Self-Esteem and Autonomic Physiology: Parallels Between Self-Esteem and Cardiac Vagal Tone as Buffers of Threat

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Self-Esteem and Autonomic Physiology: Parallels Between Self-Esteem and Cardiac Vagal Tone as Buffers of Threat

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In this article a potential physiological connection to self-esteem is suggested: cardiac vagal tone, the degree of influence on the heart by the vagus, a primary nerve of the parasympathetic nervous system. This hypothesis emerges from parallels between the two literatures that suggest both self-esteem and cardiac vagal tone function to provide protection from threat responding. This article reviews these literatures and evidence and preliminary findings that suggest in some contexts self-esteem and cardiac vagal tone may exert an influence on each other. Last, the article discusses theoretical and applied health implications of this potential physiological connection to self-esteem.

Keywords: *self-esteem; vagal tone; vagal control; heart rate variability; parasympathetic system*

> Unlike the baboon who gluts himself only on food, man nourishes himself mostly on self-esteem.
>
> Becker, 1971

Self-esteem is among the most studied concepts in psychology (PsycINFO reports more than 26,000 results with *self-esteem* as a keyword), a testament to the topic's applicability and usefulness for explaining and understanding why people behave the way they do. The links between self-esteem and physiological systems, however, have not been delineated. Such an explication would likely prove useful for a number of reasons—for broadening our understanding of self-esteem (as well as of physiological systems), for deepening our understanding of pathways between self-esteem and physical health, and for generating avenues for future research and theory building.

Herein we offer an initial step in this direction by proposing a potentially important physiological outcome of a person's state self-esteem (of which there are certainly many), the feeling that one is at present valued and of worth. Specifically, we propose a connection, likely context dependent, between self-esteem and cardiac vagal tone, defined here as the level of influence at the heart of the vagus nerve, a primary vehicle for the parasympathetic branch of the autonomic nervous system. We review a substantial body of evidence documenting parallels between self-esteem and this influence of the vagus on the heart. Research shows that these constructs share many of the same correlates, and empirically supported theories make the case that both serve similar functions by protecting against threat responses. In addition to reviewing the relevant literatures, we discuss possibilities for the nature of the pro-

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posed relationship and describe work pertaining to the possible causal influence of self-esteem on cardiac vagal tone (as well as of vagal tone on self-esteem). Finally, we discuss the theoretical and applied implications of a relationship between self-esteem and vagal tone.

THREAT-BUFFERING FUNCTION OF SELF-ESTEEM

Theoretical Perspectives

Central to this proposed connection between state self-esteem and cardiac vagal tone are parallels in the theorized functions of both constructs. First we describe theorizing that at least one function or consequence of state self-esteem is that of dampening threat responses. Particularly explicit in this theorizing, terror management theory (TMT; e.g., Greenberg, Solomon, & Pyszczynski, 1997; Pyszczynski, Solomon, Greenberg, & Stewart-Fouts, 1995) holds as a central tenet that self-esteem serves as an anxiety buffer. The theory proposes that an anxiety-buffering function of self-esteem stems from early childhood experiences. In early childhood, acquiring the love and support from the parents necessary to feel protected and safe in an otherwise dangerous and threatening world (e.g., Becker, 1971; Bowlby, 1969; Horney, 1937; Sullivan, 1953) becomes contingent on being well behaved, living up to the parents' standards, or, in short, being good. Thus early on, humans learn to associate living up to standards of goodness and being valued by important others with protection from threat. Self-esteem consequently becomes associated with a sense of security and so a reduction in the sensitivity to and severity of threat responding.

In addition, TMT suggests that the evolution of the human brain, and in particular the unprecedented increases in symbolic thinking and sense of self, led to an unprecedented sensitivity to threats to the self. Thus for humans, securing one's sense of self becomes particularly important for managing threat responses. To this end, TMT proposes that humans strive to generate and maintain a symbolic worldview that seems meaningful and permanent and from which we can maintain a feeling of being a worthy, and thus a protected part of this enduring meaning system. A strong sense of self-esteem should therefore render people generally less vulnerable to feeling threatened.

Another perspective that supports this threat-buffering function of self-esteem is self-affirmation theory (e.g., Sherman & Cohen, 2006; Steele, 1988). This theory asserts that threats to one's self pose a problem particularly because they undermine a general or overarching sense of self-integrity, defined as a basic need to feel that one is good, moral, competent, and successful. According to the theory, this overarching need for self-integrity and self-esteem can be met in various and flexible ways. Various aspects of the self when bolstered can serve the same purpose of securing an overall sense of self-integrity and self-esteem. By this logic, when one's sense of self-esteem is affirmed by a particular route, threats to other dimensions of self become less consequential and so less threatening. A strong or high overarching sense of self-esteem provides a resource to compensate for threats to any given component of the self. Thus, self-affirmation theory suggests that a strong sense of self-esteem confers a threat-buffering effect.[1]

These theoretical perspectives that integrate self-esteem with protection from threat responding do not imply that self-esteem is the only psychological construct that protects or down-regulates threat responses, and so this theorizing does not supplant existing emotion regulation or coping perspectives. For example, specifying in a more detailed way what makes people feel threatened in motivated situations, the biopsychosocial model of challenge and threat (e.g., Blascovich, Mendes, Tomaka, Salomon, & Seery, 2003) posits that threat responding is a function of the ratio of one's perceived resources relevant for meeting the perceived demands of the situation—the more one feels that one's resources can allow for meeting the demands, the less the threat response and greater the challenge response. Resources and demands are construed broadly and are subjectively determined by a variety of physical and psychological factors. Demands in any given situation are factors that increase "danger, uncertainty, and required effort"; resources are factors that include "skills, knowledge, and abilities, dispositional factors, and external support" (Blascovich et al., 2003, p. 237). Again, this ratio of resources to demands predicts threat particularly in motivated performance situations—situations in which one is active (as compared to passive) and perceives the situation as relevant or meaningful for one's self (Blascovich et al., 2003, p. 238).

Given this model of threat, the many non-self-esteem related factors that affect perceived resources, demands, and relevance of the situation for the self should affect the strength of threat responses. For example, particularly thick calluses on one's feet should mute threat responding while walking on hot pavement by way of increasing one's resources in a way that is orthogonal to self-esteem. Cooling down the pavement should reduce threat responding by way of decreasing the demands in a way that is independent of self-esteem. Perhaps extreme sleepiness while walking on hot pavement reduces threat by way of decreasing relevance of the situation to the self independent of increasing self-esteem.[2]

That said, the ability of self-esteem to dampen threat responding is also consistent with this model of threat. Self-esteem can be construed as one particular variable (but far from the only one) that affects the three determinants of threat laid out by the biopsychosocial model (e.g., Blascovich et al., 2003; Seery, Blascovich, Weisbuch, & Vick, 2004). According to TMT and self-affirmation theory, at least in some situations self-esteem should serve as a resource that decreases threat—self-affirmation theory, particularly, posits that self-esteem allows people to compensate for circumscribed threats to self, in turn rendering them less threatening. The TMT and self-affirmation theorizing further suggests that self-esteem bolsters a general feeling of protectedness and so should generally reduce perceptions of the demands or danger of a given situation, as well as reduce the relevance of a situation for one's self. Thus, this theorizing about self-esteem does not supplant existing models of threat or threat regulation but joins with them to suggest that for a variety of reasons, self-esteem is one critical psychological entity that down-regulates threat-responding.

State and Trait

To further delineate the function of self-esteem, we can distinguish between state and trait self-esteem. We define state self-esteem as one's immediate feelings of value and trait self-esteem as global feelings of value, or a person's tendency to feel of value over the long run (e.g., Brown, Dutton, & Cook, 2001). Thus this self-esteem distinction can be construed as a distinction in time course, where state self-esteem has to do with the immediate feelings and circumstances, and trait self-esteem has to do with people's tendencies over more extended periods.

From our perspective, when people feel immediately good about themselves, they should feel protected and less vulnerable to threat responding. No matter the level of trait self-esteem, feeling bad about oneself at a particular moment should at that moment increase vulnerability to more severe threat responding. As discussed, this might happen by various routes—by decreasing the relevance of the situation and threat, by decreasing the perceived demands of the situation, and/or by increasing one's perceived resources to deal with the threat.

