THE AUTONOMIC PHYSIOLOGY OF TERROR MANAGEMENT: INVESTIGATING THE EFFECTS OF SELF-ESTEEM ON VAGAL TONE

by

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ABSTRACT

Theory and research suggests a link between self-esteem and cardiac vagal tone (parasympathetic nervous system influence on the heart). A literature review suggests that vagal tone protects the body against physiological threat responding (e.g., sympathetic responding) and that vagal tone is highest when we feel secure. Terror management theory posits that humans, who live in a largely symbolic world, derive feelings of security and protection from threat by way of acquiring and maintaining self-esteem. Thus we hypothesized that if vagal tone provides physiological security, and we derive a sense of security through symbolic means by way of self-esteem, then high or increased self-esteem should lead to high or increased vagal tone. To test this hypothesis we conducted two studies in which we manipulated self-esteem by giving participants positive or negative feedback. We predicted that positive feedback would lead to higher vagal tone than negative feedback. Consistent with these predictions, in both studies we found indications that positive feedback increased vagal tone relative to negative feedback. In Study 2, to more fully test our theoretical perspective we induced threat by leading participants to believe they would receive electric shocks. We predicted that both self-esteem and vagal tone would buffer against sympathetic threat responding. Consistent with our model we found that the positive feedback eliminated the sympathetic response to threat of shock that was elicited in the negative feedback condition. Also consistent with our model, higher vagal tone predicted lower sympathetic responding to threat of shock. We discuss future directions for this research and implications for physical health.

INTRODUCTION

How do the branches of the autonomic nervous system, the parasympathetic nervous system and sympathetic nervous system, relate to self-esteem? Work on the autonomic nervous system suggests that the parasympathetic nervous system serves to buffer against sympathetic influence and amygdala-related physiological threat responses. Further, high levels of parasympathetic activity in humans tend to correspond with more secure psychological states, such as with less vulnerability to anxiety, depression, and aggression. Terror Management Theory (TMT; Greenberg, Solomon, & Pyszczynski, 1986) posits that for humans, who live in a largely symbolic world, self-esteem is a crucial provider of this security. When we feel valued by the culture we are invested in, we feel buffered from threat and anxiety. Consequently, from our analysis of the workings of the parasympathetic nervous system, we suggest that feelings of self-esteem should promote parasympathetic activity.

Self-esteem

Terror Management Theory and the Function of Self-esteem

> Unlike the baboon who gluts himself only on food, man nourishes himself mostly on self-esteem. (Becker, 1971, p.3)

We define self-esteem as the feeling that one is valued by people or a culture that one finds meaningful. Further, we use TMT to think about why it is important to people, in other words, what function self-esteem serves. Based on the writings of Ernest Becker (1971; 1974; 1975), who in turn synthesized work from a wide range of thinkers, most notably Freud, O.Rank, Darwin, N.O. Brown, and Kierkegaard, Terror Management

Theory (e.g., Pyszczynski, Solomon, Greenberg, & Stewart-Fouts, 1995) abides by the notion that the evolution of the human brain brings with it increased flexibility. Compared to other animals, we have increased self-awareness and an increased ability to think symbolically, imaginatively, and abstractly. This allows for an increased sense of self and provides the capacity for increased self-regulatory ability. Becker describes this capacity as “freedom of reactivity”. Whereas immediate circumstances and specific instincts strictly drive the behavior of other animals, humans can, with self-awareness and flexibility of thought, take stock of their current predicament and figure out how to act in order to change their predicament (cf. Carver & Scheier, 1981). Humans can construe abstract future possibilities and imagine future payoffs that can in turn guide behavior and result in delay of gratification (e.g., Mischel & Staub, 1965). Thus, humans have greater flexibility than other animals in responding to various situations and stimuli.

Fundamental for TMT, however, these powerful cognitive abilities are proposed to come with a catch, with strings attached. These abilities provide us the capacity to understand just how fragile and unpredictable our lives are. More so than any other animal, we are sensitive to our own vulnerability. We know that we are mortal and that safety and survival is never certain and is ultimately untenable. This sensitivity to our own vulnerability, TMT asserts, for an animal evolved to preserve itself and thus avoid harm and death, is particularly aversive and can provoke chronic feelings of heightened self-concern and insecurity, and thus an exaggerated potential for threat-related responding and anxiety. In mammals, this psychological threat response often finds its physiological substrate in the sympathetic nervous system (Costanzo, 2002). This system prepares the body for massive action, and specifically, fight-related or flight-related action that throughout mammalian history has been particularly well suited for dealing with threat.

Left unchecked, the immense human potential for threat and fight or flight related psychological reactions would be debilitating. Becker and TMT propose that self-threat steers cognitive resources toward the threat, and thus narrows the flexibility and utility of cognitive resources for self-regulation. Paradoxically, then, the self-awareness and cognitive flexibility that allows for enhanced self-regulation threatens to take away this regulatory ability or freedom of reactivity by way of amplifying feelings of anxiety, threat, and insecurity. Thus, TMT posits that we are motivated to address this potential for anxiety both simply because this insecurity is aversive to our organism, and also because regaining equanimity is necessary for flexible and adaptive functioning.

Humans must control these threat feelings, as any organism programmed to survive and to hold on to life would be driven to do. To this end, TMT proposes that humans strive to generate and maintain symbolic security. We work to counter our finiteness and fragility and transitory nature with faith in a symbolic world that seems meaningful and permanent, and a symbolic conception of self that is a valuable and thus a protected part of this permanent meaning system. People’s sense of self shifts from one with a physical basis that is clearly always fallible and vulnerable to extinction, to a symbolic one enmeshed in an immortal cultural worldview, and thus a self that is less vulnerable to deterioration and ultimate annihilation.

