short and long stimulus durations, but requires very short rise times. Therefore, by manipulating the duration and rise time of the stimulus it is possible to evoke (a) both cardiac defense and eye-blink startle (using stimuli of long duration and short rise time); (b) cardiac defense alone (using stimuli of long duration and long rise time); and (c) eye-blink startle alone (using stimuli of short duration and short rise time). When the two reflexes are elicited simultaneously using acoustic stimuli of long duration and short rise time, differences also appear with regard to habituation and sensitization. Whereas cardiac defense habituates rapidly, eye-blink startle habituates slowly or even shows sensitization.

The differential habituation/sensitization effect for cardiac defense and eye-blink startle requires explanation. It can be argued that fast habituation of cardiac defense, in particular its long latency acceleration/deceleration, can be due to disconfirmation of danger after the initial trial. An intense unexpected noise signals a potential danger that requires attention and preparation for quick action. If the potential danger is not confirmed, in subsequent presentations of the acoustic signal there will be no need for further response mobilization (the second acceleration/deceleration). The sensitization of eye-blink startle, when elicited simultaneously with cardiac defense, can be explained as due to emotional priming after the first defense trial: after this trial, the organism is in an aversive emotional state that, according to the *motivational priming hypothesis*, can potentiate subsequent startle. Thus, if cardiac defense and eye-blink startle are additionally potentiated by viewing aversive pictures, a synergistic effect will take place with different time courses: in the first trial for cardiac defense and in subsequent trials for eye-blink startle.

5.4. Defense and stress

The attentional-motivational model of cardiac defense also has implications for the stress concept and stress related illnesses. The traditional cognitive and motivational approaches did not emphasize the dynamic character of the defense reaction, or the simultaneous involvement of different physiological and psychological processes. The new approach fits better with the prevalent model of stress in health-related disciplines: the cognitive-transactional model (Lazarus and Folkman, 1984).

The continuous dynamic interaction between the situation and the person, leading to activation or deactivation of defense reactions, is the main feature of the transactional model. Furthermore, the new model to defense can help to better define the specific nature of stress, differentiating it from other related concepts such as fear, anxiety, or arousal. The focus of the cognitive-transactional model has been the activating mechanisms of stress (cognitive appraisal of the environmental demands and of coping strategies), the fundamental nature of stress (whether a cognitive, emotional, or motivational process) being less clearly defined. Based on the attentional-motivational model, stress can be defined as the *sustained activation of the brain's defense motivational system*. This definition emphasizes the motivational nature of stress, the difference between stress and defense being the momentary versus sustained activation of the defense system. A state of maintained activation of this system implies a variety of specific defense responses being continuously or intermittently elicited, including neural, endocrine, and immunological responses that correlate, in the long term, with poor physical and mental health (Lovallo and Gerin, 2003; Turner, 1994).

Stress, like defense, is neither a cognitive (i.e., attention, appraisal) nor emotional (i.e., fear, anxiety) process. However, the sustained activation of the defense system implies the involvement of both cognitive and emotional processes. The way individuals assess and cope with dangerous or threatening situations plays a key role in the activation or deactivation of the defense motivational system and, therefore, in its maintenance, transforming the momentary and functional defense response into chronic dysfunctional stress. Similarly, the activation of the defense system by danger or threat implies the simultaneous activation of emotional responses such as fear and anxiety. There is a growing body of evidence that allows differentiation between fear and anxiety based on specificity of the eliciting stimulus (fear is understood as the emotional reaction to specific danger whereas anxiety is considered to be elicited by unspecific contextual threatening signals), the presence versus absence of coping behavioral responses (escape/avoidance), and differential brain structures controlling fear and anxiety (the central nucleus of the amygdala for fear and the bed nucleus of stria terminalis for anxiety) (Lang et al., 2000; Öhman and Mineka, 2001). Finally, the definition of stress as the sustained activation of the defense motivational system also allows differentiating stress from general or appetitive arousal. Only sustained defensive arousal, either by itself or in combination with simultaneous activation of the appetitive system (approach–avoidance conflict), would qualify as stress.

6. Conclusion

The studies reported here shows that, contrary to the classic model, cardiac defense to intense acoustic stimulation is a complex pattern of heart rate changes with accelerative and decelerative components, with sympathetic and parasympathetic physiological mediation, and with cognitive and motivational significance. This response pattern is congruent with an interpretation of the defense reaction as a sequence of responses from heightened attention to active defense. This interpretation helps to understand individual differences in defense styles, as well as the simultaneous modulation of defense reflexes by attentional and emotional factors, allowing integration of the two opposite traditional approaches to cardiac defense: the cognitive and the motivational. However, our present knowledge is still limited. Future research will need to confirm and extend the present findings, as well as to advance knowledge on the brain mechanisms underlying cardiac defense and other protective responses that are critical for adaptability and health.

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