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# Cardiac vagal tone is correlated with selective attention to neutral distractors under load

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**Abstract**

We examined whether cardiac vagal tone (indexed by heart rate variability, HRV) was associated with the functioning of selective attention under load. Participants were instructed to detect a target letter among letter strings superimposed on either fearful or neutral distractor faces. Under low load, when letter strings consisted of six target letters, there was no difference between people with high and low HRV on task performance. Under high load, when letter strings consisted of one target letter and five nontarget letters, people with high HRV were faster in trials with neutral distractors, but not with fearful distractors. However, people with low HRV were slower in trials with both fearful and neutral distractors. The current research suggests cardiac vagal tone is associated with successful control of selective attention critical for goal-directed behavior, and its impact is greater when fewer cognitive resources are available.

**Descriptors:** Vagal tone, Heart rate variability, Selective inhibition, Emotion

Selective attention is defined as the ability to ignore irrelevant distractors during goal-directed behavior (Huang-Pollock, Carr, & Nigg, 2002; Lavie & Fox, 2000). Selective attention determines a variety of important outcomes, ranging from academic achievement (Rabiner, Murray, Schmid, & Malone, 2004) to the frequency of car accidents (Larson & Merritt, 1991). Several studies have shown that emotional distractors interfere with goal-directed behavior, an effect that is especially strong in people with neuropsychiatric problems, such as anxiety (Blair et al., 2007; Williams, Watts, MacLeod, & Mathews, 1988). The current research examined whether individual differences in cardiac vagal tone—associated with functioning of self-regulatory systems—are related to successful control of selective attention in the presence of emotional distractors. Specifically, we explored whether cardiac vagal tone is associated with efficiency in controlling selective attention to achieve goal-directed behavior when different levels of cognitive resources are available.

### Neurovisceral Integration Model and Cardiac Vagal Tone

According to the Neurovisceral Integration Model (Thayer & Lane, 2000), cardiac vagal tone is associated with the functioning of attentional and emotional self-regulatory systems (Berntson et al., 1997; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996; Thayer, Hansen, Saus-Rose, & Johnsen, 2009; Thayer & Lane, 2000). Specifically, neural circuits implicated in self-regulation are also involved in cardiac autonomic activity via the vagus nerve (see also Benarroch, 1993; Berntson et al., 1997; Ellis & Thayer, 2010; Levy, 1971). Robust vagal regulation of the heart is associated with effective functioning of self-regulatory neural circuits, which enables the organism to respond quickly and flexibly to various environmental demands (see Friedman, 2007; Porges, 1991; Thayer, Åhs, Fredrickson, Sollers, & Wager, 2012; Thayer & Friedman, 2004; Thayer & Lane, 2000; Thayer et al., 2009). Heart rate variability (HRV), which refers to the differences in beat-to-beat alterations in heart rate, measures cardiac vagal tone (Berntson et al., 1997; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996; Thayer & Lane, 2000). A number of studies have demonstrated that higher resting HRV is associated with effective self-regulatory function that results in better performance (e.g., faster responses and better accuracy) on executive cognitive tasks (Hansen, Johnsen, & Thayer, 2003; Thayer et al., 2009) and more flexible and adaptive emotional responses to meet various situational demands (Ruiz-Padial, Sollers, Vila, & Thayer 2003; Thayer & Lane, 2000).

In contrast, lower resting HRV is associated with a lack of prefrontal control of subcortical activity, which results in poor functioning of self-regulatory systems (Thayer & Lane, 2000; Thayer et al., 2009). Lower resting HRV is associated with dysfunctional, rigid emotional responses, such as the failure to recognize safety cues or to habituate to novel, neutral stimuli (hypervigilance; Friedman, 2007; Thayer, Friedman, Borkovec, Johnsen, & Molina, 2000; Thayer et al., 2009). For example, people with lower resting HRV produced enhanced startle

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responses to neutral stimuli, as if they were emotionally negative (Ruiz-Padial et al., 2003). Recently, an event-related potential study revealed that people with lower resting HRV have heightened neural responses to neutral faces (Park, Moon, Kim, & Lee, 2012). The hypervigilant response pattern and emotional dysregulation associated with lower resting HRV may increase the risk of developing physical and emotional problems (Park, Moon et al., 2012; Thayer & Lane, 2009). Indeed, lower resting HRV is frequently observed in people with various psychiatric disorders (e.g., panic disorder and generalized anxiety disorder; Friedman, 2007; Friedman & Thayer, 1998; Thayer & Lane, 2000).