One step removed, trait self-esteem should in many circumstances affect state self-esteem. Trait self-esteem as Brown and colleagues (Brown et al., 2001) suggest, generally affects the level of state self-esteem and facilitates resilience and recovery of state self-esteem. If a person knows generally or globally that he or she is a good person, then we would expect tendencies toward higher state self-esteem and quicker recovery from drops in state self-esteem than if the person possesses lower trait self-esteem. In other words, high trait self-esteem may provide more resources for maintaining high state self-esteem and resources that facilitate recovery of lowered state self-esteem. Thus, trait self-esteem too should impact and predict threat responses, but indirectly, by way of affecting state self-esteem levels and resilience over the long run.

Empirical Support

State self-esteem and protection from threat responding. Given the theoretical analyses just presented, we should find evidence that high state self-esteem predicts less threat-related responding. Consistent with this prediction, for example, Heatherton and Polivy (1991), in developing a measure of state self-esteem, consistently found significant correlations between lower state self-esteem and state threat-related emotions such as anxiety, hostility, and depression.

However, to more precisely test the predicted causal relationship between state self-esteem and threat, Greenberg et al. (1992) manipulated people's state self-esteem by giving them either very positive or neutral feedback about their personality. Participants then watched either a video of death-related footage including an autopsy and electrocution or a video of neutral nature-related footage. In the neutral video condition, the positive feedback had no effect on reported state anxiety. However, in the death video condition, the positive feedback protected people from increased anxiety that those who received neutral feedback reported feeling in response to the threatening video.

In two conceptual replications (Greenberg et al., 1992), participants were similarly provided with either neutral or positive feedback (in one study using personality feedback and the other using feedback regarding performance on an intelligence test). Participants were then exposed either to innocuous blinking lights or to the threat of electric shock. In both studies, the results showed that with no threat of shock, the self-esteem boost in the form of positive feedback had no effect on threat as indexed by skin conductance—a relatively pure indicator of sympathetic arousal (e.g., Dawson, Schell, & Filion, 2000). However, in participants expecting electric shock, the self-esteem boost eliminated an increase in skin conductance observed in the participants without the self-esteem boost. Further follow-up showed that the effects of this self-esteem boost on threat-related skin conductance did not appear mediated by self-reported positive mood.

Another similar study investigated the effects of manipulated self-esteem on heart rate increases in response to a social stressor, that of public speaking (Rector & Roger, 1997). As in the aforementioned research, positive personality feedback provided to boost state self-esteem had no effect on heart rate in the absence of the stressor, prior to the public speaking. But during the speaking exercise, the state self-esteem boost inhibited the increase in heart rate otherwise observed in those without inflated state self-esteem. The state self-esteem boost, however, did not improve recovery of heart rate after the public speaking stressor. Thus the authors surmised that state self-esteem inhibited initial threat responding but not recovery from threat responding.

Furthermore, studies on implicit self-esteem may provide evidence of state self-esteem's effect on threat responding. In simple terms, "implicit" self-esteem is determined by measuring the strength of the associations between self-words and positive words versus self-words and negative words. Although difficult to definitively classify as indexing state self-esteem, evidence exists that similar implicit measures can vary because of situational factors in both between and within-subject designs. Thus these measures seem sensitive to state changes (e.g., Blair, 2002; Gemar, Segal, Sagrati, & Kennedy, 2001).

In one implicit self-esteem study (Spalding & Hardin, 1999), people participated in a self-irrelevant and innocuous interview or a self-relevant and so potentially more threatening interview. In the innocuous interview, high and low implicit self-esteem people showed no difference in how anxious they appeared. However, in the self-relevant and potentially threatening interview, higher implicit self-esteem people appeared less anxious than low implicit self-esteem participants. In a similar vein, Greenwald and Farnham (2000) found that people with higher implicit self-esteem tended to respond less defensively to a laboratory failure.

These studies taken together suggest that higher state self-esteem, though eliciting little observable effect in the absence of threat, functions to buffer people from primary threat responding after exposure to various potential stressors.

State self-esteem contingencies and protection from threat responding. Also relevant for state self-esteem and its protective function is literature on contingencies of self-esteem. Specifically, contingencies that seem to strengthen and secure state self-esteem from drops also predict decreased threat responding. For example, Schimel, Arndt, and colleagues showed that when extrinsic and less secure bases of self-esteem were made salient, participants tended to respond in more defensives ways to various potentially threatening tasks (Arndt, Schimel, & Greenberg, 2002; Schimel, Arndt, Pyszczynski, & Greenberg, 2001). They conformed more, self-handicapped more, made more downward social comparisons, distanced more from a negative other, and made more downward counterfactuals to explain a negative event. Making a similar point, Crocker (2002) showed that people with contingencies of self-esteem that were more external tended to experience greater stress and aggressive tendencies. In addition, more diverse sources or contingencies of self-esteem, which seem to foster greater security or strength of state self-evaluations, predict lessened stress and depressed affect in response to failure and daily challenges (e.g., Linville, 1985, 1987).

In a related vein, Kernis and colleagues (e.g., Kernis, Cornell, Sun, Berry, & Harlow, 1993) developed a paradigm to directly investigate the stability of state self-esteem. In this paradigm, participants generally complete a state version of the Rosenberg self-esteem scale twice a day for a series of days. The standard deviation of these state measures is taken as an index of the stability of self-esteem. These researchers have hypothesized that greater fluctuations—likely a result of the nature of a person's self-esteem contingencies—reflect more fragile state self-esteem, and hence state self-esteem that is more vulnerable to drops (e.g., Kernis, 2005).

Consistent with our model and predictions, a number of studies suggest that greater stability of self-esteem predicts reduced threat responses. For example, unstable self-esteem people appear more likely to exhibit anger and hostility during their daily lives (Kernis, Grannemann, & Barclay, 1989). In addition, those with unstable self-esteem appear more likely to exhibit physiological threat patterns relative to physiological challenge patterns during engagement in a difficult task as evidenced by relatively lower cardiac output and higher total peripheral vascular resistance (Seery, Blascovich, Weisbuch, & Vick, 2004). Furthermore, work generally shows an inverse relationship between stability of self-esteem and depression (de Man & Sterk, 2001; Kernis, Grannemann, & Mathis, 1991; Roberts & Kassel, 1997)—a link that may be particularly strong with depression as characterized by suicidal ideation (de Man & Gutierrez, 2002). Thus, state self-esteem that is less vulnerable to drops predicts dampened threat responses.

Yet another body of research supporting the effect of self-esteem on threat-responses is the self-affirmation literature. By way of bolstering people's values and bases of self-esteem, self-affirmation manipulations also appear to secure or stabilize people's sense of state self-esteem (e.g., Sherman & Kim, 2005). In turn, after these momentary self-affirmations, studies consistently show evidence of reduced threat responses, such as reduced denial of threatening health information (Sherman, Nelson, & Steele, 2000), reduced reported stress in response to a serial subtraction task (Keough, 1998), reduced threatened responding to being negatively stereotyped (Martens, Johns, Greenberg, & Schimel, 2006), reduced rationalizing of difficult choices (Steele, Spencer, & Lynch, 1993), reduced biases in response to failure (Sherman & Kim, 2005), and reduced defensive responding to reminders of mortality and worldview inconsistent information (G. L. Cohen et al., 2007; Schmeichel & Martens, 2005).

Trait self-esteem and protection from threat responding. The aforementioned group of studies provides evidence that high state self-esteem buffers people from primary threat responding. If trait self-esteem affects both current state self-esteem levels and state self-esteem resilience, then we should also see a link between trait self-esteem and protection from threat experience and behavior. In support of this hypothesis, low trait self-esteem has been linked to anxiety (e.g., Brockner, 1983; M. Rosenberg, 1979), to depression (e.g., Harter, 1990; Schmitz, Kugler, & Rollnik, 2003; Watson, Suls, & Haig, 2002), to aggression and delinquent behavior (e.g., Donnellan, Trzesniewski, Robins, Moffitt, & Caspi, 2005), to increased negative emotional responses to failure (Kernis, Brockner, & Frankel, 1989) and to increased physiological fight or flight threat responses to stressors (Taylor, Lerner, Sherman, Sage, & McDowell, 2003). In addition, low trait self-esteem predicts the experience of greater stress in response to a variety of difficult circumstances, such as police work (Lester, 1986), firefighting (Petrie & Rotheram, 1982), transitioning into parenthood (Osofsky, 1985), medical internships (Linn & Zeppa, 1984), a husband leaving for war (Hobfoll & London, 1986), and death of a spouse in elderly people (Johnson, Lund & Dimond, 1986).