From this perspective, when we meet our symbolic goals we achieve self-esteem, and also a kind of symbolic and cultural immortality. This self-esteem and symbolic immortality might come through producing art or theory or invention or business that will survive after one's physical body disintegrates. Or we might achieve a kind of value and immortality through children. By both bearing them and teaching them we can infuse ourselves into a future generation and thus survive beyond our physical organism (McAdams & de St. Aubin, 1992). Or we might live in such a way as to qualify for survival beyond physical death in an afterlife, if that is part of our cultural worldview. In sum, if we are to understand how the human being achieves a sense of security, Becker and TMT argue that we must take into account self-esteem. Self-esteem, achieved by living up to various culturally prescribed standards, offers a sense of symbolic immortality and thus security from vulnerability. This, in turn, buffers against an otherwise heightened or exaggerated potential for feeling anxiety, and consequently also against a narrowing and depletion of cognitive resources and self-regulatory abilities.

Empirical Review

Level of state self-esteem and protection from threat

TMT proposes that the self-worth or sense of self-esteem that we feel at any given moment, serves to protect us from feeling threatened and anxious. Thus, to assess this TMT proposition we should find evidence that that high state self-esteem is associated with lower potential for the triggering of anxiety and threat-related psychological and physiological experiences. Indeed, Heatherton and Polivy (1991), in developing a measure of state self-esteem, consistently found significant correlations between lower state self-esteem and threat-related emotions such as anxiety, hostility, and depression.

To more precisely test the predicted causal relationship between state self-esteem and anxiety/threat, however, Greenberg et al. (1992) manipulated people's sense of self-worth by giving them very positive or neutral feedback about their personality. Participants then watched either a video of death-related footage such as an autopsy and electrocution, or of neutral nature-related footage. Those who received the neutral feedback and viewed the death footage reported heightened anxiety. Those who received the positive feedback, the self-esteem boost, did not report this increase in anxiety.

In a conceptual replication (Greenberg et al., 1992), control participants showed heightened skin conductance, a measure of sympathetic nervous system arousal that in response to threat is generally taken to indicate anxiety, in anticipation of an electric shock. However, those who received positive intelligence feedback, and thus a boost to self-esteem, did not show this increase in skin conductance. Further, follow-up showed that the effects of this self-esteem boost on inhibited skin conductance did not appear mediated by self-reported positive mood. Thus, these studies provided strong evidence that high state (manipulated) self-esteem buffers people from the experience of anxiety.

Security of self-esteem and protection from threat

In addition to the mere level of state self-esteem, we should also predict that the security of self-esteem serves to buffer from threat and anxiety. Even a person with high state self-esteem, if it is fragile and insecure, may be prone to heightened anxiety and threat responding. People may feel momentarily good about themselves, but with a certain knowledge that the feeling is fleeting, may at the same time feel more vulnerable and threatened. Also, insecure self-esteem should mean more sudden and frequent drops in state self-esteem, further increasing vulnerability to threat. Thus, the security of self-esteem and constructs that promote the security of state self-esteem should also be associated with protection from threat.

Relevant to this proposition, Kernis and colleagues have developed a paradigm to investigate not simply the level of self-esteem, but to investigate the stability of self-esteem or how much self-esteem tends to fluctuate, as it affects emotional behavior and various threat responses. In their investigations, 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 and thus security of self-esteem.

A number of studies suggest that stability of self-esteem works as a threat buffer. For example, unstable self-esteem people appear more likely to exhibit anger and hostility during their daily lives (Kernis, Grannemann, & Barclay, 1989) and more likely to exhibit greater physiological threat patterns relative to physiological challenge patterns during engagement in a difficult task (Seery, Blascovich, Weisbuch, & Vick, 2004). Further, work generally shows a link between greater instability of self-esteem and greater depression (Roberts & Kassel, 1997; de Man & Sterk, 2001; Kernis, Grannemann, & Mathis, 1991). One study suggests that the link may be particularly strong between this instability and depression as characterized by suicidal ideation (de Man & Gutierrez, 2002).

Also suggesting that insecure self-esteem disposes one to threatened experience is work investigating narcissism. Narcissistic personalities have shown greater fluctuations in self-esteem as a consequence of performance on a purported intelligence task (Rhodewalt & Morf, 1998), and those scoring high on narcissism have expressed more anxiety, anger, and aggression after and experimentally manipulated failure or insult (Rhodewalt & Morf, 1998; Bushman & Baumeister, 1998).

Investigating security of self-esteem and threat in yet another way, particular contingencies of self-esteem seem to offer more security and protection from psychological threat. 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 threatened ways (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 showed that contingencies of self-esteem that are more external predict greater stress and aggression (Crocker, 2002). Additionally, in a related vein, more diverse sources or contingencies of self-esteem also seem foster greater stability in self-evaluations, and this self-complexity predicts lessened stress and depressed affect in response to failure and daily challenges (e.g., Linville, 1987; Linville, 1985).

Trait self-esteem, in addition to predicting state self-esteem levels, may also be conceptualized as a construct that affects the security of self-esteem. Brown and colleagues (e.g., Brown, Dutton, & Cook, 2001) suggest that trait self-esteem impacts not only the level, but the resilience of state self-esteem. High trait or global self-esteem people should be better at protecting state self-esteem than low trait self-esteem people. They are better at interpreting events in ways that promote state self-esteem, that make drops in state self-esteem less frequent, less severe, and more transient. In support, in self-esteem stability studies, scores on the Rosenberg trait self-esteem scale, as well as averaged state self-esteem levels, tend to be inversely correlated with instability of state self-esteem. (e.g., Kernis, Grannemann, & Barclay, 1989; Kernis, Cornell, Sun, Berry, & Harlow, 1993).

Consistent with the prediction that trait self-esteem protects from threat, likely by promoting both security and state level of self-esteem, low trait self-esteem has been linked to anxiety (e.g., Brockner, 1983; Rosenberg, 1979), as well as to depression as indexed by scores on the BDI, DSM, and NEO Personality Inventory (e.g., Schmitz, Kugler, & Rollnik, 2003; Watson, Suls, & Haig, 2002). In addition, low trait self-esteem predicts negative emotional and physiological threat responses to failure and stressors (Kernis, Brockner, & Frankel, 1989; Taylor, Lerner, Sherman, Sage, McDowell, 2003).

Threat responding has also been predicted by "implicit" self-esteem, determined generally by measuring the strength of the associations between self-words and positive/negative words. For example, Spalding and Hardin (2000) found that higher implicit self-esteem participants appeared less anxious during a self-relevant and thus potentially self-esteem-threatening interview. In a similar vein, Greenwald and Farnham (2000) found that higher implicit self-esteem people responded less defensively to a laboratory failure.