Recent research suggests that HRV may also be implicated in emotional attention. For instance, a recent paper revealed that cardiac vagal tone is related to the ability to inhibit fearful and neutral distractors and to instigate novelty search (Park, Van Bavel, Vasey, & Thayer, 2012). Specifically, people with lower resting HRV had difficulty keeping their attention from returning to the location where fearful and neutral faces were presented. In contrast, people with higher resting HRV were able to keep their attention from returning to the location of fearful and neutral face cues (Park, Van Bavel, Vasey, & Thayer, 2012). Their ability to keep attention from being directed to the fearful distractor was most pronounced when a top-down cortical mechanism for inhibition was required (Park, Van Bavel, Vasey, & Thayer, 2012). That is, people with higher resting HRV showed greater attentional inhibition to fearful faces presented at high spatial frequency (HSF) ranges.[1] Neuroimaging studies reported that HSF fearful faces appear to be conveyed via the parvocellular pathway to the primary visual cortex and mediated by prefrontal activity (Vuilleumier, Armony, Driver, & Dolan, 2003; Winston, Vuilleumier, & Dolan, 2003). As such, HRV may be closely tied to the functioning of top-down control of attention to an emotional distractor (see also Park, Van Bavel, Vasey, Egan, & Thayer, 2012). In the current research, we expanded our previous finding by showing that high resting HRV is associated not only with highly functional inhibition of emotionally salient stimuli, but also with effective selective attention to achieve successful goal-directed behavior under different levels of perceptual load.

### Selective Attention and Cognitive Control

Selective attention allows for focusing on task-relevant stimuli in the presence of distractors (Huang-Pollock et al., 2002). According to the Load Theory of Selective Attention and Cognitive Control (henceforth referred to as *Load Theory*), the locus of selection depends on perceptual load, or the total amount of potentially task-relevant information that is available (see Lavie, 1995). In this view, perception is limited, but all stimuli are processed automatically when there is available capacity (Lavie, 1995). When the processing of task-relevant information is less demanding, spare processing capacity can be used to process irrelevant distractors (Lavie, Hirst, Fockert, & Viding, 2004). As a result, irrelevant distractors interfere with performance under low load (an effect called *distractor interference*). However, when perceptual load is high, either by increasing the amount of task-relevant information or by making the task difficult, limited processing capacity is exhausted (Lavie, 2005). As a result, there are fewer resources available to process irrelevant distractors (Lavie, 2005; Lavie & Fox, 2000).

According to Load Theory, task-relevant stimuli and task-irrelevant distractors compete for processing resources (Lavie, 1995). For effective task performance, top-down attentional control is required to facilitate the perceptual processing of task-relevant stimuli and to inhibit the processing of task-irrelevant distractors (Bishop, Jenkins, & Lawrence, 2007, Mitchell et al., 2007).[2] Indeed, research suggests that individual differences in top-down attentional control play an important role in selectively attending to target stimuli under low perceptual load (Lavie, 2005). For instance, elderly people and young children who are both characterized by limited top-down attentional capacity show greater distractor interference under low perceptual load than do young adults (Lavie, 2005; Maylor & Lavie, 1998).

A number of behavioral and neuroimaging studies have reported that the processing of emotional stimuli is prioritized: emotional stimuli grab one's attention, are detected faster, and reach awareness faster than neutral stimuli (Pourtois & Vuilleumier, 2006; see Vuilleumier & Brosch, 2009, for a review). Therefore, greater attentional control is required to prioritize processing resources to task-relevant stimuli and to inhibit the processing of task-irrelevant emotional distractors (Dolcos & McCarthy, 2006; Mitchell et al., 2007). Availability of cognitive resources under different levels of perceptual load may play an important role in determining the extent to which top-down attention control is exerted to reduce interference effects of emotional distractors. For example, it may be easier to permit top-down attentional control under low load when more cognitive resources are available than under high load when limited cognitive resources are available. Furthermore, individual differences in top-down attentional control may play an important role in exerting top-down attentional control to efficiently focus on goal-directed behavior and to inhibit emotionally salient distractors. In the current research, we examined whether individual differences in cardiac vagal tone might predict the level of interference experienced under different levels of perceptual load.

We reasoned that people with higher resting HRV, associated with superior top-down attentional control (Hansen et al., 2003, Hansen, Johnsen, Sollers, Stenvik, & Thayer, 2004; Park, Van Bavel, Vasey, & Thayer, 2012, Thayer et al., 2009), may find it easier to focus on task-relevant stimuli and inhibit attention to irrelevant emotional distractors under low load when there are ample cognitive resources available to permit top-down attentional control. In contrast, people with lower resting HRV, associated with inferior top-down attentional control, may find it more difficult to focus on task-relevant stimuli and inhibit attention to irrelevant emotional distractors even though sufficient cognitive resources are available. However, under high load, there are limited cognitive resources available to permit top-down attentional control to inhibit the processing of task-irrelevant emotional distractors. Therefore, it may be difficult—even for people with higher resting HRV—to inhibit the processing of task-irrelevant emotional distractors. As a result, they may show impaired task performance with fearful distractors under high load. However, people with higher resting HRV may have superior performance with neutral distractors under

1. The spatial frequency is described by the energy distribution in the scale specified as the number of cycles per degree of visual angle and/or the number of cycles per image, and HSF images typically contain more than 24 cycles per image (Morrison & Schyns, 2001; Park, Moon et al., 2012; Park, Van Bavel, Vasey, & Thayer, 2012; Parker, Lishman, & Hughes, 1996).