Thus level of trait self-esteem, which appears to feed into and predict state self-esteem, predicts threat-related responses too. These findings then provide further evidence consistent with the basic contention that state self-esteem functions to dampen threat responses, on both psychological and physiological (e.g., sympathetic) levels. From this model of self-esteem we next turn to the autonomic nervous system literature to elucidate a possible physiological connection to self-esteem. Specifically, in the next sections we review the literature on cardiac vagal tone and the parasympathetic nervous system (PNS), especially as they relate to threat responding. This work suggests that the threat responses dampened by state self-esteem are also dampened by cardiac vagal tone. Thus the functions of self-esteem and cardiac vagal tone in some respects parallel each other.

THREAT-BUFFERING FUNCTION OF CARDIAC VAGAL TONE

The Autonomic Nervous System. The autonomic nervous system helps to regulate the vital organs in the body and is not obviously under voluntary or conscious control. The autonomic nervous system consists of two major branches, the sympathetic nervous system (SNS) and PNS, and the two systems generally have opposite effects on the organs they innervate. The SNS generally excites or facilitates activity in the body and is a primary vehicle for the fight or flight response. The PNS generally inhibits or slows activity and aids in restoration of the body (Costanzo, 2002; Lovallo & Sollers, 2000). Although they may tend to act in a reciprocal and coordinated fashion (i.e., when parasympathetic activity decreases, sympathetic activity increases, and vice versa), they need not; they may also operate somewhat independently, or they may both increase or both decrease together (Bernston, Cacciopo, & Quigley, 1991, 1993).

Furthermore, when the SNS and PNS are active they do not necessarily affect all organs to the same degree, though the SNS is considered to act in a grosser way than the PNS. In other words, when we see SNS activity in one part of the body, the SNS tends to be active in other parts of the body as well. The PNS less often acts in concert. For example, PNS flow to the heart does not necessarily mean PNS flow to the intestines. Measurement of the PNS, particularly in relation to psychology, however, has been done predominantly from one organ—the heart. This is because only from the heart can PNS levels be easily and noninvasively measured. Furthermore, the heart's critical function, delivering nutrients to the body to facilitate action and thinking, makes clear its connection to vital variables.

Parasympathetic and Sympathetic Nervous System Functioning at the Heart

To exert their effects, the PNS and SNS consist of preganglionic neurons that stem from the brain, which connect to postganglionic neurons that travel to and affect the heart. The preganglionic neurons, whether in the PNS or SNS, all excite postganglionic neurons with the same neurotransmitter, acetylcholine. However, the SNS postganglionic neurons produce and release norepinephrine at the junctions with the heart, the neuroeffector juntions. The PNS postganglionic neurons produce and release acetylcholine at the neuroeffector junctions.

These neurotransmitters respond and affect the heart at different speeds, and consequently, the branches of the autonomic nervous system differ in the time course with which they affect the workings of the heart (e.g., Bradley, 2000). The parasympathetic system's acetylcholine affects the heart very quickly, and thus the heart responds to parasympathetic change in less than a second. The sympathetic system's norepinephrine often takes several seconds to exert an influence on the heart. Acytelcholine also dissipates more quickly than norepinephrine, and thus the PNS can withdraw its influence more quickly than the SNS.

Parasympathetic and sympathetic direct effects. Innervating the heart, the PNS and SNS exert their effects directly in several different places and ways. Most often noted, they innervate the sinoatrial (SA) node to affect heart rate (Costanzo, 2002). The SA node is the natural pacemaker for the heart. In the absence of any outside influence (e.g., the autonomic and endocrine systems), it spontaneously fires at approximately 105 beats per minute, and the heart therefore beats at 105 beats per minute. The PNS serves to slow this firing of the SA node and the SNS serves to speed this firing.

In addition to innervating the SA node, the SNS and PNS innervate the atrioventricular node. Innervation at this node affects the speed with which electrical signals are conducted from the atria to the ventricles (and thus affects the amount of blood that moves from the atria into the ventricles before the left and right ventricles expel the blood into the aorta and pulmonary artery, respectively). The PNS serves to decrease the conduction speed, whereas the SNS serves to increase the conduction speed (Costanzo, 2002).

The PNS and SNS also affect the strength with which the heart contracts (Costanzo, 2002). Specifically, the PNS and SNS appear to ease and strengthen, respectively, the force of contractility in both the atria and ventricles, though ventricular contractility has generally been believed to be affected only by the SNS. However, increases in heart rate increase the force of ventricular contraction (Costanzo, 2002) and so PNS effects on heart rate that result from innervation of the SA node would seem also to indirectly affect the force of ventricular contractility.

Parasympathetic–sympathetic interaction. As mentioned, the PNS and SNS do not necessarily operate at the heart in a reciprocal and coordinated fashion (e.g., Bernston et al., 1991). Yet evidence does show that these two systems tend to interact. In other words, the levels of activity in the PNS and SNS do not simply summate but instead interact to affect the end state of the heart. Levy and colleagues, building on early research by Rosenblueth and Simeone (1934) and working generally with anesthetized dogs, have provided a good deal of evidence for this interaction effect. To investigate this process, at different frequencies and in different combinations they have stimulated parasympathetic and sympathetic nerves that innervate the heart. One might expect that if, for instance, they stimulated the PNS and the SNS equally, both should equally oppose each other and cancel each other out. Furthermore, one might expect that if stimulated at differing levels, the end state of the organ would be determined by calculating how much more active one system is than the other. But this does not occur. Activity in one system does not serve to negate a comparable level of influence by the other system. Instead, the PNS appears dominant, to hold a trump card, termed by Levy, *vagal preponderance* or *accentuated antagonism* (e.g., Levy, 1995). With the PNS highly active or stimulated, SNS activity generally plays a lesser role in affecting the heart. When the PNS is less active, the SNS plays a more substantial role.

These interactions have been demonstrated at various places in the heart. First, Levy and colleagues have shown these vagal preponderance effects at the SA node and thus on heart rate (e.g., Levy, 1990). They concluded from a number of studies that when the vagus and sympathetic nerves were stimulated simultaneously or when stimulation of the vagus began before sympathetic stimulation, vagal influence dominated—vagal stimulation reduced sympathetic effects (e.g., Levy & Zieske, 1969).

In a series of studies, Levy and colleagues have also assessed sympathetic-parasympathetic interactions on ventricular contractility and excitability in anesthetized dogs. Unlike chronotropic effects, vagal stimulation alone had little direct impact on contractility and excitability, whereas sympathetic stimulation alone clearly increased the force of ventricular contractions and excitability. However, Levy and colleagues found that during simultaneous sympathetic and vagal stimulation, the activity of the vagus did play a role, that vagal stimulation somewhat attenuated the effects of sympathetic stimulation on contractility and excitability. Still, research has been mixed here, and other work suggests little influence of the parasympathetic system on ventricular contractility (e.g., Brownley, Hurwitz, & Schneiderman, 2000). Levy (1990) has shown comparable vagal antagonism effects on atria contractility.

Summary

From the work just presented, a consistent picture of vagal-sympathetic interaction emerges. The PNS exerts inhibitory effects on SNS excitatory influences. As a consequence, when the PNS is less active, the SNS plays a more substantial role in affecting the heart. When the PNS is more active, it serves to antagonize and limit the ability of the SNS to affect the heart. Therefore, the PNS effect on the heart may be viewed as dual. It (a) directly calms the body by slowing the firing of the SA node and slowing conduction speed at the atrioventricular node and (b) protects the body from fight-or-flight-related physiological patterns by inhibiting or buffering the excitatory effects of the SNS on the speed at which the SA node fires and perhaps on the force of ventricle and atrium contractility. Thus elevated PNS influence at the heart seems to have threat-buffering effects roughly parallel to those of high state self-esteem.

Polyvagal theory. Consistent with the PNS and SNS pattern of interaction put forth above, Porges (1995) proposed a polyvagal theory that further explicates the function and components of the PNS and its interaction with the SNS. The polyvagal theory proposes that the PNS consists of two main branches, the smart mammalian vagus and the vegetative reptilian vagus. In general, the vegetative vagus affects the workings of lower organs, such as the stomach and intestines, though to a lesser extent it also innervates the heart and other organs, and controls very basic responses and reflexes. Porges (1995) posited that this branch evolved in cold-blooded vertebrates, evolutionary predecessors of reptiles, to help regulate their bodies and responses to the environment. The reptilian vagal strategy is for vagal tone to be generally or tonically low, which allows for activity in an animal that does not have an idling SNS to propel it. However, in reptiles, without the ability to become quickly sympathetically super-powered and super-mobile, the vegetative vagus mediates the threat response—a freezing response. Thus, though tonically low, the reptilian vagus becomes active to cope with threat by facilitating freezing. In humans too, Porges suggested that the reptilian vagus is generally dormant but may activate in response to threat, and so facilitate freezing particularly if the SNS is withdrawn.

