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Resilience and vagal tone predict cardiac recovery from acute social stress

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Abstract

Previous studies showed that heart period decreases during and recovers after an acute stress. We investigated if individual predispositions and emotional priming influence heart period recovery after a speech stress task. Psychometric scales and resting cardiac vagal tone were used to measure individual traits. The presentation of a sequence of either pleasant or unpleasant pictures, as emotional primers, preceded the speech stress. Heart period was measured throughout the experiment. Stress induced tachycardia irrespective of emotional priming or traits. In the recovery period, participants with higher resting cardiac vagal tone or presenting higher resilience significantly reduced the heart acceleration. Furthermore, these traits interacted synergistically in the promotion of the recovery of heart period. Pleasant priming also improved recovery for participants with lower negative affect. In conclusion, the stress recovery measured through heart period seemed dependent upon individual predispositions and emotional priming. These findings further strengthen previous observations on the association between greater cardiac vagal tone and the ability to regulate emotion.

Keywords: *Emotional priming, heart period, heart rate variability, international affective picture system (IAPS), speech stress, resilience*

Introduction

Resilience is a dynamic process involving an interaction between both risk and protection factors, internal and external to the individual, that act to modify the effects of an adverse life event (Rutter 1999). It corresponds to the process of adapting well in the face of adversity, trauma, tragedy, threats of harm or other significant sources of stress (Yehuda et al. 2006). Resilience has been thought of as not so much an invulnerability to stress, but rather as an ability to recover from negative events (Garmezy 1991).

The study of psychophysiological factors is critical for the understanding of successful adaptation to stress. The autonomic system, particularly parasympathetically-mediated cardiac recovery, plays a key role in both the organism's adaptive response and in the recuperation from the effects of stress. It has been proposed that individuals with greater cardiac vagal tone may show more endurance under stressful situations inasmuch as they are constitutionally more open to experience and more capable of self-soothing under stress (Movius and Allen 2005; Porges 2007).

Another important internal factor that is presumed to modulate the recovery from stress is the individual variability in affective predisposition. The finding that positive emotions facilitate adaptive coping and adjustment to acute and chronic stress has been extensively documented (Tugade et al. 2004). On the other hand, negative traits have been shown

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to be associated with increased susceptibility to ill health and disease (Thayer and Brosschot 2005).

External factors may influence mood states and, potentially, affect recovery from stress. A number of paradigms have been developed for inducing mood states in laboratory settings and include techniques as diverse as listening to music, watching movies, imagining scenes, recalling past life events, and winning or losing money. Perhaps the most widely employed paradigm is the presentation of pictures from the International Affective Picture System (IAPS) (Lang et al. 1999). These stimuli evoke psychophysiological reactions that are interpreted as signaling the pre-activation of basic motivational systems to approach pleasant and avoid unpleasant stimuli (Bradley et al. 2001). Presentation of a series of affective pictures of similar valence produces emotional and behavioral reactions that are sustained over time (Azevedo et al. 2005; Pereira et al. 2006).

The goal of this study was to investigate the effects of resilience, cardiac vagal tone, and affective predispositions modulated by pleasant or unpleasant stimuli upon the recovery of heart period from an acute social stress. For this purpose, participants first filled out psychometric measures of resilience and affective traits and then had their resting cardiac vagal tone recorded. Next, they were shown series of either pleasant or unpleasant affective pictures selected from the IAPS that functioned as positive or negative emotional primers, respectively. Finally, all subjects undertook a speech stress task. Heart period was measured throughout the experimental session.

Materials and methods

Sixty-four undergraduate students (34 women, 30 men) from the Federal University of Rio de Janeiro aged 21.4 (SD = 3.54) years volunteered for this study. Participants were all non-smokers, reported no mental disorders and were not taking any medication at the time of the experiment. All volunteers gave written, informed consent and were told of their right to discontinue their participation in the study at any time. The study protocol was approved by the Institutional Review Board of the Federal University of Rio de Janeiro.