2. There may be instances, however, when task-irrelevant distractors are processed under high load (Van Bavel, Park, Hill, & Thayer, 2012).

high load because they can recognize neutral faces as "safety cues" and effectively focus on task-relevant stimuli. That is, such cues may be less distracting because they are recognized as safe. In contrast, people with lower resting HRV may show undifferentiated responses in trials with fearful and neutral face distractors under high load because they may fail to recognize neutral face distractors as "safety cues" and treat them as threatening (Park, Moon et al., 2012; Ruiz-Padial et al., 2003).

### Overview

The current research investigated whether resting HRV would predict effective control of selective attention to achieve successful goal-directed behavior under high and low perceptual load when emotionally salient versus neutral distractors were presented. Participants completed a letter detection task in which letter strings were superimposed either on fearful or neutral facial distractors and were asked to detect target letters (Bishop et al., 2007). We predicted that individual differences in HRV would potentially reflect the capacity to exert top-down attentional mechanisms, and therefore predict the level of distractor interference when different levels of cognitive resources are available. Specifically, we tested the following hypotheses: (a) higher levels of resting HRV should be associated with faster reaction times (RTs) to detect targets regardless of levels of perceptual load, indicating a superior ability to inhibit irrelevant distractors and focus on task-relevant stimuli (Hansen et al., 2003); (b) higher resting HRV should be associated with faster RTs to detect targets with fearful distractors only under low perceptual load; and (c) under high load, higher resting HRV should be associated with faster RTs for trials with neutral distractors.

## Method

### Participants

Seventy-seven undergraduate students participated in the study for partial course credit. Participants were asked to refrain from smoking or drinking caffeinated beverages for 4 h before the experiment (Hansen et al., 2003). All participants had normal or corrected-to-normal vision (20/20 visual acuity). People with a history of vision disorders or dysfunctions, neurological or psychiatric disorders, cardiovascular disorders, or medical conditions such as diabetes were excluded from this experiment. The behavioral and cardiovascular data from two participants were lost due to a computer error. We also excluded two participants who had more than 15% of missing trials due to errors and outliers, which yielded 73 participants (42 females; mean age = 20; mean baseline HRV = 6.57).

### Stimuli

As can be seen in Figure 1, each display consisted of a face with the middle of the nose at fixation and a string of six letters, written in blue, superimposed across this middle point. We selected fearful and neutral facial expressions of 12 different individuals (six females and six males) from *Pictures of Facial Affect* (Ekman & Friesen, 1976). Each face was edited using Adobe PhotoShop CS3 software (Adobe System, San José, CA) to remove extraneous background information. Each face measured 6.0° horizontally and 7.5° vertically against a white background. Each letter measured 0.6° × 0.8° of visual angle and was separated from its neighbors by 0.4°.

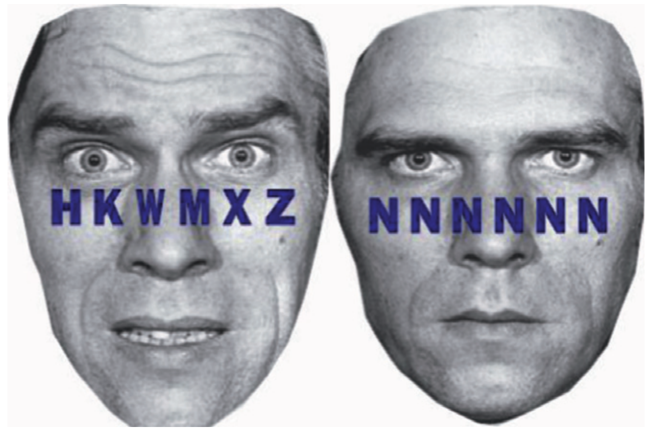


**Figure 1.** Example stimuli. A string of six letters was superimposed on fearful and neutral facial distractors. Under high load, letter strings consisted of one target letter and five nontarget letters (H, K, M, W, or Z) arranged in random order (left). Under low load, the letter string consisted of six Xs or six Ns (right).

In the high perceptual load condition, the letter string comprised one target letter (X or N) and five nontarget letters (H, K, M, W, or Z) arranged in random order. In the low perceptual load condition, the letter string consisted of six Xs or six Ns. Though Lavie's Load Theory does not provide the precise threshold for high and low load, the concept of high perceptual load has been defined as adding more items for the same task or requiring greater operational demands to perform a task for the same number of items (Lavie & Fox, 2000, Lavie et al., 2004). Therefore, more items or more demanding operations consume attentional capacity in processing task-relevant stimuli and inhibiting task-irrelevant distractors.

Viewing distance was approximately 60 cm. The particular faces used for high and low perceptual load were counterbalanced across participants. The combination of target letter identity and target letter position was also counterbalanced across four different conditions. Four conditions crossing two distractor types and two perceptual load conditions were administered in a between-subjects design. We used a between-subjects design because there might be a significant practice effect over time with a within-subject design.