The mammalian vagus, on the other hand, generally affects higher regions such as the heart, larynx, and facial muscles. Porges (1995) hypothesized that this vagal branch evolved in mammals to control their excitatory sympathetic system. He described the mammalian vagus as a "persistent brake to inhibit the metabolic potential" of high-powered mammals, without which we would be "literally, bouncing of walls" in fight-or-flight fashion (p. 306). The mammalian vagal strategy, therefore, is to keep vagal levels generally or tonically high and to withdraw this vagal inhibition in response to threat or when in need of energy. By removing this "persistent brake" the SNS can then fuel action and mobilization. Thus, in response to perceived threat or challenge, the mammalian vagus withdraws its tonic inhibitory influence and a fight-or-flight sympathetic response is potentiated.

In sum, this polyvagal model is fairly consistent with the research just cited by Levy and colleagues on parasympathetic-sympathetic interaction and provides a fairly clear picture of PNS and SNS functioning. Less influence from the mammalian vagus potentiates the SNS, allowing its influence on the heart particularly in response to threat. However, Porges (1995) also suggested that decreased mammalian vagal influence potentiates the reptilian vagal freezing response. He argued, drawing from John Hughlings Jackson, that the more recently evolved systems predominate and inhibit the older systems (Porges, 1998). Thus, decreased levels of activity in the mammalian vagal system may potentiate both the reptilian vagal freezing response to threat and sympathetic mobilization responses to threat. In other words, in general the mammalian vagus seems to buffer against threat responses, whether mediated by the reptilian vagus or the SNS.

Measurement of cardiac vagal tone. The influence of the vagus on the heart—cardiac vagal tone—can be estimated by obtaining an electrocardiogram (EKG) signal, the heart signal, ideally of two minutes or more. However, vagal tone cannot be ascertained by heart rate alone. More vagal outflow slows heart rate, but one cannot assume that a slowed heart always corresponds with increased vagal input. Heart rate may also slow because of SNS withdrawal. Consequently a specific index of vagal tone must be extracted from the EKG signal. This extracted index of vagal tone is termed respiratory sinus arrhythmia (RSA)—the variability in heart rate that occurs roughly in time with breathing.

As Porges (1992) described, the reason vagal influence can be estimated by RSA is that the PNS does not affect the heart with a constant flow of stimulation. The parasympathetic neurons that innervate the heart (and according to Porges, particularly the neurons in the mammalian branch) have a respiratory frequency. Their influence waxes and wanes in time with breathing. As we inhale, parasympathetic outflow decreases, and so the interval between heartbeats is generally shortened. With exhalation, the parasympathetic system generally resumes its inhibitory influence on the heart, and so the interval between beats is lengthened. Therefore, little variability in heart rate because of the respiratory rhythm indexes low PNS influence over the heart or low vagal tone. Greater variability in heart rate in time with breathing indexes more PNS influence or higher vagal tone.

There are various methods for extracting RSA. These measures, the most common of which is termed high-frequency heart rate variability, tend to correlate quite highly (e.g., Allen, Chambers, & Towers, 2007) and their validity has been tested in a number of ways, most commonly with drugs known to diminish vagal functioning (e.g., Porges, 1986, 1992). However, there is also debate about how well RSA corresponds with vagal influence at the heart or under what conditions they best correspond. For example, abnormal respiration patterns may increase dissociation between RSA and actual cardiac vagal tone or influence (Grossman & Taylor, 2007). Furthermore, though not all laboratories support this conclusion (Porges, 2007), some data suggest that higher levels of cardiac sympathetic influence can reduce RSA (see Grossman & Taylor, 2007). One possible reason for this could be that cardiac sympathetic influence alters or interferes with vagal influence on the heart. So it may be that RSA best indexes the functional influence or *effectiveness* of vagal influence, as distinguished from vagal output at the level of the central nervous system (Grossman & Taylor, 2007).

Porges's polyvagal theory also puts forth that RSA indexes a specific branch of the vagus—that RSA indexes the mammalian branch and not the reptilian branch. He reasoned that only the mammalian branch, which is myelinated, can act quickly enough to speed and slow heart rate with respiration, whereas the unmyelinated reptilian vagus cannot affect the heart this quickly (Porges, 2007). On the other hand, other researchers often do not find it important or necessary to distinguish between branches of the vagus nerve. Future research examining the proposed functions of these two branches and whether RSA indexes only the mammalian branch seems imminent.

Thus there are a number of considerations to take into account when thinking about the relationship between RSA and cardiac vagal tone, and future research surely will continue to clarify the exact nature of this relationship. Yet the evidence does at least suggest that under relatively normal conditions, RSA provides a reasonable index of cardiac vagal tone or influence.

State and trait. As with self-esteem, it is useful to distinguish between state and trait vagal tone. The work of Levy and colleagues just presented indicates that state levels of vagal tone provide protection against immediate physiological threat responses. At the heart itself, the current output from the vagus nerve inhibits the impact of the present sympathetic forces. Whatever the level of vagal tone typically or dispositionally, it is cardiac vagal influence at the moment, or state vagal tone, that determines the presence of chemicals that protect against sympathetic influence. Thus, as with self-esteem, the most basic relationship emerges between state levels of cardiac vagal tone and physiological threat responses.

Certainly it stands to reason, however, that just as with self-esteem, trait vagal tone by definition should impact state vagal tone levels and recovery from drops in state vagal tone. Tonic vagal tone has been conceptualized as a resource that enables cognitive and emotional regulation (e.g., Beauchaine, 2001; Thayer & Lane, 2000). This implies that researchers conceptualize tonic vagal tone as important for state vagal tone and state emotional levels. However, assessing trait vagal tone seems to have its complications. An index of tonic vagal tone gathered from several minutes of resting EKG data does not necessarily provide an index of trait vagal tone. Though taken during resting conditions, it may still be better thought of as state vagal tone, just as if we assess state self-esteem during resting conditions we may not acquire an accurate index of trait self-esteem. Furthermore, we can ask a person what their self-esteem is like generally or dispositionally, but there is no way to get from several minutes of EKG data what a person's vagal tone looks like dispositionally.

Future research may therefore better investigate the nature of trait cardiac vagal tone, perhaps by taking measurements over the course of weeks or months. Or alternatively, we might conceive of trait cardiac vagal tone as having to do with a person's typical range or fluctuation of state vagal tone, or with the degree of change that various stimuli elicit (cf. Wallace, 1966). As discussed earlier, these types of characterizations have been used with self-esteem (e.g., Kernis, 2005). In this article, however, we generally conceptualize vagal tone measurement as indexing state levels that should at a basic and immediate level most clearly function to protect from threat responses.

Empirical support in humans. The relatively recent innovation in measuring vagal influence has led to a surge in research in humans, some particularly relevant to the basic models put forward here that state vagal tone stems physiological threat responses. For example, research has found that vagal influence as indexed with RSA tended to override sympathetic influence in predicting heart rate (e.g., Uytdehaage & Thayer, 1989). In another study, researchers measured orienting and defensive cardiac patterns in a conditioning paradigm (Thayer, Friedman, Borkovec, Johnsen, & Molina, 2000). The results showed that people with lower RSA (who were also diagnosed with general anxiety disorder) showed persistent defensive responses to threatening words that high RSA people responded to only with orienting. Low RSA people also tended to respond with persistent vigilance or orienting to nonthreatening stimuli to which high RSA people quickly habituated.

In addition to this research at the heart, work suggests that vagal tone buffers from physiological threat responses elsewhere in the body. For example, one study suggests its inhibiting effect on the eyeblink startle reflex (Ruiz-Padial, Sollers, Vila, & Thayer, 2003), a defensive response that becomes stronger when we feel threatened (e.g., Bradley, Moulder, & Lang, 2005). Higher RSA predicted less forceful startle responses triggered by blasts of white noise during both neutral and positive stimuli presentations. Thus, high RSA people appeared less easily threatened by loud, sudden noises. Research also suggests that the vagus provides a similar protective function in its impact on immune system inflammatory responses, responses that if left unchecked and unregulated can contribute to autoimmune diseases (e.g., Bernik et al., 2002; Czura & Tracey, 2005; Yien et al., 1997). The vagus appears to regulate and inhibit these responses that, like sympathetic responding and startle eyeblink, are threat responses generated to cope with and protect our bodies from some sort of attack or insult.