Summary

In sum, the above research supports the notion that high state self-esteem and a secure sense of self-esteem provide a sense of security to the human animal, which serves to dampen the potential for threat and fight or flight related emotional and physiological experience. Though a feeling of security in other animals may stem, by and large, from the presence or absence of physical and relatively immediate threats, security for the human animal stems, in addition and perhaps more importantly, from a sense of symbolic worth, from self-esteem. Work has shown this by means of self-esteem manipulations, measuring state self-esteem, measuring stability of self-esteem, contingencies of self-esteem, self-complexity, narcissism, and trait self-esteem. Central to this paper, however, is how state self-esteem and secure self-esteem as anxiety-buffers, are reflected in the nervous system. Threat and fight or flight emotions like anxiety and rage often find a physiological substrate in the sympathetic nervous system. But does self-esteem have a physiological substrate in the autonomic nervous system? The following sections will provide an overview of autonomic nervous system—its mechanics and its psychological correlates—to suggest that self-esteem may find a substrate in a branch of the parasympathetic nervous system, specifically, as indexed by the workings of the vagus nerve.

The Parasympathetic and Sympathetic Nervous Systems

The ANS helps to regulate the vital organs in the body, and is not obviously under voluntary or conscious control. The ANS consists of two major branches, the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS), and the two systems usually have opposite effects on the organs they innervate. The SNS generally excites and facilitates activity in the body, whereas the PNS generally inhibits or slows activity (Constanzo, 2002; Lovallo & Sollers III, 2000).

Though the PNS and SNS complement each other by affecting the body generally in an opposite manner, they do not always work in a reciprocal or coordinated fashion. In other words, an increase in the activity of one system does not necessarily mean a decrease in the activity of the other system, though the notion of this reciprocal relationship has guided ANS theory for most of the century (e.g., Bernston Cacioppo, & Quigley, 1991; Ohman, Hamm, & Hugdahl, 2000). Bernson, Cacioppo, and Quigley (1991; 1993), in their explication of autonomic space particularly in regards to the regulation of the heart, note that the two systems may influence the heart in an uncoupled, non-reciprocal manner. One system may become more or less active while the other system remains unchanged. Furthermore, the SNS and PNS may act in a coupled but non-reciprocal way. They may both become more or less active together.

Additionally, 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. Thus, SNS activity in one part of the body often means the same thing psychologically as activity in another part of the body. The PNS less often acts in concert, however. Parasympathetic flow to the heart does not necessarily mean PNS flow to the intestines. Consequently, measuring PNS effects in one part of the body likely signals something different than measurements taken in another part of the body. 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 non-invasively measured. Further, the heart's critical function, delivering nutrients to the body to facilitate action and thinking, suggests its connection to vital psychological 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 (ACh). However, the SNS postganglionic neurons produce and release norepinephrine (NE) at the junctions with the heart, the neuroeffector juntions. The PNS postganglionic neurons produce and release ACh at the neuroeffector junctions.

These neurotransmitters respond and affect the heart at different speeds, and consequently, the branches of the ANS differ in the time course with which they affect the workings of the heart (e.g., Bradley, 2000). The PNS' ACh affects the heart very quickly, and thus the heart responds to parasympathetic change in less than a second. The sympathetic system's NE often takes several seconds to exert an influence on the heart. Acytelcholine also dissipates more quickly than NE, 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). These effects on rate are termed chronotropic effects. 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 infiltrate the atrioventricular (AV) 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 ANS influences on conduction velocity are termed dromotropic effects. 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, termed inotropic effects (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. Increases in heart rate increase the force of ventricular contraction (Constanzo, 2002) and so PNS instigated chronotropic effects that result from innervation of the SA node would seem also to indirectly affect the force of ventricular contractility. Further, as will be discussed in the next section, in contrast to most descriptions (e.g., Brownley, Hurwitz, & Schneiderman, 2000), research has demonstrated that the PNS does indeed innervate the ventricles, though its effects only emerge clearly in interaction with SNS activity.

Parasympathetic-sympathetic interaction

First shown by Rosenblueth and Simeone (1934), Levy and colleagues, working generally with anesthetized dogs, have provided a good deal of evidence that the effects of the PNS and SNS do not simply summate, but instead interact to affect the end state of the heart. To investigate this process, they have stimulated parasympathetic and sympathetic nerves that innervate the heart at different frequencies and in different combinations. 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. Further, 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 was than the other. But this did not occur. Activity in one system did not serve to negate a comparable level of influence on the heart by the other system. Instead, the PNS appeared dominant, to hold a trump card, termed by Levy, *vagal preponderance* or *accentuated antagonism*. The term *vagal preponderance* stems from the name of the nerve that serves as the main vehicle for PNS influence on the heart: the vagus nerve. With the PNS or vagus nerve highly active or stimulated, SNS activity generally plays a lesser role in affecting the heart. Only when the PNS is less active does the SNS play a substantial role.

These interactions have been demonstrated at various places in the heart. First, Levy and colleagues have shown these vagal preponderance interaction effects at the SA node and thus on heart rate (Levy, 1990). They conclude from a number of studies that when the vagus and sympathetic nerves are stimulated simultaneously or when the vagal stimulation preceded simultaneous vagal and sympathetic stimulations, vagal influence dominates, generally completely wiping out 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. This null direct vagal effect on the ventricles has likely led many to believe that PNS nerves do not innervate the ventricles. However, Levy and colleagues found that during simultaneous sympathetic and vagal stimulation, the activity of the vagus played a clear role. Vagal stimulation nearly wiped out the effects of sympathetic stimulation on contractility and excitability. Thus, in the ventricles the vagal influence on contractility and excitability emerges clearly only through its antagonism of sympathetic influences. Comparable vagal antagonism effects have also been shown on atria contractility (Levy, 1990).