### Procedure

All participants were tested individually in a dimly lit room. They were brought to the lab, and three surface electrodes were attached—the negative electrode below the left collar bone, the positive electrode below the right rib cage, and the ground electrode below the left rib cage—to obtain electrocardiographic (ECG) data. After placement of electrodes, resting HRV was recorded for 5 min, during which participants sat and rested quietly in a sound-isolated room. Participants then performed the letter detection task.

**The letter detection task.** In the letter detection task, participants were presented with a series of letter strings and were instructed to identify whether each letter string contained an X or an N by pressing the corresponding keys on the keyboard as quickly and accurately as possible. Each block started with 12 practice trials with just the letter strings presented, followed by 48 experimental

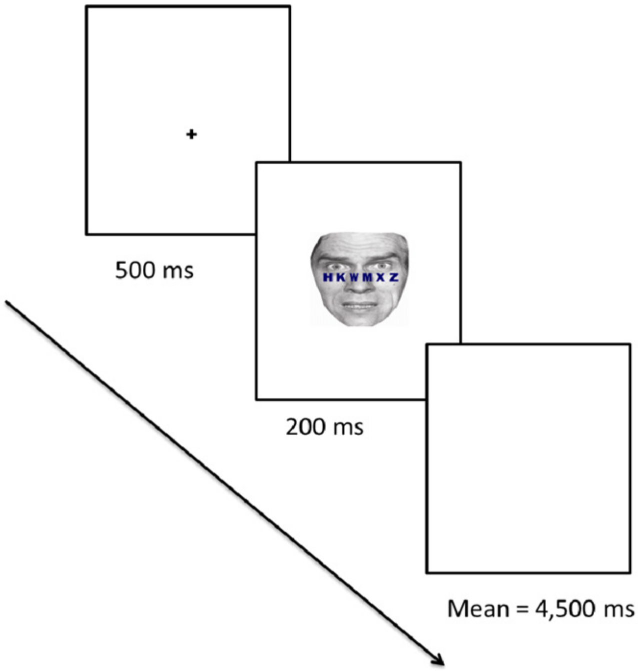


**Figure 2.** Example of experimental sequence. The fixation cross was presented for 500 ms and followed by the display with a string of six letters superimposed on a face for 200 ms. The interstimulus interval was randomly generated with a mean of 4,500 ms. Stimuli are not drawn to scale.

trials in random order. Each experimental trial began with a fixation cross for 500 ms, followed by the display of the string of six letters superimposed on a face for 200 ms. The interstimulus intervals were randomly generated with a mean of 4,500 ms (see Figure 2). Participants were told to ignore the faces. When participants failed to respond, they received feedback indicating that they had not responded in time. Response accuracy and RT were recorded on each trial. After the task, participants went through a 5-min recovery period.

### Physiological Measurements

We recorded ECG activity via a standard 3-electrode (lead II) setup. The ECG signals, which were sampled at 1000 Hz (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996), passed through Mindware Technology's BioNex 50-3711-02 two-slot mainframe to an Optiplex GX620 personal computer (Pentium D, 2.80 GHz, 2.00 GB RAM) running Mindware Technology's BioLab 1.11 software, which received digital triggers (100-ms pulses) via a parallel port connection with a second Optiplex GX620 running E-Prime 1.1.4.1 (Psychology Software Tools, Inc.). The ECG signals were inspected offline using Mindware Technology's HRV 2.51 software with which the ECG trace (plotted in mV against time) was carefully reexamined. Successive R spikes (identified by an automatic beat detection algorithm) were visually inspected, and any irregularities were edited. Successive interbeat intervals (in milliseconds) within the baseline period were written to a single text file. Time and frequency domain indices of the heart period power spectrum were analyzed and performed using the Kubios HRV analysis package 2.0 (http://kubios.uef.fi/), through which we obtained high frequency HRV power that primarily reflects vagal influences (Thayer & Ruiz-Padial, 2006). Spectral estimates of high frequency power (in milliseconds squared per hertz) were transformed logarithmically (base 10) to normalize the distribution (Ruiz-Padial et al., 2003).[3]

### Analyses

RTs of fewer than 150 ms, more than 1,500 ms, or more than two standard deviations above the mean were considered outliers and were excluded (2% of trials; Ratcliff, 1993). All reported analyses on RT excluded outliers and incorrect trials (Ratcliff, 1993).

### Statistics

To assess the success of the load manipulation, mean RTs and percent error rate data were subjected to a 2 (Perceptual Load: high, low) × 2 (Distractor Emotion: fearful, neutral) between-subjects analysis of variance (ANOVA). To evaluate whether higher levels of resting HRV were associated with faster RTs to detect targets in the task, regardless of levels of perceptual load (Hansen et al., 2003), log-transformed high frequency HRV power and RT data were *z*-standardized, and interaction terms were computed from these standardized scores (Aiken & West, 1991). We conducted a regression analysis in which HRV was the predictor and RT was the dependent variable. To assess the effects of resting HRV on task performance under high and low perceptual load with fearful and neutral distractors, we conducted a 2 (Distractor Emotion: fearful, neutral) × 2 (Perceptual Load: high, low) × continuous (HRV) multiple regression analysis on RTs and errors. Separate effect-coded variables were created for facial emotion (fear = 1, neutral = −1), and perceptual load (high = 1, low = −1).