Future and further examination of this effect of state vagal tone on physiological threat responses could come from measuring cardiovascular threat/challenge patterns explicated by the Biopsychosocial Model of Challenge and Threat Motivation (e.g., Blascovich et al., 2003; Mendes, Major, McCoy, & Blascovich, 2008). The model suggests a division in the sympathetic response. Sympathetic threat responses (elicited when one feels one's perceived resources cannot meet the perceived situational demands) are characterized by lower cardiac output and higher total peripheral vascular resistance relative to challenge responses (elicited when one's perceived resources will allow for meeting the situational demands). Given these physiological threat and challenge patterns, we would predict here that the higher the level of vagal tone, the higher the cardiac output and the lower the total peripheral resistance during a potentially threatening motivated performance situation.

POTENTIAL CAUSAL INFLUENCE BETWEEN SELF-ESTEEM AND CARDIAC VAGAL TONE

The work just presented makes the case that humans come to feel security and safety in part through state self-esteem. In the human adult, at any given moment, state self-esteem functions to provide a buffer against threat responding. This is observed with both reduced psychological threat responses such as anxiety and with reduced physiological threat responses such as sympathetic arousal. We have also presented the case that state cardiac vagal tone functions in part to provide a buffer from these same physiological threat responses. State levels decrease to potentiate threat-related (e.g., sympathetic) responses, presumably when our organism feels the potential for danger. State cardiac vagal tone increases to inhibit threat responses, presumably when our organism feels secure and protected from threat.

These analyses of self-esteem and cardiac vagal tone clearly show similarities. State levels in both self-esteem at the psychological level and cardiac vagal tone at the physiological level appear to function to down-regulate immediate threat responding. Thus state cardiac vagal tone seems a plausible candidate for a physiological outcome of state self-esteem. More specifically, if cardiac vagal tone provides and indicates on a physiological level that a person is secure or protected from threat responding, and human beings in part acquire a sense of security and protection through feelings of self-esteem, then self-esteem should impact vagal tone. One possibility is that increases in state self-esteem systematically increase state vagal tone and decreases in state self-esteem should decrease state vagal tone. Another possibility is that higher state self-esteem does not automatically increase vagal tone but increases a person's *capacity* for higher state vagal tone or the ability to mobilize vagal tone.

Furthermore, that self-esteem may affect cardiac vagal tone does not preclude the possibility that cardiac vagal tone affects self-esteem. If our physiological state is a secure one, then we might attribute this state to our value, to a psychologically secure sense of self. Or with increased state vagal tone we might see a greater *capacity* for increased state self-esteem. Indeed, theory on emotion (e.g., Schachter & Singer, 1962; Zillman, 1988) suggests that our physiological states can inform and influence our psychological states. In addition, the vagus travels both from the brain to other organs, and from these organs back to the brain (e.g., George et al., 2000). Thus, the anatomical evidence suggests that vagal activity affects the brain and so cognitive processes.

Empirical Support I: Vagal Tone Correlates Parallel Self-Esteem Correlates

If self-esteem and cardiac vagal tone have the potential to affect each other such that under some conditions state levels will vary together, then we would expect them to have correlates in common. Consistent with this prediction, the psychological variables inversely associated with RSA closely parallel those psychological variables inversely associated with self-esteem reviewed earlier—the threat-related emotional experiences of anxiety, depression, and hostility. Next we present these psychological correlates of vagal tone.[3]

Anxiety. Studies have frequently found a relationship between cardiac vagal tone and anxiety-related experience. For example, participants diagnosed with panic disorder have shown lower RSA or trends toward lower RSA as compared to nonanxious controls during rest, deep breathing, under threat of electric shock, and during a cold pressor task (Friedman & Thayer, 1998; Klein, Cnaani, Harel, Braun, & Ben-Haim, 1995; Rechlin, Weis, Spitzer, & Kaschka, 1994; Yeragani et al., 1993). General anxiety disorder has also been investigated in relation to vagal tone. In two similar studies (Lyonfields, Borkovec, & Thayer, 1995; Thayer, Friedman, & Borkovec, 1996), general anxiety disorder diagnosed participants showed lower RSA compared to nonanxious control participants during baseline resting periods. In addition, a study investigating attachment showed that both higher levels of trait attachment anxiety as well as greater insecurity in one's current attachments predicted lower RSA (Diamond & Hicks, 2005).

Further linking anxiety to vagal tone, research has shown that participants diagnosed with posttraumatic stress disorder exhibited lower resting levels of RSA than control participants with no known diagnosed illnesses (H. Cohen et al., 1997). In addition, the September 11 attacks that elicited and exacerbated posttraumatic stress disorder and other anxiety-related symptoms in many across the United States (e.g., Pyszczynski, Solomon, & Greenberg, 2002) also appeared to have elicited drops in RSA (Lampert, Baron, McPherson, & Lee, 2002). In a related vein, a daily diary study showed that participants who tended to experience more negative emotional arousal as a consequence of daily stressors also exhibited lower baseline RSA (Fabes & Eisenberg, 1997).

Depression. Just as research links low self-esteem to depression, research also shows a connection between cardiac vagal tone and depression. A number of studies show that people diagnosed with depression exhibit lower baseline and phasic RSA levels (Dalack & Roose, 1990; Hughes & Stoney, 2000; Rechlin et al., 1994) than nondepressed people. In other work, the degree of depressive symptoms has inversely correlated with RSA (O'Connor, Allen, & Kaszniak, 2002) and improved depressive symptoms over time has corresponded with increased RSA (Chambers & Allen, 2002).

Further research suggests a specific type of depressed affect associated with lower cardiac vagal tone. Analysis of BDI subscales has shown that higher RSA predicted lower scores on the Suicidality subscale but that higher RSA predicted higher scores on the Sadness subscale (Rottenberg, Wilhelm, Gross, & Gotlib, 2002). Perhaps consistent with these findings, in other work, participants diagnosed with major depression of the melancholic type showed no difference in baseline RSA as compared with nondepressed control participants (Moser et al., 1998). In addition, viewing an excerpt of a sad video that induced crying did not affect RSA in normal participants (though following crying, RSA tended to increase only in nondepressed participants; Rottenberg, Wilhelm, Gross, & Gotlib, 2003). Thus low vagal tone seems most clearly associated with depressed affect having to do with threats to the self, such as is reflected in suicidality, and not with sadness, particularly as it pertains to the predicaments of other people. This parallels research on self-esteem discussed earlier that shows a relationship between self-esteem and suicidality (de Man & Gutierrez, 2002).

Hostility. Further paralleling self-esteem research, work has suggested an association between cardiac vagal tone and hostility. Brosschot and Thayer (1998) noted that hostility is often characterized by poor cardiovascular recovery following anger induction. This slow recovery is indexed by sustained sympathetic arousal—high heart rate and blood pressure. From this evidence and following evidence that vagal tone exerts an inhibitory effect on sympathetic arousal, Brosschot and Thayer surmised that greater hostility should correspond with lower vagal tone. Empirical work has begun to bear out this link. In one study, for example, lower RSA measured during negative and positive affective verbal tasks predicted higher Cook-Medley hostility scores (W. W. Cook & Medley, 1954; Demaree & Everhart, 2004). In another study, lower baseline RSA predicted slower self-reported recovery from thinking about an anger-inducing event (Diamond & Hicks, 2005).

Empirical Support II: Manipulating Vagal Tone

Of course, the most convincing support for the proposal that self-esteem and vagal tone are causally linked would show that manipulating one variable effects a change in the other. To this end, a procedure emerged approximately a decade ago that enables stimulation of the vagus nerve in humans. This procedure entails inserting a pocket-watch-sized device into the chest wall with wires that extend to wrap around the vagus nerve in the left side of the neck. Sending electricity through these wires stimulates the vagus. This portion of the vagus consists of approximately 80% afferent nerve fibers carrying signals from the periphery to the brain and 20% efferent fibers carrying information to the periphery (e.g., George et al., 2000).