Three psychometric measures were used to evaluate individual traits. The Positive and Negative Affect Schedule-trait version (PANAS-T) (Watson et al. 1988) is a 20-item scale consisting of adjectives that describe mood traits. Participants are asked to rate the degree to which they feel each emotion *in general*. They rated each mood adjective on a 1–5 scale (1, very slightly or not at all to 5, extremely). The questionnaire is divided into two subscales: positive affect (PA) and negative affect (NA). The Ego-Resiliency Scale (ER-89) (Block and Kremen 1996) is a 14-item scale consisting of phrases that describe resilience traits. This scale measures the quality of resilience by assessing the way each person manages the fluctuations in daily life and what they do about their own experiences. Subjects rated each phrase on a 1–4 scale (1, does not apply at all to 4, applies very strongly). High score in the ER-89 suggests that the respondent possesses above-average resilience qualities. Such individual could be expected to have a secure personality marked by energy, enthusiasm and ability to recover from stress, to enjoy the company of others and to be generous. The State-Trait Anxiety Inventory (STAI-T) (Spielberger 1983) is a 20-item scale consisting of phrases which refers to a relatively stable disposition to respond to stress with anxiety and a tendency to perceive a wider range of situations as threatening. The instructions asked participants to rate how they feel *in general*. They rated each phrase on a 1–4 scale (1, almost never to 4, nearly always).

Respiratory effort and electrocardiographic (ECG) recordings were collected simultaneously at a sampling frequency of 240 Hz to measure respiratory frequency and heart period, respectively. Data acquisition and analysis employed Acknowledge (BIOPAC Systems, Inc. EUA) and Matlab 6.5 (Math Works) software, respectively. An off-line peak detection algorithm (derivative plus threshold) was used to estimate R-wave fiducial points, after which the series was screened by hand and corrected for artifacts. R-R interval series were re-sampled by cubic spline interpolation at 2 Hz and generated heart period (HP), following the recommendations of the Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology (1996). We performed spectral analyses using a Fast Fourier Transform (FFT) algorithm on the resting tachogram to extract the amplitude of the high frequency (HF: 0.15–0.4 Hz) power of the heart rate variability (HRV). The HF-HRV has been associated with respiratory-modulated parasympathetic outflow and used to index "vagally" mediated HRV or cardiac vagal tone (Hayano et al. 1991). In addition, spectral analyses of respiratory data using a FFT algorithm were calculated to exclude participants presenting spontaneous breathing outside the HF band.

In preparation for the study, participants were asked to abstain from alcohol during the 24 h preceding the experiment, from caffeine and forced exercise at the day of the test, and from food and drink (except for water) for 1 h before the experimental session. All subjects were tested at approximately the same time in the afternoon. Volunteers had a 30 min period of adaptation during which psychological traits were assessed through questionnaires. After that, participants were seated in front of a monitor and ECG electrodes and a respiration belt (around the middle ribs) were attached. They received instructions to relax during 2 min while baseline measures were made. Next, a set of affective pictures were presented on the monitor. Participants were randomly assigned to one of two groups: "pleasant-primed" or "unpleasant-primed". The pictures† were selected from the International Affective Pictures System (Lang et al. 1999). The pleasant set comprised 40 pictures featuring families and babies, nature scenes, puppies, sports and romance. The 40 pictures of the unpleasant set showed mutilated bodies, human and animal attack, pollution and accidents. According to published norms (Lang et al. 1999), the mean scores on a 9-point rating scale for the hedonic valence and the arousal dimensions of the selected pictures were respectively 7.5 (SD = 0.49) and 5.1 (SD = 1.10) for the pleasant block; and 2.5 (SD = 0.88) and 6.3 (SD = 0.82) for the unpleasant block. Each picture was presented for 5 s with an inter-picture interval of 2 s. The block presentation, including preliminary instructions, lasted 5 min. Next, participants were given 3 min to rate the global valence and arousal of the whole set of pictures they had just seen using a modified version of the Self Assessment Manikin Scale (Lang et al. 1999). Afterwards, participants were given 5 min to prepare a speech about a neutral theme. They were told that the session would be video-taped and that the experimenters would monitor them through a camera. Additionally, the speech task instructions stated that the performance tape would be later evaluated by senior researchers. Speech delivery had a mean duration of 5.8 (SD = 1.38) min. After speech delivery, participants were instructed to relax for 5 min.

Physiological parameters were continuously monitored during the whole session. Heart periods were averaged over 2 min from samples at baseline, beginning of the speech preparation and during the fourth and fifth minutes after the end of the speech delivery (recovery). The first 2 min of the task were used because it has been shown that cardiac reactivity peaks early, when novelty and uncertainty are greatest, and then declines with continuous exposure (Kelsey et al. 1999).