Summary

From this above work, a consistent picture of vagal-sympathetic interaction emerges. The PNS exerts powerful inhibitory prejuntion and postjunction effects on SNS excitatory chronotropic and inotropic influences. However, SNS activity, only when the PNS is first inactive, can also mildly and temporarily inhibits PNS influence. As a consequence, only when the PNS is less active does the SNS plays a substantial role in affecting the heart. When the PNS is more active, it serves to antagonize and greatly limit the ability for the SNS to affect the heart. Therefore, the PNS effect on the heart may be viewed as dual. It (1) directly calms the body by slowing the firing of the SA node and slowing conduction speed at the AV node, and (2) 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, the force of ventricle and atrium contractility, and the excitability of the ventricles.

Polyvagal Theory

Consistent with the PNS and SNS pattern of interaction put forth above, Porges (1995) has 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 it also innervates the heart and other organs, and controls very basic responses and reflexes. Porges posits that this branch evolved in cold blooded 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 sympathetic nervous system 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 suggests that the reptilian vagus is generally dormant, but may trigger in response to threat, and so facilitate freezing particularly if the sympathetic nervous system is withdrawn.

The smart vagus, on the other hand, generally affects higher regions such as the heart, larynx, and facial muscles. Porges hypothesizes that this vagal branch evolved in mammals to control their excitatory sympathetic system. He describes 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 (Porges, 1995, p.306). The mammalian vagal strategy, therefore, is to keep vagal levels generally or tonically high, but to withdraw this vagal inhibition in response to threat or when in need of energy. By removing this "persistent brake" the SNS can prepare us for action and allow for 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 dual vagal model aids in understanding the PNS and SNS response to threat. In response to threat, the mammalian vagus withdraws. This withdrawal of the mammalian vagus then potentiates the SNS. However, Porges (1995) also suggests that withdrawal of mammalian vagal outflow potentiates the reptilian vagal freezing response. He argues, drawing from John Hughlings Jackson, that the more recently evolved systems predominate over the older systems (Porges, 1998). Thus, withdrawal of the mammalian vagal system may potentiate both the reptilian vagal freezing response to threat, and sympathetic mobilization responses to threat. From this Polyvagal Theory, the mammalian vagus seems in general to buffer against threat responses, whether mediated by the reptilian vagus or the SNS.

Measurement of Parasympathetic Activity

Innovation in measuring PNS activity in humans has occurred relatively recently, within the past 20 years, and is having a substantial influence on the field of psychophysiology. Specifically, the level of parasympathetic influence at the heart, termed *vagal tone*, can be estimated by obtaining an electrocardiogram (EKG) signal generally of two minutes or more. However, vagal tone cannot be ascertained by HR alone. More vagal outflow slows HR, but one cannot assume that a slowed heart always corresponds to increased vagal input. Heart rate may also slow due to SNS withdrawal. If the SNS and PNS always acted and responded reciprocally, we could accurately infer vagal and SNS changes from HR changes. For example, a HR increase would always signal vagal withdrawal and an increase in SNS activity. But as mentioned, the PNS and SNS do not necessarily work in a reciprocal fashion (Bernson, Cacioppo, & Quigley, 1991; Bernson, Cacioppo, & Quigley 1993).

A method has been derived, however, to extract PNS influence from the EKG signal. Specifically, respiratory sinus arrhythmia (RSA), extracted from EKG data, provides this vagal tone index. Respiratory sinus arrhythmia is the variability in interbeat intervals due to breathing. As Porges (1992) describes, the reason vagal influence can be estimated by this procedure is that the PNS does not affect the heart with a constant flow of stimulation. The parasympathetic neurons that innervate the heart have a respiratory frequency. Their influence waxes and wanes in time with breathing. As we inhale (particularly during the mid to late phase of inhalation), parasympathetic outflow is inhibited or interrupted, 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. Consequently, little variability in heart rate due to breathing indexes low PNS control over heart rate or low vagal tone. Greater variability in heart rate length due to breathing indexes more PNS control over heart rate or higher vagal tone.

One can compute this RSA and parasympathetic tone in a number of ways by performing operations on an interbeat interval series—the series of the times in between each heartbeat. Commonly, one filters this series to arrive at the variability in interbeat intervals in the frequency band that corresponds with breathing. Because humans under normal circumstances breathe between once every two and half seconds and once every eight seconds, passing the frequencies of between .12 to .4 Hz in the interbeat interval series provides the strength of RSA. This is often labeled high frequency heart rate variability (HF HRV), and the validity of the measure has been tested in various ways both in humans and in animals (e.g, Porges, 1992; Porges, 1986).

Another way to measure vagal tone is with the computationally straightforward pNN50. The pNN50 is the proportion of consecutive interbeat intervals with durations that differ by more than 50ms. Because vagal outflow is presumably the only influence on the heart fast enough to affect changes that dramatically from beat to beat, the percentage of such changes in any given series is taken to index the strength of vagal control on the heart. Correlations with standard RSA measures are generally quite high (e.g., greater than .85, Allen, 2002). The pNN50 is particularly appealing because it is simple to compute and interpret, and is more resistant to outlier data than other indices such as RSA (Burr et al., 2003).

Vagal Tone Connections to Psychological Threat

This innovation in measuring parasympathetic influence has led to a surge in vagal tone related work in humans that tends to support the threat-buffering perspective of parasympathetic nervous system functioning at the heart. Contributing to a shift in focus away from the sympathetic system that for most of the century dominated the field, this body of data generally focuses on vagal tone as a predictor of anxiety, hostility, and depression. In addition, a body of work also investigates vagal tone in conjunction with more cognitive and attentional processes.

Below we will review much of this work. The review, however, will be limited to work in adults. Infant and child data will not be brought to bear on theorizing about vagal tone in adults for two main reasons. First, the vagus nerve controls the heart substantially less in infancy than afterwards (e.g., Porges, Doussard-Roosevelt, Portales, & Suess, 1994; Izard, Porges, Simons, Haynes, & Cohen, 1991). This makes vagal tone in infants and adults difficult to compare. For instance, high vagal tone in infants would be considered low vagal tone if compared with adults. A second reason to avoid drawing conclusions about vagal tone in adults from vagal tone correlates in infancy is that vagal tone in infancy may simply index much different psychological constructs. Infants and adults are different physiological and psychological beings. For instance, infants have a relatively undeveloped prefrontal cortex. Consequently, if vagal tone in adults is tied to a sense of symbolic security, a sophisticated cognitive construction, then vagal tone may carry a different psychological meaning in infants without the ability to form such a construction. In sum, psychological correlates of vagal tone in infants and children may not be particularly useful for understanding the psychology of vagal tone in adults.