## Results

### Load Manipulation Check

We first assessed the success of the load manipulation. Mean RT and percent error rate data were subjected to a 2 (Perceptual Load: high, low) × 2 (Distractor Emotion: fearful, neutral) between-subjects ANOVA. Mean RTs and percent error rate in the letter identification task were significantly greater under high ($M_{\text{RTs}} = 854$ ms, $SD = 106$; $M_{\text{error rate}} = 22\%$, $SD = 8\%$) than low ($M_{\text{RTs}} = 432$ ms, $SD = 105$; $M_{\text{error rate}} = 3\%$, $SD = 8\%$) perceptual load, suggesting that we successfully manipulated perceptual load, $F(1,65) = 291.16$, $p < .01$, $\eta_p^2 = .82$ for RT; $F(1,65) = 104.83$, $p < .01$, $\eta_p^2 = .62$ for errors. Consistent with Load Theory, the high load condition in our study was associated with slower RTs and more errors than the low load condition. Furthermore, our mean levels of RTs and accuracy in high versus low load match the previous work. For example, Jenkin, Lavie, and Driver (2004) used the similar letter identification task with neutral face distractors only and reported that mean RTs and percent error rate were 876 ms and 16% errors under high load and 422 ms and 2% errors under low load. By comparison, our study showed that mean RTs and percent error rate were 854 ms and 22% errors under high load

3. It should be noted that four groups did not differ in log-transformed high frequency HRV power, $F(3,69) = .99$, $p = .40$, $\eta_p^2 = .04$, mean heart rate, $F(3,69) = .24$, $p = .87$, $\eta_p^2 = .01$, and respiration examined by the high frequency peak (hz), $F(3,69) = .43$, $p = .73$, $\eta_p^2 = .02$ (see Table 2).

**Table 1.** *Means and Standard Deviations of Reaction Times (in ms) and Percentage of Errors (%) as a Function of Perceptual Load and Distractor Emotion*

| | | Fearful distractor | Neutral distractor |
|---|---|---|---|
| High load | Mean | 880.8 | 833.7 |
| | SD | 139.8 | 157.6 |
| | % | 17.9 | 26.5 |
| | SD | 8.5 | 12.8 |
| | N | 20 | 15 |
| Low load | Mean | 427.2 | 440.3 |
| | SD | 66.3 | 56.1 |
| | % | 3.1 | 3.2 |
| | SD | 4.0 | 4.2 |
| | N | 18 | 20 |

*Note*. SD = standard deviation; N = sample size.

and 432 ms and 3% under low load. Therefore, the results suggested that the manipulation of load in the current study was successful.

The main effect of distractor emotion was also significant on percent error rate, $F(1,65) = 6.03$, $p < .02$, $\eta_p^2 = .09$, such that people made fewer errors on trials with fearful ($M = 10\%$, $SD = 8\%$) than neutral ($M = 15\%$, $SD = 8\%$) distractors, which was qualified by the interaction between load and distractor emotion, $F(1,65) = 5.24$, $p < .03$, $\eta_p^2 = .08$. Replicating previous research (Bishop et al., 2007), participants made fewer errors in trials with fearful ($M = 18\%$, $SD = 8\%$) than neutral ($M = 27\%$, $SD = 13\%$) distractors under high perceptual load, $t(33) = -2.39$, $p < .05$, $d = .84$ (see Table 1). But there was no difference in accuracy between fearful ($M = 3\%$, $SD = 4\%$) and neutral distractors ($M = 3\%$, $SD = 4\%$) under low perceptual load, $t(36) = -.11$, $p = .91$, $d = .04$.

### Analysis of Overall Task Performance and HRV

We predicted that higher levels of resting HRV would be associated with faster RTs to detect targets in the task, regardless of levels of perceptual load (Hansen et al., 2003). We conducted the regression analysis in which HRV was the predictor and RT was the dependent variable. The regression analysis showed that HRV did not significantly predict RTs, $\beta = -.10$, $t(71) = .87$, $p = .10$. Therefore, contrary to our prediction, higher resting HRV was not associated with faster RTs to detect targets in the task.

To assess the effects of resting HRV on task performance under high and low perceptual load with fearful and neutral distractors, we conducted a 2 (Distractor Emotion: fearful, neutral) × 2 (Perceptual Load: high, low) × continuous (HRV) multiple regression analysis on $z$-standardized RTs and errors. As expected, there was a significant three-way interaction between perceptual load, distractor emotion, and HRV, $\beta = -.38$, $t(65) = -2.85$, $p < .01$.[4] There was no significant three-way interaction on errors ($p = .35$), suggesting that there was no speed-accuracy tradeoff. To decompose the three-way interaction on RTs, we separately examined the two-way interactions between emotion and HRV for high and low perceptual load.