Age and traits were compared between the two emotional priming groups by Student's *t*-test for independent samples. Based on a mean-split of each trait score, participants in the pleasant-primed or unpleasant-primed groups were independently assigned to "low" or "high" sub-groups. The high frequency power of heart rate variability (cardiac vagal tone) was also averaged and those presenting values below or above the mean were assigned, respectively, to the low and high sub-groups. Modulation of heart period was evaluated using mixed designs ANOVA with Greenhouse–Geisser correction. One ANOVA was performed with TIME (basal, preparation and recovery) as a within-subject factor and EMOTIONAL PRIMING (pleasant and unpleasant) as a between-subject factor. The other five ANOVAs were similar to the previous one except for including each TRAIT (high and low), that is—resilience, cardiac vagal tone, negative affect, positive affect and anxiety—as between-subject factors. *Post hoc* tests were performed with Tukey's HSD. Spearman correlations analysis was used to evaluate the relationship between the individual predispositions. Finally, a multiple linear regression model (Kleinbaum et al. 1998) was used to investigate the existence of a multiplicative interaction suggested by the ANOVA analyses. For the regression analysis, the dependent variable was constructed from the difference between heart period during recovery minus heart period during preparation.

Statistical significance was taken as $p < 0.05$.

Results

Participants in the pleasant-primed and unpleasant-primed groups did not differ significantly with respect to age and traits. Five participants were excluded from the analyses of heart period data, three of them due to technical problems with the recording and the other two due to basal respiratory rates above the established normal range.

As expected, valence ratings for the pleasant sequence of pictures were significantly different from those of the unpleasant series ($t = 11.96$, $p < 0.001$). On the arousal dimension, the comparison of the ratings for the two groups of participants did not reach statistical significance ($t = -1.65$, $p = 0.1$).

To investigate the relationships between the predisposition traits, we ran a series of pair-wise correlations between the measures, as depicted in Table I. This analysis showed that resilience correlated directly with positive affect and inversely with anxiety. Further, negative affect correlated directly with anxiety.

The examination of differences in heart period through the TIME × EMOTIONAL PRIMING mixed design ANOVA revealed a significant TIME effect ($F_{(2,114)} = 40.18$, $p < 0.001$, $\epsilon = 0.91$), with significantly decreased heart period during preparation compared to basal ($p < 0.001$) and increased heart period during recovery compared to preparation ($p < 0.001$). Thus, as a whole, participants reacted to and recovered from stress.

Next we conducted a series of mixed design ANOVAs to explore the role of individual predisposition factors in the cardiac recovery from stress. The

†IAPS numbers for unpleasant pictures in the sequence of presen-tation used here are: 3530, 6260, 6350, 3500, 6313, 6560, 6570, 6312, 1050, 1120, 1300, 1930, 1303, 1321, 1220, 1931, 3060, 3110, 3130, 3170, 3000, 3053, 3064, 3030, 9600, 9910, 9920, 9921, 9911, 9912, 9611, 9620, 9300, 9320, 9290, 9373, 9390, 9340, 9560, 9410; for pleasant pictures are: 5000, 5760, 5780, 5830, 5600, 5200, 5260, 5982, 2070, 2340, 2360, 2311, 2345, 2341, 2057, 2260, 1460, 1750, 1440, 1710, 1920, 1721, 1463, 1722, 8190, 8200, 8210, 8400, 8180, 8370, 8490, 8185, 4660, 4533, 4532, 4599, 4641, 4640, 4250, 4608.

Table I. Spearman correlations among the individual trait variables.

	Resilience	Cardiac vagal tone	Positive affect	Negative affect	Anxiety
Resilence					
Cardiac vagal tone	0.001				
Positive affect	0.344*	− 0.032			
Negative affect	− 0.168	0.034	0.229		
Anxiety	− 0.271*	− 0.026	− 0.064	0.47*	

* $p < 0.05$.

first ANOVA (TIME × EMOTIONAL PRIMING × TRAIT-resilience) revealed a significant interaction between TIME and TRAIT-resilience ($F_{(2,110)} = 5.59$, $p = 0.006$, $\epsilon = 0.91$), such that only the participants in the high resilience subgroup significantly increased heart period during recovery as compared to preparation phase ($p < 0.001$) (Figure 1). There were no significant interactions of EMOTIONAL PRIMING with the other factors (TIME and TRAIT-resilience).