Vulnerability to anxiety

A number of studies investigate vagal tone in relation to anxiety-related experience. For example, participants diagnosed with panic disorder have shown lower vagal tone or trends toward lower vagal tone than non-anxious controls during rest, deep breathing, under threat of electric shock, and during a cold pressor task (Klein, Cnaani, Harel, Braun, & Ben-Haim, 1995; Rechlin, Weis, Spitzer, & Kaschka, 1994; Yeragani, Pohl, Balon, Ramesh, Glirtz, Srinivasan, & Weinberg, 1993; Friedman & Thayer, 1998).

In addition to panic disorder, researchers have demonstrated a link between other anxiety disorders and vagal tone. For example, one study (Cohen, Kotler, Matar, Kaplan, Miodownik, & Cassuto, 1997) shows that participants diagnosed with post traumatic stress disorder (PTSD) exhibited lower resting levels of vagal tone than control participants with no known diagnosed illnesses. Additionally, the September 11th attacks that elicited or exacerbated PTSD and other anxiety-related symptoms in many across the country (e.g., Pyszczynski, Solomon, & Greenberg, 2002) also appeared to have elicited drops in tonic vagal tone levels (Lampert, Baron, McPherson, & Lee, 2002).

General Anxiety Disorder (GAD) has also been investigated in relation to vagal tone. In two similar studies (Lyonfields, Borkovec, & Thayer, 1995; Thayer, Friedman, & Borkovec, 1996), GAD diagnosed participants showed lower vagal tone compared to non-anxious control participants during baseline rest periods. Further, in these studies, all participants, both those with GAD and without anxiety disorders, showed lowered vagal tone when induced to worry about a topic that currently concerned them.

A number of other studies too show that experimentally manipulated state anxiety decreases vagal tone. For example, decreased vagal tone 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 an anxiety provoking public speaking task (Mauss, Wilhelm, & Gross, 2001), and in participants engaged in an anxiety-provoking serial subtraction task (Movius & Allen, 2004). Making a similar point, participants led through a relaxation exercise exhibited an increase in vagal tone relative to a control group instructed only to rest (Sakakibara, Takeuchi, & Hayano, 1994).

Though the work discussed above shows a link between vagal tone and anxiety, some data is more equivocal. For example, studies tend not to show links between self-report anxiety measures and vagal tone (Mauss, Wilhelm, & Gross, 2001, Gerlach, Wilelm, & Roth, 2003; Dishman, Nakamura, Garcia, Thompson, Dunn, & Blair, 2000; Movius & Allen, 2004). Perhaps one reason effects do not emerge is because of various problems with self-report measures. People’s introspective abilities may not be particularly sophisticated (Nisbett & Wilson, 1977), and their self-reports may be distorted due to impression management and self-enhancement concerns (e.g., Tedeschi, Schlenker, & Bonoma, 1971; Taylor & Brown, 1984). Indeed, some work shows that lower vagal tone predicts a greater tendency to respond in socially desirable ways as measured by Marlow-Crowne Social Desirability Scale (Allen). Further, there is some evidence that people with lower levels of vagal tone have more difficulty accessing and assessing their own emotional states (Sollers, Mueller, & Thayer, 1997).

In addition to inconclusive self-reported anxiety evidence, work has not always evidenced the links between vagal tone and diagnosed anxiety disorders (Kollai & Kollai, 1992; McCraty, Atkinson, Tomasino, & Stuppy, 2001; Stein & Asmundson, 1994). Stein and Asmundson (1994) note that one reason for differences between these results and other studies that do show a relationship with vagal functioning, may have to do with apprehension created by the testing environment. It may be that both particularly comfortable conditions and particularly stressful conditions wipe out individual differences in vagal tone levels between anxious and non-anxious people.

Vulnerability to threat responses

Research also investigates how vagal tone level predicts the amount of threat people are prone to perceive or experience in various situations, and thus the extent to which people react defensively to various circumstances. In one example, participants took part in a conditioning paradigm in which orienting and defensive cardiac responses were tracked (Thayer, Friedman, Borkovec, Johnsen, & Molina, 2000). The authors showed that people diagnosed with GAD and who showed lower vagal tone tended to respond with persistent vigilance or orienting to non-threatening stimuli to which high vagal tone people quickly habituated. Low vagal tone people also showed persistent defensive responses to threatening words that high vagal tone people responded to only with orienting.

In another work supporting the notion that vagal tone indexes the potential for threat responding (Fabes & Eisenberg, 1997), a daily diary study showed that the participants with higher baseline vagal tone tended to experience less negative emotional arousal as a consequence of their stressors. Research also connects vagal tone to the eyeblink startle reflex (Ruiz-Padial et al., 2003), a response that appears mediated by the central nucleus of the amygdala. Higher baseline indices of vagal tone predicted less forceful startle responses triggered by blasts of white-noise during neutral and positive stimuli. Thus, low vagal tone people appeared to be more easily threatened, or in more defensive states than high vagal tone people when primed with non-threatening neutral and positive slides.

Vulnerability to hostility

Further implicating low vagal tone in potentiating fight or flight and threat-related experience, research has suggested an association between vagal tone and hostility. Brosschot and Thayer (1998) note that hostility is often characterized by poor cardiovascular recovery following anger induction. This slow recovery is indexed by sustained sympathetic arousal—high HR and blood pressure. From this evidence Brosschot and Thayer surmised that, following evidence and theory that vagal tone exerts an inhibitory effect on sympathetic arousal, hostility should correspond with lower vagal tone.

Empirical work has in part born out this vagal tone and hostility link (Sloan, Shapiro, Bigger, Bagiella, Steinman, & Gorman, 1994). In younger participants (under 40) during the daytime, higher hostility scores on the Cook-Medley Hostility Scale (Cook & Medley, 1954) predicted lower the vagal tone. However, this correlation did not reach significance with vagal tone measured during the night-time hours, nor did it reach significance in older adults (over 40). Perhaps as with anxiety disorders, vagal tone differences in hostile people tend not to emerge in highly comfortable situations, such as during sleep.