### Analysis of Task Performance and HRV under Low Load

Under low load, there was a marginally significant interaction between HRV and distractor emotion, $\beta = -.31$, $t(34) = -1.82$, $p = .08$.[5] Simple slopes analyses (Aiken & West 1991; Preacher, Curran, & Bauer, 2006) revealed that HRV was not associated with task performance when the distractor emotion was fearful, $\beta = .26$, $t(34) = 1.32$, $p = .20$, and neutral, $\beta = -.36$, $t(34) = -1.29$, $p = .20$ (see Figure 3A).[6]

### Analysis of Task Performance and HRV under High Load

Under high load, there was an interaction between HRV and distractor emotion, $\beta = .45$, $t(31) = 2.19$, $p < .04$.[7] Simple slopes analyses revealed that higher HRV was associated with faster RTs when the distractor emotion was neutral, $\beta = -.78$, $t(31) = -2.16$, $p < .04$ (see Figure 3B). However, HRV was not associated with task performance when the distractor emotion was fearful, $\beta = .12$, $t(31) = .65$, $p = .52$.[8] Therefore, consistent with our hypothesis, resting HRV was positively associated with RTs under high load when the distractor emotion was neutral.

## Discussion

There is growing evidence that cardiac vagal tone is associated with top-down control mechanisms that are critical for prioritizing processing resources to task-relevant stimuli in the presence of an emotionally salient distractor (Bishop, Duncan, Brett, & Lawrence, 2004; Park, Van Bavel, Vasey, & Thayer, 2012). In this study, we examined whether resting HRV—an index of cardiac vagal tone—was associated with the ability to exert selective attention under load. In our task, more distractors were added for the same task under high perceptual load, thereby demanding greater attentional capacity to perform a goal-directed task. Contrary to our prediction, higher resting HRV was not associated with faster overall performance or with faster task performance with fearful

4. We also divided the participants into two groups, higher or lower resting HRV, based on the median split of log high frequency HRV during baseline (median = 6.5) and conducted a 2 (Perceptual Load: high, low) × 2 (Distractor Emotion: fearful, neutral) × 2 (HRV: high, low) between-subjects ANOVA (Hansen et al., 2003; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996; Thayer & Lane, 2000). The ANOVA analysis was consistent with the multiple regression analysis, showing that a three-way interaction on the RT data was significant, $F(1,64) = 7.56$, $p < .01$, $\eta_p^2 = .11$ (see Table 3).

5. We also conducted a 2 (Distractor Emotion: fearful, neutral) × 2 (HRV: high, low) ANOVA under low load. The interaction between HRV and distractor emotion was significant, $F(1,34) = 7.12$, $p = .01$, $\eta_p^2 = .17$.

6. Participants with lower resting HRV ($M = 411$ ms, $SD = 62$) were significantly faster in trials with neutral distractors than participants with higher resting HRV ($M = 464$ ms, $D = 39$), $t(18) = 2.35$, $p = .03$, $d = .73$. Contrary to our prediction, there was no difference between higher and lower resting HRV groups in trials with fearful distractors ($p = .16$). As predicted, participants with lower resting HRV showed no difference in RTs for trials with fearful and neutral distractors ($p = .28$). However, participants with higher resting HRV were faster with fearful distractors ($M = 404$ ms, $SD = 30$), as compared with neutral distractors ($M = 464$ ms, $SD = 39$), $t(18) = 3.78$, $p < .01$, $d = 1.46$.

7. We also conducted a 2 (Distractor Emotion: fearful, neutral) × 2 (HRV groups: high, low) ANOVA under high load. The interaction between HRV and distractor emotion was significant, $F(1,31) = 3.29$, $p = .04$, $\eta_p^2 = .10$, one-tailed.

8. Although there was no significant difference in RTs between the high HRV and the low HRV groups when distractors were fearful ($p = .95$), participants with higher resting HRV were significantly faster than participants with lower resting HRV when distractors were neutral, $t(13) = -2.57$, $p < .03$, $d = .89$ (see Figure 4).

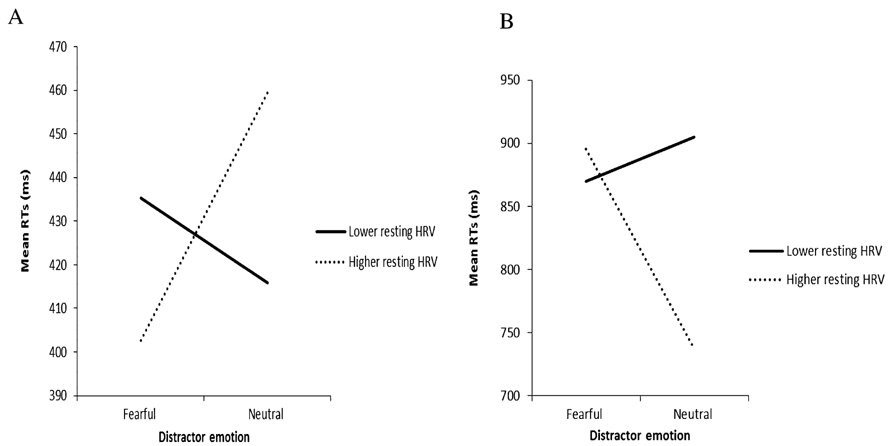


**Figure 3.** A: Mean reaction times (RTs) as a function of resting HRV and distractor emotion under low load. B: Mean RTs as a function of resting HRV and distractor emotion under high load.