Second, we found a significant interaction between TIME and TRAIT-vagal tone ($F_{(2,110)} = 4.47$, $p = 0.017$, $\epsilon = 0.90$). Only those subjects with high basal vagal tone significantly increased heart period during recovery as compared to the preparation phase ($p < 0.001$) (Figure 2). There were no significant interactions of EMOTIONAL PRIMING with the other factors (TIME and TRAIT-vagal tone).

Third, there was a significant triple interaction between TIME, TRAIT-negative affect and EMOTIONAL PRIMING ($F_{(2,110)} = 8.50$, $p < 0.001$; $\epsilon = 0.97$). Only those with low negative affect and exposed to pleasant priming significantly increased heart period during recovery compared to preparation ($p < 0.001$) (Figure 3).

Finally, there were no significant effects for TRAIT-positive affect and TRAIT-anxiety.

To explore if the effects of resilience and vagal tone upon cardiac recovery (heart period during recovery minus preparation) were synergic we conducted a multiple linear regression. It must be noted that co-linearity between these variables was already excluded (Table I). Modeling strategy consisted in entering first cardiac vagal tone and resilience as independent variables. After that, we added the interaction term including both variables. The model revealed that

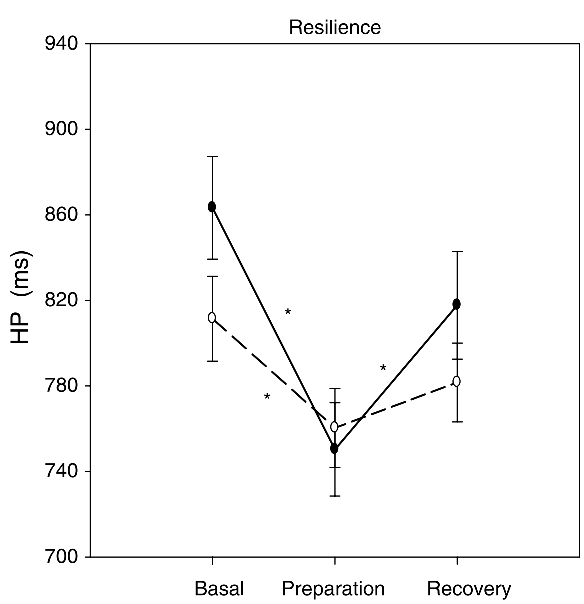

Figure 1. Resilience and cardiac recovery from speech stress task. Modulation of heart period (HP) is depicted at three time points: basal, preparation and recovery. Note that diminished HP corresponds to heart rate acceleration. Based on a mean-split of the Ego-Resilience scale, participants were assigned to “high” or “low” sub-groups. High resilient participants ($n = 29$) are represented by solid lines, and low resilient participants by dashed lines ($n = 30$). The graph shows mean and standard errors of HP. Asterisks indicate statistical significance $p < 0.05$.

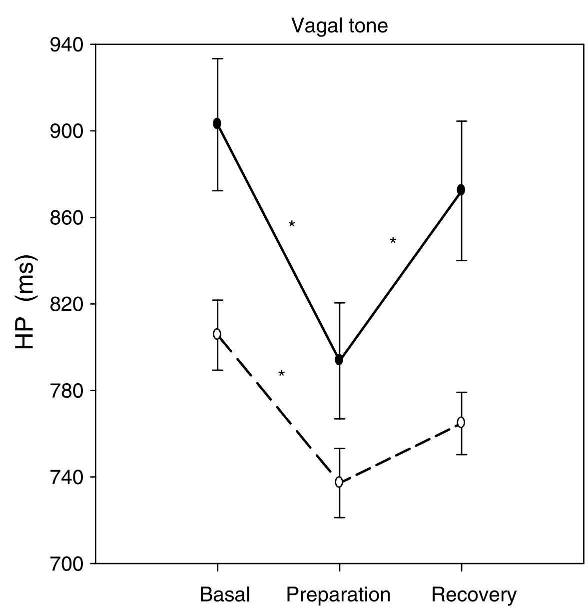

Figure 2. Cardiac vagal tone and cardiac recovery from speech stress task. Modulation of heart period (HP) is depicted at three time points: basal, preparation and recovery. Based on a mean-split of the resting cardiac vagal tone, participants were assigned to “high” or “low” sub-groups. High vagal tone participants ($n = 19$) are represented by solid lines, and low vagal tone participants by dashed lines ($n = 40$). The graph shows mean and standard errors of HP. Asterisks indicate statistical significance $p < 0.05$.