The device was initially developed to reduce seizures by way of intermittent stimulation of the vagus. Research, however, has tied electric kindling and seizures to heightened fearfulness and anxiety (e.g., Adamec, 1976; Kellett & Kokkinidis, 2004; Trimble, 1991). Furthermore, researchers began to note an effect of vagal nerve stimulation in these seizure patients on mood and well-being. This led to further research assessing the impact of vagus nerve stimulation on depression. Although the mechanism by which this vagal stimulation affects the brain and exerts psychological effects is poorly understood, this work has generally supported the possibility that intermittent vagal stimulation can help alleviate depressive and anxiety-related symptoms (e.g., George et al., 2000; Groves & Brown, 2005).

Given that vagal nerve stimulation seems to exert these effects on mood, anxiety, and depression and that self-esteem is intricately linked to these issues—indeed depression is often characterized in part by low self-esteem (e.g., Abramson et al., 1999)—it seems plausible that vagal nerve stimulation can boost self-esteem.

Tentatively, then, this research is consistent with the hypothesis that changes in vagal tone can lead to corresponding changes in self-esteem.

Future research could examine this prediction by assessing self-esteem in people receiving vagal nerve stimulation. This might be investigated using any number of self-esteem measures—explicit, implicit, indices of self-esteem stability, or combinations of these types of measures (e.g., Jordan, Spencer, Zanna, Hoshino-Browne, & Correll, 2003; Kernis, 2005). Furthermore, we can make various predictions about the time course with which vagal nerve stimulation should affect self-esteem. We might predict that stimulation of the vagus immediately increases or secures self-esteem, or we might predict that this influence of the vagus on self-esteem occurs more slowly, as people over time less readily attribute their more secure physiological state to the electrical stimulation and more easily attribute it to their own sense of self and self-worth. Or perhaps vagal nerve stimulation increases a person's capability to respond to successes or praise with a feeling of increased state self-esteem, or increases people's ability to mobilize their self-esteem when in self-esteem relevant situations.

Empirical Support III: Manipulating Self-Esteem

Indirect evidence. Similar to the vagal stimulation research just presented, a number of studies, though not intended to manipulate state self-esteem, may nevertheless indicate that changes in state self-esteem affect changes in state vagal tone. For example, decreased RSA has been observed in participants videotaped singing "Old McDonald" or "This Old Man" who then viewed the embarrassing video with others (Gerlach, Wilelm, & Roth, 2003), in participants engaged in a stressful public speaking task (Mauss, Wilhelm, & Gross, 2001), and in participants engaged in a stressful serial subtraction task (Movius & Allen, 2005). Given that theses tasks effectively present the participants to others in a negative light and elicit embarrassment, it is likely that the tasks also decreased state self-esteem in participants. Thus, these findings are very much consistent with an influence of state self-esteem on state cardiac vagal tone.

Other studies provide similar evidence. In two studies partially described earlier (Lyonfields et al., 1995; Thayer et al., 1996), both anxious (diagnosed with general anxiety disorder) and nonanxious participants exhibited drops in RSA when induced to worry about a topic that currently concerned them. Given the likelihood that topics of substantial concern relate to a person's self-esteem, it may be that the effects of these worry sessions on RSA emerged as a consequence of decreased state self-esteem. In another study (Schwarz, Schachinger, Adler, & Goetz, 2003), researchers monitored high-level chess players during championship matches. Just after the games, the players reviewed the game and described their feelings after each move. The results showed that during transitions to greater hopelessness, RSA tended to decrease. During shifts to greater optimism and control, RSA tended to increase. Given the importance of chess for these committed and high-level players, we can surmise that feeling as if they were winning or losing at any given moment affected their state levels of self-esteem. Thus the vagal tone decreases and increases after what appeared to be bad and good moves, respectively, may have been the result of shifts in state self-esteem.

Self-esteem research. Adding to these studies that are consistent with the idea of a causal link between self-esteem and vagal tone, we (Martens, Allen, Greenberg, & Johns, 2006) have recently undertaken initial research to more directly test this hypothesis. In a first study, we manipulated state self-esteem by providing participants with either negative or positive personality feedback and then examined the effect on RSA.

The experimenter, blind to conditions, gave participants 3 min in private to read over this feedback—a personality report ostensibly derived from their responses on a previously completed mass psychological survey. Adapted from a similar manipulation used successfully in previous research (Greenberg et al., 1992), the feedback was made general enough as to be applicable to most people. The negative feedback, for example, included statements such as, "While you may feel you have some personality strengths, your personality weaknesses affect your life to a much greater extent" and "Most of your aspirations are unrealistic." The positive feedback included statements such as, "While you may feel that you have some personality weaknesses, your personality is fundamentally strong" and "Most of your aspirations tend to be pretty realistic." The feedback appeared effective—responses toward the end of the study to the question "How did the personality feedback make you feel about yourself" (rated on a 9-point scale that ranged from *very bad* to *very good*) showed that the negative feedback led participants to feel worse about themselves than the positive feedback.

We assessed cardiac vagal tone during purported 3-min "recalibration" periods just before and just after the feedback manipulation, in which participants sat quietly. Participants, however, were led to believe that the attached electrodes were to allow for the examination of activity and communication between the left and right sides of the body in a study about the relationship between this type of communication and people's personalities. From the EKG data collected during these 3-min periods, we calculated RSA. Specifically, CMetX software (Allen et al., 2007) converted each interbeat interval series (derived from each three-minute EKG recording) to a time-series sampled at 10 Hz, filtered the series using a 241-point optimal finite impulse response digital filter designed using FWTGEN V3.8 (E. W. Cook & Miller, 1992) with half-amplitude frequencies of .12 and .40 Hz, and then took the natural log of the variance of the filtered waveform to be used as the estimate of RSA.

The results showed that, after accounting for prefeed back level of RSA, the negative personality feedback led to lower state RSA than the positive feedback. Furthermore, across all participants we found that, again controlling for prefeedback RSA, the better people reported the feedback made them feel about themselves, the higher their postfeedback RSA. We also accounted for change in general levels of positive and negative affect by administering the Positive and Negative Affect Schedule (Watson, Clark, & Tellegen, 1988) both just prior to the prefeedback vagal tone assessment and again just after the postfeedback vagal tone assessment. Neither negative affect nor positive affect accounted for the effect of feedback on RSA or the relationship between the self-reported impact of the feedback and RSA. Thus general self-reported mood did not predict change in RSA because of the self-esteem manipulation, but feelings specifically about the self (how bad/good participants felt as a consequence of their personality feedback) did predict change in RSA because of the self-esteem manipulation. In sum, this study provided further evidence supportive of the hypothesis that state self-esteem change can affect state cardiac vagal tone.

To complement this experiment demonstrating an effect of manipulated self-esteem on RSA, we recently conducted a study to examine whether people's state self-esteem tendencies correlate with resting levels of RSA. Participants recorded their state self-esteem for 14 consecutive days by rating each day how much they agreed on a 10-point scale with the statement "Today I have high self-esteem." Participants then came into the lab to provide 10 min of EKG data from which we extracted RSA. The results showed that mean level of state self-esteem positively correlated with RSA—the higher a person's state self-esteem on average over the course of the 2-week recording period, the higher a person's RSA over the course of the 10 min. Thus, converging with the finding that manipulated state self-esteem increased RSA levels, people's naturally existing state self-esteem tendencies positively correlated with resting levels of RSA.

Future work could extend this work in various ways. Research could look into the particular contexts in which we are likely to observe state self-esteem influencing or matching up with vagal tone. Perhaps self-esteem influences vagal tone particularly in circumstances in which self-esteem is made relevant or salient. Also, the initial results of our studies measured vagal tone levels during resting conditions, so it would be informative for future research to examine the impact of state self-esteem on vagal tone reactivity or vagal tone measured during particular tasks or during exposure to various stimuli. The relationship between self-esteem and vagal tone may differ depending on whether vagal tone is measured at rest or in response to some stimuli or task, and the literature on vagal tone reactivity shows that people are not necessarily homogeneous in their styles of vagal tone responses. Although vagal tone decreases in response to stressors are typically predicted (e.g., Porges, 1995), substantial individual differences exist in the way vagal tone responds to stressors. In response to the same stressors, although some people exhibit the predicted vagal tone decreases, some people exhibit no change, and some exhibit vagal tone increases (Glenn & Ditto, 2003).