distractors under low load.[9] However, as predicted, higher resting HRV was associated with superior task performance with neutral distractors, specifically under high load. In other words, when processing resources are sufficient to permit top-down attentional control, people with higher resting HRV may be capable of inhibiting fearful, as well as neutral, distractors to achieve goal-directed behavior. When processing resources are scarce, people have trouble inhibiting emotional distractors, regardless of their HRV levels. Importantly, those persons with low HRV may also have difficulty directing attention away for neutral distractors and respond to them as if they are threatening. This suggests that resting cardiac vagal tone is associated with task performance with neutral distractors under high load (cf. Forster & Lavie, 2007).

The current research suggests that people with higher resting HRV make adaptive responses under high load. They are able to focus on performing goal-directed behavior, even under high load when there are fewer cognitive resources available. People with higher resting HRV did not show evidence of distractor interference to neutral distractor faces, suggesting that they may be processed as safety cues and be ignored in order to effectively perform a goal-directed task. However, people with higher resting HRV were distracted by the emotionally salient distractor under high load and showed impaired task performance. Indeed, fearful distractors were distracting under high load, regardless of resting HRV levels. In contrast, those with low resting HRV were equally distracted by neutral and fearful distractors suggesting that the neutral distractors were processed as if they were threatening (cf. Ruiz-Padial et al., 2003).

The current study also extends the Load Theory, which proposes that under high perceptual load there are reduced interference effects and individual differences disappear (Lavie, 2005; Maylor & Lavie, 1998). Although there is extensive evidence that distractor interference primarily occurs under low load, some studies have provided evidence of distractor interference under high load. For instance, when famous faces such as President Clinton are used as distractors, participant's ability to detect a target is significantly diminished—regardless of the level of perceptual load—leading Lavie (2005) to speculate that load does not moderate the distractor interference of faces because they are socially important. A subsequent study found that facial emotion influenced distractor interference under high load: participants were more accurate on trials with fearful compared to neutral faces under high load (Bishop et al., 2007). The differential effects of emotional distractor faces on performance under high load introduce the possibility that interference depends not only on load, but also on the emotional or cognitive processes engaged by distractors. The current research provides evidence that individual differences in cardiac vagal tone are associated with differential interference effects under high perceptual load.

We expected that people with higher resting HRV would show faster RTs to fearful distractors under low load. Whereas the results were in the predicted direction, HRV was not significantly related to performance under low load using the regression analysis (but see Footnote 6). It appears that when a task demands relatively little

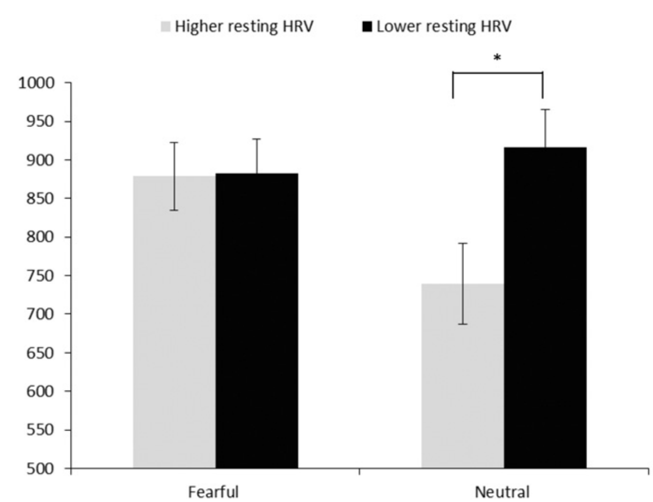


**Figure 4.** Mean reaction times (RTs) as a function of high and low resting HRV levels and distractor emotion under high load.

9. Using the median split of HRV, we did find that higher resting HRV was associated with faster task performance with fearful distractors under low load (see Footnote 6). However, whereas the results of both analysis approaches were in the predicted direction, only the median split analysis yielded statistically significant results. Future research is needed to clarify the extent to which HRV is associated with task performance under low load.

cognitive effort and there is available cognitive capacity to perform the task, resting HRV may not play as important a role in moderating interference effects of emotional distractors. Therefore, the current study seems to suggest that the influence of individual differences in HRV may depend on the availability of cognitive resources, and its impact is greater when there are fewer cognitive resources available.