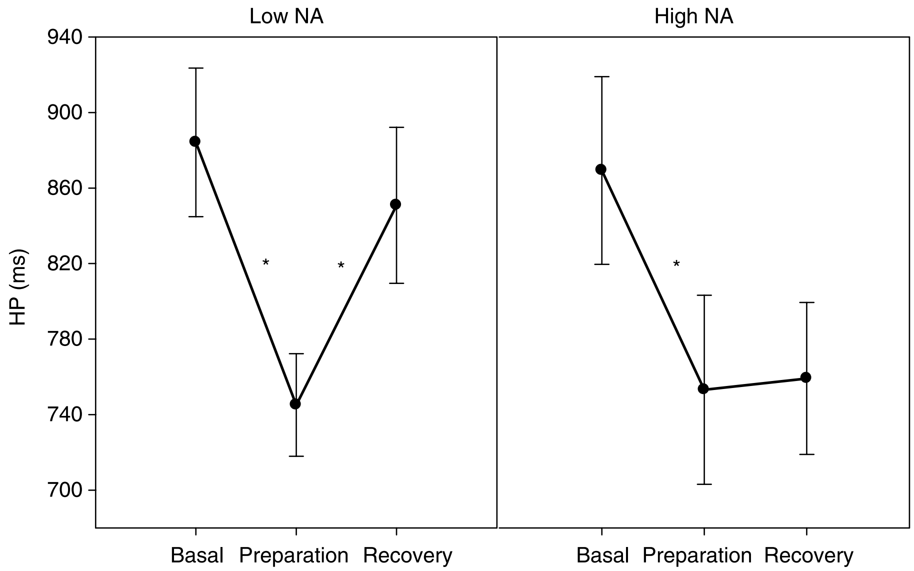

Figure 3. Pleasant priming, negative affect and cardiac recovery from a speech stress task. Only data for the pleasant-primed group are illustrated. Based on a mean-split on the negative affect (NA) scale, participants were assigned to "high" or "low" sub-groups. The graph on the left presents the results for participants with low NA ($n = 29$), and that on the right for those with high NA ($n = 30$). Modulation of heart period (HP) is depicted at three time points: basal, preparation and recovery. The graph shows means and standard errors of HP. Asterisks indicate statistical significance $p < 0.05$.

participants with increasingly higher scores on the resilience scale showed progressively more cardiac recovery from stress (coefficient $= 4.65$, $p = 0.007$). There was a trend in the same direction when modeling for the individual resting cardiac vagal tone (coefficient $= 0.009$, $p = 0.075$). More important, the analysis confirmed the hypothesis of a multiplicative interaction between these two variables to improve recovery (coefficient $= 0.002$, $p = 0.047$).

The same modeling strategy was used to analyse the interaction between emotional priming and negative affect on cardiac recovery. Neither the valence of emotional priming nor the score on the negative affect scale showed a significant effect on cardiac recovery in the multiple linear regression modeling (coefficient $= 16.19$, $p = 0.4$ and coefficient $= -2.63$, $p = 0.2$, respectively). Nevertheless, there was a significant interaction between these factors so that pleasant priming improved recovery for the participants with low scores on the negative affect scale and this effect declined for the subjects with higher scores (coefficient $= -16.87$, $p < 0.001$).

Discussion

The study tested if psychophysiological and psychometric variables predicted the recovery from decreased heart period after a speech stress. We found that only the participants with high cardiac vagal tone or those with high resilience recovered from the speech stress. Furthermore, cardiac vagal tone and resilience interacted synergistically in the promotion of stress recovery. Finally, emotional priming interacted with the negative affect trait, so that recovery was only evident in participants with low negative affect exposed to pleasant pictures.