Based on the theory and evidence that self-esteem provides a buffer against threat and that vagal tone aids in buffering threat responding at the physiological level, state self-esteem may be a key variable that determines the type and degree of vagal tone response during threat-related conditions. Specifically, high state self-esteem may predict maintaining of vagal tone levels during potential stressors or an increasing of vagal tone as part of the mechanism by which self-esteem buffers from threat. Conversely, low state self-esteem may predict decreases in vagal tone in response to potential stressors, facilitating stronger threat responses. Thus, future work might examine self-esteem as a variable that can help account for some of the variability or individual differences in vagal responses to potentially stressful conditions.

Some research examining psychological variables that moderate these differences in vagal tone reactivity is consistent with this possibility. For example, in response to negatively valenced film clips, people with borderline personality disorder showed no change in vagal tone, whereas control participants showed an increase in vagal tone (Austin, Riniolo, & Porges, 2007). In response to a mental arithmetic task, people with posttraumatic stress disorder showed no change in vagal tone relative to control participants who showed an increase in vagal tone (Sahar, Shalev, & Porges, 2001). In a recovery period after a sadness-inducing and crying-inducing film clip, depressed people showed smaller vagal tone increases than control participants (Rottenberg et al., 2003). During an interview about academic performance, university students who prior to the interview exhibited adaptive positive illusions with respect to their academic performance showed increases in vagal tone, whereas those who did not show this positive self-bias showed no increase in vagal tone (Gramzow, Willard, & Mendes, 2008). Given the relationship between self-esteem and these psychological individual difference variables (e.g., Harter, 1990; Mueser, Essock, Haines, Wolfe, & Xie, 2004; Taylor & Brown, 1988; Zeigler-Hill & Abraham, 2006) that have predicted vagal tone response to stressors, it seems plausible that state self-esteem too may help distinguish between those who will respond to various tasks and stressors with decreased vagal tone, those who will respond with maintained vagal tone, and those who will respond with increased vagal tone.

Research could additionally investigate the various types of self-esteem and self-esteem measurement we have described (e.g., explicit, implicit, types of contingencies, stability levels, etc.) in conjunction with cardiac vagal tone and/or the capacity to increase or mobilize vagal tone. In as far as these various self-esteem indices suggest varied contributors to a person's self-esteem, from everyday associations and conditioning to how others treat us to what we base our self-esteem on, this work may also suggest particular tactics for shoring up those aspects of self-esteem that threaten to diminish our health. Along these lines, theorizing and supportive evidence is recently tying the attachment system—a system intimately linked to self-esteem and sense of security—to cardiac vagal tone (Diamond, 2001; Diamond & Hicks, 2005).

IMPLICATIONS AND FUTURE DIRECTIONS

Self-Esteem Theory and Research

One hope for this article is that it may offer direction for generating theory and research having to do with the biology of self-esteem. By broadening self-esteem theory to include physiological systems we can better test theoretical perspectives and build a fuller and more integrative model. For example, the present proposal that self-esteem affects a physiological threat-buffer provides more data for the TMT and self-affirmation theory notion that self-esteem can function to secure our organism and protect people from threat. Furthermore, this expansion should lead to further integration of self-esteem with other areas of research, such as with health, an idea we consider further in the Health section.

Contexts in which self-esteem and vagal tone relate. Future work might also examine whether there are certain conditions under which state vagal tone can predict a person's self-esteem, or in other words, whether conditions exist where we can surmise from changes in state vagal tone that changes in state self-esteem have occurred. This is a difficult task, however, and evidence that manipulating state self-esteem affects state vagal tone does not allow us to conclude that state vagal tone changes indicate state self-esteem changes. There are many variables that affect state vagal tone that surely have nothing to do with self-esteem, such as physical exertion and body posture. Similarly, there must be many variables that affect self-esteem that are independent of vagal tone. Thus, if there is a relationship between state self-esteem and state cardiac vagal tone it is a "many-to-many" relationship (Cacioppo, Tassinary, & Bernston, 2000), where many variables other than vagal tone affect self-esteem and many variables other than self-esteem affect vagal tone. Only in specific circumstances will the possibility exist that we will find a relationship in which both constructs reliably predict each other. For example, it may be particularly in self-esteem relevant situations—situations in which one's self-concept and self-esteem are accessible or salient—that we find one's self-esteem predicts and affects vagal tone. We hope that future research will soon begin to flesh out these conditions that bring out the relationship.

Self-esteem and the brain. This self-esteem and vagal tone proposal may also suggest possibilities for central nervous system connections to self-esteem. Certainly self-esteem is not isolated to one region of the brain and instead likely involves networks and communication between different systems and regions. However, based on our hypothesis and on links between the vagus and the central nervous system, we might nevertheless suggest regions that should be candidates for future research. For example, Thayer and Lane (2000) hypothesized a connection between vagal tone and the medial prefrontal cortex and showed that vagal tone positively correlates with activity in this region using functional magnetic resonance imaging (Lane, Reiman, Ahern, & Thayer, 2001). Thus, from our analysis, it seems plausible that the medial prefrontal cortex is a region similarly important for self-esteem.

Our analysis also suggests that if the medial prefrontal cortex is associated with self-esteem and vagal tone, then it should serve a threat-buffering function. Indeed, this region plays a role in regulation and inhibition of amygdala-related regions (e.g., Garcia, Vouimba, Baudry, & Thompson, 1999; Lieberman et al., 2007; Morgan & LeDoux, 1995; Quirk, Russo, Barron, & Lebron, 2000), the brain regions that function as a threat system and activate the SNS (e.g., Davis & Whalen, 2001; LeDoux, 2000). Furthermore, this prefrontal function is consistent with many other models that posit more generally that the cortex inhibits limbic structures (e.g., Davidson, 2003; Drevets, 1999; Jackson, 1958, as cited in Porges, 1998; Mayberg, 1997; Ter Horst, 1999; Thayer & Lane, 2000).

Other lines of work also converge on this possibility that central nervous system connections with self-esteem may be found in the medial prefrontal cortex. This region, in comparison with nonhuman mammals, appears larger and more complex in its connectivity (e.g., McBride, Arnold, & Gur, 1999; Schoenemann, Sheehan, & Glotzer, 2005; Semendeferi, Armstrong, Schleicher, Zilles, & Van Hoesen, 2001) and has been tapped as important for people's conception of "self" (Macrae, Heatherton, & Kelley, 2004). Functional magnetic resonance imaging research, for example, shows increased activity in this region during self-referential tasks relative to non-self-referential tasks (Kelley et al., 2002; Macrae, Moran, Heatherton, Banfield, & Kelley, 2004). This is what we would expect for a self-esteem-related region—that it is associated with sophisticated self-reflective and symbolic thinking and that it is more complex in humans than in other animals whose sense of security likely stems less from elaborate and symbolic constructions of worth. Thus, from the proposal and our work presented here, investigating the medial prefrontal cortex seems one potential inroad for future research aimed at understanding self-esteem in the central nervous system.

Health

Yet another avenue for future research suggested by this proposal is investigation into implications of self-esteem for physical health. The present research posits a link between self-esteem and the PNS. Thus, this work begins a fine-tuned understanding of at least one avenue by which self-esteem affects the body and physiology. In turn, other research connects parasympathetic and vagal functioning to a host of health issues. Generally this work follows a theme consistent with that of this article—that vagal functioning inhibits the body's emergency or threat systems, which if left unchecked can deteriorate the body and lead to disease.

With respect to the heart and vasculature, the vagus stems sympathetic impact that in excess deteriorates cardiac health. For example, chronic and particularly strong sympathetic activity has been linked to hypertension and hardening of the arteries, both of which contribute to heart disease (e.g., Kamarck et al., 1997; Krantz & Manuck, 1984; Menkes et al., 1989). By controlling and dampening these sympathetic stress responses, vagal control should protect the heart from disease (Jennings & Follansbee, 1985). Supportive of this hypothesis, research links lower vagal control to greater hardening of artery walls and to sudden heart arrhythmia that can lead to cardiac arrest (Chamberlain, 1978; Hinkle, Carver, & Plakun, 1972; Jennings, van der Molen, Somsen, Graham, & Gianaros, 2002; Kent, Smith, Redwood, & Epstein, 1973).