Vulnerability to depression

Research on depression further links vagal tone to threat experience. A number of studies show that depressed participants exhibit lower tonic vagal tone (Dalack & Roose, 1990; O'Conner, Allen, & Kaszniak, 2001; Rechlin, Weis, Spitzer, & Kaschka, 1994). Further work has linked vagal tone to state changes in hope and hopelessness (Schwarz, Schachinger, Adler, & Goetz, 2003).

In other work, improvement in depression over time corresponded with increased levels of vagal tone (Chambers & Allen, 2002). In yet another study, higher baseline levels of depression corresponded with a less increase in vagal tone during a cold pressor task and a greater withdrawal of vagal tone during a stressful speech task (Hughes & Stoney, 1999). Thus, a greater tendency for vagal withdrawal and a lesser tendency for vagal increase predicted depression.

Further research suggests that a specific type of depressed affect is associated with lower vagal tone. Analysis of BDI subscales showed a negative correlation between the suicidality subscale and vagal tone, but a positive correlation between the sadness subscale and vagal tone (Rottenberg, Wilhelm, Gross, & Gotlib, 2002). In other work, participants diagnosed with major depression of the melancholic type showed no difference in resting vagal tone with non-depressed control participants (Moser, Lehofer, Hoehn-Sarie, McLeod, Hildebrandt et al., 1998). Additionally, viewing an excerpt of a sad video that induced crying did not affect vagal tone in normal participants, though following crying, vagal tone tended to increase only in non-depressed 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.

Vulnerability to attention and cognitive inflexibility

Further work relevant to the vagal tone as threat-buffer hypothesis shows links between vagal tone and cognitive/attentional flexibility, performance, and regulation. If vagal tone signals security from threat responding, then vagal tone should also generally correspond with flexible cognitive and attentional abilities in as far as these abilities become consumed and constrained by threat, and freed when our organism feels more secure. Indeed, this co-occurrence has been noted by psychophysiologists. Thayer and Lane (2002) review evidence that ruminative and inflexible thought patterns are a staple of emotional disorders that are associated with low vagal tone. For example, people with depression or heightened anxiety tend to ruminate or fixate on certain thoughts generally linked to their emotional deficits. Further, there is evidence to suggest that anxiety, threat, and arousal causes attentional inflexibility. Emotional arousal and threat has been shown to narrow attention and diminish inhibitory abilities, which in turn impairs cognitive performance (e.g., Easterbrook, 1959; Pallak, Pittman, & Heller, 1975).

In addition to the evidence that links disorders associated with low vagal tone to cognitive rigidity, some work has also more directly shown ties between cognitive performance and vagal tone. For example, higher vagal tone has predicted shorter reaction times on a Stroop task (Johnsen et al., 2003). In another study (Hansen, Johnsen, & Thayer, 2003), participants with higher vagal tone similarly showed shorter reaction times on an attention task. Additionally, in the same study, higher vagal predicted better performance on a working memory task. Thus, this work showing that higher vagal tone predicts greater cognitive flexibility is consistent with the hypothesis that higher vagal tone signals greater security from threat.

Current Psychological Models of Vagal Tone

This review has presented a case that state vagal tone, and perhaps secure vagal tone, index the strength of people's buffer against threatened fight or flight experience, and thus the likelihood and strength with which this type of experience and responding will occur. In support, the research reviewed above shows links between vagal tone and anxiety, threat, depression, aggression, and compromised attentional abilities. However, several related theoretical perspectives have also been developed to explain the psychology of vagal tone. Though in many ways consistent with the vagal tone threat-buffer hypothesis, they also deviate to some extent from this perspective.

Porges' with his Polyvagal Theory, the physiology of which was described earlier, is perhaps most influential in his theorizing about the psychology of vagal tone. He posits that vagal tone indexes attention regulation as well as emotional regulation, because vagal tone indexes metabolic demand. Attention processes and "the primary emotions are often related to survival" and survival is tied to the ability to mobilize and thus regulate the heart (p.314, 1995). Thus, "vagal tone is actively withdrawn in response to external demands, including metabolically demanding states such as exercise, stress, attention, and information processing" (p.306, 1995).

Other perspectives similarly interpret vagal tone as having to do with emotion and attention regulation, but tend to distinguish more between tonic and phasic changes in vagal tone. The general consensus is that high tonic 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., Friedman and Thayer, 1998; Thayer & Lane, 2000; Beauchaine, 2001). Consequently, reduced flexibility indexed by low tonic 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), "negative emotional traits" (Beauchaine, 2001, p.199).

There is less agreement upon the meaning of phasic changes in vagal tone. Porges and Beauchaine (2001) generally posit that large phasic decreases in vagal tone can be thought to indicate "emotional lability of a fight or flight nature" (Beauchaine, 2001, p.198-199) and "negative emotional states", as compared to more "moderate vagal withdrawal" (Beuchaine, 2001, p.199). However, Gottman and colleagues (e.g., Gottman, Katz, & Hooven, 1996; Katz & Gottman, 1997), and to some extent Thayer, Lane, Friedman and colleagues, generally put forth that greater magnitude of phasic vagal tone withdrawal, or vagal tone modulation, indexes more positive psychological adjustment to the environment. Whereas high tonic levels index attention and emotion flexibility, it is lower levels after phasic withdrawal that indexes this psychological flexibility.

There are reasons, however, to be skeptical of this latter argument that large vagal withdrawal indexes positive and flexible psychological states. Gottman and colleagues take as their evidence findings that higher resting vagal tone is associated with greater vagal withdrawal. Tonic vagal tone tends to correlate in their work with the magnitude of phasic withdrawal at about .6. But the law of initial values suggests that the magnitude of phasic vagal withdrawal is an artifact of starting tonic level. First described by Wilder (1957; see also Gratton, 2000) the law puts forth that in any physiological system, the closer the system is to an extreme the less likely it is to move further towards that extreme. Thus, vagal withdrawal in someone with high tonic vagal tone may be considered less significant than a similar withdrawal in someone with low tonic vagal tone. With this in mind, it may not be appropriate to consider larger phasic vagal tone drops as an index of greater cognitive and emotional flexibility if these relative large phasic drops are from higher tonic vagal tone people.