Although early research on the linkage between stress and the autonomic nervous system tended to emphasize the role of the sympathetic branch, recent work has highlighted the relevance of the vagal system. Much of the responsibility for this change is due to the seminal work of Porges (2007), for a review on the Polyvagal Theory. This theory conceives autonomic reactivity, in particular the modulatory command of the phylogenetically "new" vagus (with its origin in the nucleus ambiguus) over heart rate variability, as an adaptive function within the context of the evolution of the vertebrate autonomic nervous system. Indeed, the high-frequency power of heart rate variability, an index of cardiac vagal tone and an important measure of autonomic flexibility, is emerging as a neurobiological marker of individual differences in the capacity for emotional regulation. High levels of basal cardiac vagal tone are associated with faster habituation to threat-related words (Thayer et al. 2000), with self-reports of enhanced regulatory control in the face of moderate to intense stressors (Fabes and Eisenberg 1997), with differentiated emotion-modulated startle reflex (Ruiz-Padial et al. 2003), and with acceptance and active coping in bereavement (O'Connor et al. 2002). On the other hand, low vagal tone is not only associated with mental disorders (Friedman and Thayer 1998) but also has a prognostic value in other systemic diseases (Thayer and Lane 2007).

In the present study, recovery from the effects of a social stress was found to be associated with high cardiac vagal tone at rest. If, as suggested by Porges (2007), modulation of vagal tone is one of the main ways through which the brain circuits regulating complex social behaviors influence interpersonal interactions, it is conceivable that individuals presenting higher vagal tone at rest are endowed with higher capacity to withstand social stresses and to recover quickly from their effects. It would be worthwhile to investigate whether the apparent psychophysiological benefits of a higher cardiac vagal tone would, in the long run, result in better health status and increased survival.

Our finding of a strong positive correlation between the scores on the Ego-Resiliency Scale and recovery from the speech stress corroborates previous work by Tugade et al. (2004). This is consistent with the notion that trait-resilient individuals are characterized by high flexibility in response to changing situational demands and by the ability to bounce back from negative emotional experiences (Block and Kremen 1996).

Although high heart rate variability has been associated with resilience (Friedman et al. 2006; Ruiz-Padial et al. 2006) scarce empirical evidence has been produced so far to substantiate this assumption. In fact, to the best of our knowledge, this study is the first to demonstrate the existence of a synergistic effect between an index of cardiac vagal tone and a psychometric assessment of resilience. Our results showed that high resilience and high cardiac vagal tone together promoted the recovery from stress to a degree that exceeds the sum of their effects separately.

Finally, we observed that pleasant priming improved cardiac period recovery in participants with low negative affect, but not in those with high negative affect. Participants primed with unpleasant stimuli did not show a significant recovery post-stress. Watson et al. (1988) proposed that individuals with lower scores on the negative affect trait are calmer and more serene and less prone to develop the psychological symptoms of distress; in contrast, individuals with higher scores are more likely to experience significant levels of distress and dissatisfaction. Therefore, under two putatively positive influences—an internal one, represented by a low predisposition towards negative affect; and an external one, brought about by the exposure to pleasant pictures—cardiac reaction to stress became more flexible and "better" regulated.

In contrast with the deleterious effects of negative priming, the beneficial effects of positive priming are relatively under studied. Our findings fit well with those of Robinson and Kirkeby (2005) who, using emotional words as primers, showed that the magnitude of the positive priming effect was predicted by higher scores on a life satisfaction scale. Taken together, these observations highlight the often underestimated role played by individual differences in affective traits in determining the effects of emotional priming.

This study has some limitations that are worth noting. First, only healthy college students were investigated, and this may have limited the generalizability of the findings to some degree. It will be important to analyze samples of different age groups and cultural backgrounds as well as clinical samples. Further, since it is conceivable that the positive primer we have used may exert its full effects only in a subgroup comprised of more susceptible individuals, it would be worthwhile to employ more efficient stimuli in future studies. Indeed, our group has recently tested another category of pictures drawn from the IAPS, consisting of pleasant scenes with an affiliative content (e.g. images of babies and/or families). These studies revealed that the viewing of pictures with affiliative content improved performance in a visual detection task (Pereira et al. 2006) and induced postural reactions that favor attachment (Facchinetti et al. 2006). We are presently testing this category as positive primer in a similar speech stress paradigm.

The present study identified a set of physiological, emotional and psychological predispositions that predict recovery from the cardiovascular effects of stress. Further, it demonstrated that some of these factors may operate synergistically. Finally, our results indicated that priming may reveal resilience factors that would have otherwise remained hidden. These findings suggest that protective factors against the deleterious effects of stress may interact in complex ways that need to be taken into account in the development of new theories and in the planning of future studies.

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