Another possibility is that the influence of HRV on effective inhibition to emotional distractors under low load depends not only on the availability of cognitive resources, but also on stimulus characteristics. Our previous research showed that individual differences in HRV were associated with a top-down inhibitory attentional mechanism in response to fearful faces at high spatial frequency (Park, Van Bavel, Vasey, & Thayer, 2012). The inhibition of return (IOR) refers to the attentional phenomenon that prevents one's attention from going back to previously attended locations and preferably exploring novel locations to facilitate visual search (Posner, Rafal, Choate, & Vaughan, 1985; Stoyanova, Pratt, & Anderson, 2007; Sumner, 2006). In the IOR task, participants were presented with a fixation point in the middle of a screen and two gray boxes on either side of the fixation point. Participants were instructed to detect a target presented on either side of the gray box, followed by either fearful or neutral face cues, as quickly and accurately as possible. Participants were also told that a preceding cue did not predict where the target would appear and that they should ignore the face cues. In the task, there are sufficient cognitive resources that allow for recruiting top-down attentional mechanisms to inhibit emotional distractors, which is similar to the low load condition in the current study. People with lower resting HRV had difficulty keeping attention from cues and instigating novelty search. In contrast, people with higher HRV were able to keep their attention from fearful, as well as neutral, face cues and instigated novelty search. However, they showed superior attentional inhibition when fearful faces were presented at high spatial frequency ranges. Therefore, it appears that the availability of cognitive resources, as well as the bottom-up stimulus characteristics, may play an important role in attention. It would be interesting to further examine whether the HRV modulation on emotional distractors under low load may depend on stimuli characteristics (e.g., high spatial frequency) in future research.

In the current research, lower resting HRV was associated with making undifferentiated responses to neutral and fearful distractors under both high and low load, which is consistent with previous findings (Ruiz-Padial et al., 2003; Thayer et al., 2000). According to the Neurovisceral Integration Model (Thayer & Lane, 2000; Thayer et al., 2009), lower resting HRV is associated with hyperactive sympathoexcitatory circuits resulting from a lack of prefrontal inhibitory control. This may result in the failure to recognize safety signals in the environment, which causes an organism to make hypervigilant threat responses. People with lower resting HRV in the current research responded to even neutral distractors as if they were threatening. As a result, their performance on the task was less efficient with neutral distractors compared to people with higher resting HRV. This is consistent with the idea that lower resting HRV is associated with dysfunctional emotional regulation.

**Table 2.** *Means and Standard Deviations of Log-Transformed High Frequency HRV Power, Heart Rate, and Respiration Examined by the High Frequency Peak (hz) as a Function of Perceptual Load and Distractor Emotion*

| | | Fearful distractor | Neutral distractor |
|---|---|---|---|
| High load | HRV | 6.4 | 6.4 |
| | SD | 1.6 | 1.0 |
| | Heart rate | 76.2 | 74.1 |
| | SD | 16.0 | 10.5 |
| | Respiration | .26 | .27 |
| | SD | .05 | .05 |
| Low load | HRV | 6.3 | 7.0 |
| | SD | 1.1 | 1.5 |
| | Heart rate | 78.0 | 75.5 |
| | SD | 14.8 | 10.3 |
| | Respiration | .27 | .25 |
| | SD | .04 | .07 |

*Note*. HRV = heart rate variability; SD = standard deviation.

One limitation of the study is that we used a between-subjects design to avoid the practice effect, and therefore results on RTs might have been influenced by some degree of between-subject variability. However, it should be noted that there were no differences in cardiovascular data among the different groups (see Table 2). Also, random assignment to conditions should mitigate against individual differences. Furthermore, our primary hypotheses and results were based on interaction effects, which helps rule out any mundane simple explanations based on group differences.

## Conclusion

The current research expands our previous finding that individual differences in resting cardiac vagal tone were associated with

**Table 3.** *Means and Standard Deviations of Reaction Times (in ms) and Percentage of Errors (%) as a Function of Perceptual Load, Distractor Emotion, and Resting HRV Levels*

| | | Higher resting HRV | | Lower resting HRV | |
|---|---|---|---|---|---|
| | | Fearful distractors | Neutral distractors | Fearful distractors | Neutral distractors |
| High load | Mean | 878.69 | 739.27 | 883.00 | 916.35 |
| | SD | 75.90 | 167.71 | 188.37 | 94.08 |
| | % | 16.90 | 29.86 | 18.80 | 23.50 |
| | SD | 9.19 | 16.43 | 8.05 | 8.72 |
| Low load | Mean | 404.18 | 464.21 | 450.21 | 411.00 |
| | SD | 29.99 | 39.14 | 85.07 | 61.72 |
| | % | 3.67 | 1.73 | 2.44 | 5.00 |
| | SD | 5.20 | 2.20 | 2.40 | 5.39 |

*Note*. HRV = heart rate variability; SD = standard deviation.

successful goal-directed behavior under load (see also Park, Van Bavel, Vasey, & Thayer, 2012). Specifically, this study showed that resting HRV is positively associated with the capacity to control selective attention under high load to achieve goal-directed behavior, extending the previous research to neutral faces and selective attention. Together with previous research, the current study suggests that cardiac vagal tone is associated not only with highly effective inhibitory function to emotionally salient stimuli, but also with efficiency in controlling selective attention to neutral distractors to achieve effective goal-directed behavior.

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