As briefly reviewed earlier, research suggests that the vagus provides a similar protective function in its impact on the immune system. The vagus appears to regulate and inhibit immune system inflammatory responses that if left unchecked and unregulated contribute to autoimmune diseases (e.g., Czura & Tracey, 2005). Like sympathetic responding, then, these inflammatory responses are generated to cope with and protect our bodies from some sort of threat or insult. Also like sympathetic activity, these immune responses if prolonged and in excess can damage the body they were originally generated to protect. Examples of inflammatory autoimmune diseases include rheumetoid arthritis, Crohn's disease, lupus, diabetes, and sepsis. Evidence linking these issues to vagal tone is beginning to emerge. For example, one study found that low vagal tone predicted higher mortality rates because of sepsis (e.g., Yien et al., 1997). Other research has revealed an association between lower vagal tone and diabetes (Masi, Hawkley, Rickett, & Cacioppo, 2007)

Inflammatory immune responses may also play a role in other health issues, in turn suggesting a potential projective role of vagal control in these other diseases too. A body of work now suggests inflammation plays a role in the development and progression of at least some forms of cancer (e.g., Balkwill & Mantovani, 2001; Karin & Greten, 2005; Marx, 2004). Similarly, a growing body of research ties inflammation to Alzheimer's disease (e.g., Bamberger, Harris, McDonald, Husemann, & Ladreth, 2003; P. B. Rosenberg, 2006; Streit, 2004). One hypothesis puts forth that Alzheimer's disease stems in part from a prolonged threat or immune response in the brain. This leads to chronic inflammation and cellular processes that over time prove toxic and fuel deterioration of the brain (Combs, Johnson, Karlo, Cannady, & Landreth, 2000; Yates et al., 2000). Here, too, evidence has begun to emerge suggesting a connection between Alzheimer's and vagal tone, specifically between increased vagal functioning and improved symptoms in Alzheimer's disease patients (Sjogren et al., 2002).

These types of disease that stem from the body's threat responses having cascaded and "gone too far" correspond well with a similar analysis that psychological disorders emerge as threat responses spiraled and blown out of proportion. Hence the logic of cognitive therapy approaches in which people work to be more rational and to correct "distorted" patterns of thinking about problems and threats (e.g., Beck, 2005). Thus perhaps the human potential for chronic or excessive psychological threat can help explain the body's "irrational" physical threat responses. Furthermore, if some forms of autoimmune-related and sympathetic-arousal-related disease stem from psychological threat-sensitivity particularly evident in humans, then self-esteem should provide some protection against these autoimmune and cardiovascular diseases. Consequently, it might prove fruitful for future work to investigate the possibility that self-esteem affects cardiovascular and autoimmune issues via vagal tone. This could also suggest advocating that avenues for effectively dealing with both potentially lethal heart complications and immune system and inflammatory-related disease should include a consideration of self-esteem as a protective psychological variable.

Vagal Tone Theory

The emphasis of this article has been first and foremost to suggest a possible physiological connection of self-esteem—a physiological variable that self-esteem may affect and that may affect self-esteem. We have not sought to theorize about the *best* psychological characterization of cardiac vagal tone. Indeed, there is a good deal of such theorizing. The generally agreed-upon perspective interprets cardiac vagal tone as having to do with emotion and attention regulation (e.g., Porges, 1995). Often distinguishing between tonic or baseline levels and phasic or state changes, this analysis suggests that high tonic or baseline levels of vagal tone index attention and emotion inhibition resources, and thus the ability to flexibly regulate attention and emotion in ways appropriate to the situation (e.g., Beauchaine, 2001; Friedman & Thayer, 1998; Thayer & Lane, 2000). Consequently, reduced flexibility indexed by low baseline vagal tone manifests itself in psychological difficulties such as "poor attentional control," (Thayer & Lane, 2000, p. 206), "poor affective information processing" (Thayer & Lane, 2000, p. 213), and "negative emotional traits" (Beauchaine, 2001, p. 199). Though less agreed upon, the meaning of large phasic or state decreases in vagal tone may be thought of in roughly the same way, as indicating "emotional lability of a fight or flight nature" (Beauchaine, 2001, pp. 198-199) and "negative emotional states," as compared to more "moderate vagal withdrawal" (Beauchaine, 2001, p. 199).

This theorizing, that cardiac vagal tone indexes the ability and resources to inhibit and regulate negative emotional and attentional states, fits fairly well with our proposed vagal tone and self-esteem connection. Self-esteem should provide for increased emotion and attention regulatory abilities by way of its threat-buffering function. Threat and threat-related arousal narrows attention, diminishes inhibitory abilities, and impairs cognitive performance (e.g., Easterbrook, 1959; Pallak, Pittman, & Heller, 1975; Schmader & Johns, 2003). With stronger threats, presumably people more rigidly direct self-regulatory resources toward that threat, making flexible self-regulation less possible (e.g., Pyszczynski & Greenberg, 1987). Conversely, emotion and attention regulation abilities should also have positive implications for self-esteem. With greater flexibility and control over these responses, people can presumably better interact with others and succeed at higher levels, which in turn garner approval and feelings of self-worth. Thus we need not substitute self-esteem for existing theoretical perspectives on the psychological meaning of cardiac vagal tone in laying out a possible connection between cardiac vagal tone and self-esteem.

Yet it is also possible that future work will refine how we think about the psychology of vagal tone. Perhaps regulatory abilities best characterizes the psychological implications of cardiac vagal tone or perhaps other characterizations are more accurate, such as an ability to down-regulate or buffer threat responses. Although these two characterizations are highly similar and often make the same predictions with respect to threat responses, they may also differ in some cases in their predictions. More regulatory ability predicts the experience of both particularly low and high levels of threat depending on the circumstances and what may be most "appropriate." Threat-buffering ability predicts reduced threat responding, period. Thus, future research could examine cardiac vagal tone in situations in which *greater* threat-related negative emotions would be considered *appropriate*. But whatever the case, it seems that enough theorizing and research exists to warrant consideration of and investigation into state cardiac vagal tone as a physiological variable that may both result from and give rise to self-esteem, though of course the specific paths and conditions under which this relationship emerges have not yet been clearly determined.

CONCLUSION

In sum, a substantial literature suggests a link between state self-esteem and state cardiac vagal tone. This theory and research shows clear parallels between the two constructs. They both appear to protect from threat responding of a psychological and physiological nature. Furthermore, work suggests that manipulating state levels of each construct can affect corresponding changes in the other. In turn this hypothesized link may aid future theorizing and new avenues of research that expand and elaborate how we think about the biology of self-esteem both at the autonomic and central nervous system levels. In doing so, the hope is also that this research will continue to shed light on self-esteem's potential health implications.

NOTES

1. Other theorizing—the sociometer theory (Leary, Tambor, Turdal, & Downs, 1995)—puts forth a different function of self-esteem. Here it serves as a gauge or signal that alerts people to the degree they are socially included and so satisfying a need to belong. The merits of this perspective as compared to TMT have been discussed elsewhere (e.g., Leary, 2004; Pyszczynski, Greenberg, Solomon, Arndt, & Schimel, 2004), but irrespective of this discussion, the sociometer theory does not appear to specify whether self-esteem should have consequences for the severity of threat responses. Leary—the author of the sociometer theory—has noted too that the theory is consistent with the possibility. He "would agree that self-esteem does, in fact, buffer people against anxieties of all sorts" (Leary, 2004, p. 479).

2. Indeed, the many variations of stress and coping theories are generally consistent with this biopsychosocial model of threat. They generally examine and construe people's ability to cope with stress as a function of increasing their resources in one form or another (e.g., Hobfoll, 2002) and/or decreasing demands and adopting more realistic goals.

3. We review only data from adults here. Research with children suggests that vagal tone may function differently for them. Thus these data may not be appropriate for theorizing about the psychology of vagal tone in adults. Specifically, the vagus nerve controls the heart significantly less in infancy and in children than afterward (e.g., Izard, Porges, Simons, Haynes, & Cohen, 1991; Porges, Doussard-Roosevelt, Portales, & Suess, 1994). As a consequence, it makes vagal tone in children and adults difficult to compare. For instance, high vagal tone in infants would be considered low vagal tone if compared with adults. Yet researchers have examined the data only as if vagal tone level relative to one's age group is important. Furthermore, infants and children have a relatively undeveloped prefrontal cortex, and if vagal tone is intricately tied to the prefrontal cortex as is theorized (Thayer & Lane, 2000), then vagal tone should reflect somewhat different cortex-related processes in childhood than in adulthood. Indeed, these cortex-related processes very likely relate to the psychological issues in question—to anxiety, depression, hostility, cognitive inflexibility, and, central to this article, a sense of self-worth, or self-esteem.

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