In addition to this concern, the evidence that Gottman and colleagues draw from to support their hypothesis comes from children, and no data from adults indicates that greater vagal modulation predicts greater cognitive and emotion regulatory abilities. Adult studies consistently show that greater state decreases in vagal tone correspond with state anxiety, depression, and hostility (e.g., Mauss, Wilhelm, & Gross, 2001; Thayer, Friedman, & Borkovec, 1996; Sloan, Shapiro, Bigger, Bagiella, Steinman, & Gorman, 1994; Schwarz, Schachinger, Adler, & Goetz, 2003; Chambers & Allen, 2002). Research also has associated larger vagal decreases and more frequent decreases with trait measurements of depression and hostility (e.g., Hughes & Stoney, 2000). In addition, there are reasons that infant and child data should not be brought to bear on theorizing about vagal tone in adults. The vagus nerve controls the heart significantly less in infancy than afterwards (e.g., Porges, Doussard-Roosevelt, Portales, & Suess, 1994; Izard, Porges, Simons, Haynes, & Cohen, 1991). As a consequence, it makes vagal tone in infants and adults difficult to compare and suggests that vagal tone levels in infancy may index much different psychological constructs than in adults. Indeed, infants and adults are different physiological and psychological beings. Thus, Gottman's analysis may not be particularly appropriate or applicable to understanding the psychological meaning of vagal tone in adults, and it seem reasonable to conclude that just as with high tonic levels vagal tone, higher state levels after phasic changes also signal psychological—attention and emotional—flexibility.

This perspective that vagal tone indexes attention and emotion regulatory resources and flexibility generally gels with the proposed vagal tone as threat-buffer hypothesis. Feeling buffered or protected from threat should makes people's cognitive and regulatory abilities more free and flexible than when less buffered. Anxiety and threat seem to make the ability to think clearly and rationally, in a way that can allow for delaying behavior, more difficult. With a greater potential for threat, presumably people more rigidly direct self-regulatory resources towards the potential for threat, making flexible self-regulation less possible. Indeed, work on self-regulation and depression makes this point—Pyszczynski and Greenberg (1987) posit that flexible self-regulation becomes compromised when the self is threatened, such as by undermined self-worth during depression, because self-regulatory resources become fixated on the given threat. Hence the perseveration that is characteristic of many psychological disorders (Thayer & Lane, 2002). We can therefore see how the threat-buffer hypothesis would predict a vagal tone connection to self-regulatory abilities.

Yet there may be instances in which the two psychological constructs—threat and self-regulation ability—dissociate. For example, when approaching or during sleep regulatory abilities appear to be less than when fully awake, yet during these instances people seem to feel relatively secure (indeed, sleep becomes difficult under threat). Vagal tone increases during sleep, however (Porges, 1995). This supports the perspective that vagal tone is more directly related to people's threat-buffer than to self-regulatory abilities. Also, the data investigating depression characterized by suicidality versus melancholia suggests that vagal tone indexes not simply poor regulation of negative emotions, but instead indexes the experiencing of specific negative emotions—that is, negative emotions about the self or about threats to self. Further, Fabes and Eisenberg (1997) provide statistical analyses showing that vagal tone predicts increased emotion regulation and coping abilities indirectly by way of first directly lessening initial threat responses. Thus, different lines of evidence converge to suggest that vagal tone first and foremost indexes the strength of a person's buffer from threat and anxiety, and that by way of this buffer, predicts self-regulatory abilities. In different words, it seems that vagal tone, first and foremost, decreases primary appraisals of threat. Through this inhibition, this lessening of initial perceived threat, vagal tone likely also affects secondary threat appraisals and so predicts increased ability to cope with threats.

In sum, is seems likely that vagal tone indexes the extent of people's primary buffer from threat responding. As reviewed, this perspective comes from a number of sources. First, work by Levy and colleagues suggests that vagal and sympathetic forces interact at the heart such that vagal tone limits or buffers sympathetic influence. Second, a substantial body of research supports this claim by showing links between vagal tone and various threat responses, sympathetic and amygdala related responses, and psychological traits and states that are characterized by feeling of self-threat, such as anxiety, depression, aggression, and cognitive inflexibility. Third, this vagal tone as threat-buffer hypothesis is generally consistent with the theorizing about the psychological meaning of vagal tone—that it indexes self-regulatory abilities and emotion and attention flexibility. However, it provides a framework with which to view these constructs in relation to vagal tone—that they are related to vagal tone not directly, but by means of their relation to feelings of threat and vulnerability to threat. Thus, though there exists other accounts for the psychological meaning of vagal tone, the hypothesis that vagal tone indexes people's buffer from the potential for threat experience seems viable and therefore in need of further assessment.

Connections Between Vagal Tone and Self-esteem

We have made the case vagal tone, deriving from the mammalian branch of the PNS, signals the extent to which a person is buffered from threat. The vagus withdraws its influence when our organism feels danger in order to potentiate the defensive fight or flight response or freezing response. The vagus imposes its inhibitory influence when our organism feels secure and protected from threat. We have also presented the case that the human organism, enmeshed in a symbolic world, comes to feel security from threat through self-esteem, by feeling of worth. In other words, TMT posits that self-esteem is a primary psychological provider of security in the human adult. We are made insecure out of an evolved capacity for symbolic and imaginative thought overlaid onto an instinct for self-preservation, but we also with symbolic thought, secure ourselves through achieving culturally agreed upon standards of value. In our species, life and death, organismic safety and security, has in part transferred itself from being about physical danger and shelter and food, to being about self-esteem. Thus, we argue that the strength and security of self-esteem should promote or secure vagal tone.

Physiological Parallels

This hypothesis that self-esteem promotes vagal tone is supported by a significant body of research showing parallels between physiological correlates of self-esteem and physiological correlates of vagal tone. Specifically, both self-esteem and vagal tone protect from defensive physiological responding. Increases in state self-esteem have been shown to buffer from sympathetic arousal as indexed by skin conductance increases in response to the threat of electric shock (Greenberg et al., 1992). In parallel, vagal stimulation in dogs has been shown to buffer the effects of sympathetic stimulation on heart rate (e.g., Levy, 1990) and in humans vagal influence on the heart appears to override sympathetic influence on the heart (e.g., Uytdehaage and Thayer, 1989). Greater tonic vagal tone also predicts protection from other physiological threat responses, such as the eye-blink startle response and defensive cardiac patterns in response to various stimuli (Ruiz-Padial, Sollers, Vila, and Thayer, 2003; Thayer, Friedman, Borkovec, Johnsen, & Molina, 2000).

Psychological Parallels

In addition to these similar physiological correlates supportive of the hypothesis that self-esteem promotes vagal tone, research links both self-esteem and vagal tone to threat-related psychological experiences. Lower state self-esteem and insecure self-esteem predict more psychological defensiveness, less anxiety, and less hostility (e.g., Schimel, Arndt, Pyszczynski, & Greenberg, 2001; Greenberg et al., 1992; Kernis, Grannemann, & Barclay, 1989). Further, low state and/or insecure self-esteem has been linked to depressed affect, particularly as it relates to concerns about the self, for example, as a consequence of failure or as manifested in suicidality (de Man and Gutierrez, 2002). Similarly, state decreases in vagal tone and/or insecurity of vagal tone predict the experience of threat-related psychological responses. Vagal withdrawal or a propensity for vagal withdrawal predicts various anxiety-related experiences and hostility (e.g., Mauss, Wilhelm, & Gross, 2001; Thayer, Friedman, & Borkovec, 1996; Sloan, Shapiro, Bigger, Bagiella, Steinman, & Gorman, 1994). Further, as with self-esteem, low vagal tone or insecure vagal tone predicts depression particularly when tied to concerns about the self, such as when characterized by suicidality (Rottenberg, Wilhelm, Gross, & Gotlib, 2002). Depressed affect that is not tied to the self, such as sadness about the state of other people, does not appear to correspond with lowered vagal tone (Rottenberg, Wilhelm, Gross, & Gotlib, 2002). Thus, the psychological correlates of state and/or insecure self-esteem parallel in many ways the psychological correlates of state and/or insecure vagal tone.

State and Trait

To further delineate the connection between self-esteem and vagal tone, we can think in more detail about the relationship between self-esteem and threat and between vagal tone and threat. To do so, work by Lazarus (e.g., Lazarus, 1991a; Lazarus, 1991b) suggests thinking about two different kinds of threat responses. He distinguishes between primary and secondary threat appraisals. Primary threat appraisals essentially lead to initial threat responses, perhaps automatic threat responses. Secondary appraisals are essentially how people respond to the threat after the initial response and include how people cope with the threat and who they blame for the threat. Thus, we can think of any threat as comprised of a primary threat response and then a secondary response to the threat.

Given this distinction, if we want to connect self-esteem and vagal tone to threat, we should specify more clearly their connection to both primary and secondary threat responses. To do so, we might distinguish between two types of self-esteem and/or vagal tone—one type that more directly buffers people from primary threat responses, and one that more directly buffers people from secondary threat responses. The distinction between state and trait may be a particularly applicable one. State levels of self-esteem and vagal tone should specify momentary and immediate levels of a person's psychological and physiological buffer or security. Trait levels should specify global and/or typical levels of psychological and physiological security. Thus, we posit that state self-esteem and state vagal tone should most directly buffer from and predict primary threat responses, whereas trait self-esteem and trait vagal tone should most directly buffer from and predict secondary threat responses, or responses to threat over longer periods of time.

If a person feels insecure at a particular moment (i.e., low state self-esteem and low state vagal tone), trait or global level of security shouldn't matter for the person's primary response to threat. The person feels immediately insecure even if he/she doesn't feel that way generally, and should therefore be more vulnerable to immediate or primary threat responding. Data consistent with this prediction shows that manipulating self-esteem buffers from immediate threat responding (Greenberg et al., 1992). Also, at the heart itself, the current output from the vagus nerve buffers the impact of current sympathetic forces (e.g., Levy, 1990). Whatever the level of vagal tone typically or dispositionally, it is vagal activity at the moment, or state vagal tone, that determines the presence of chemicals that buffer sympathetic influence. Thus, it seems that state self-esteem and state vagal tone should most directly determine and predict the strength of a person's primary threat response, or short term threat response. From this analysis, that state self-esteem and state vagal tone both protect against primary threat responses, we therefore posit that state self-esteem should be linked particularly to state vagal tone and thus should affect state vagal tone levels.

Details of a trait self-esteem and trait vagal tone link to threat may be more complicated. Nevertheless, it may be that trait self-esteem and trait vagal tone have implications most directly for secondary threat responses. Trait self-esteem as Brown and colleagues (Brown, Dutton, & Cook, 2001) suggest, should facilitate resilience of state self-esteem. If a person knows generally he/she is a good person, then we would expect quicker recovery from drops in state self-esteem than if the person is less generally or dispositionally sure about his/her worth. In different words, high trait self-esteem may provide more resources for maintaining high state self-esteem, and so more tools to facilitate recovery of depressed state self-esteem. By means of affecting the recovery of state self-esteem, trait self-esteem should therefore predict secondary threat responses—how well people cope with threat and recover from the primary threat. In parallel, tonic vagal tone has been conceptualized as a resource that enables cognitive and emotional regulation (e.g., Thayer & Lane, 2000, Beauchaine, 2001). This means that researchers conceptualize tonic vagal tone as important for regulation of threat responses, or in other words, as important for secondary threat responses. Thus, it seems that trait self-esteem and trait vagal tone likely play an important role in buffering secondary threat responses. Consequently, from this analysis linking both trait self-esteem and trait vagal tone to secondary threat responses, we posit that trait self-esteem should correspond with trait vagal tone.

As mentioned, however, this connection may be more complicated than that between state self-esteem and state vagal tone. For one, the notion of trait vagal tone seems less clear than that of trait self-esteem. An index of tonic vagal tone gathered from several minutes of resting EKG data does not necessarily provide an index of trait vagal tone, and though taken during resting conditions, 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). Further, 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. Perhaps we need state vagal tone measurements over the course of weeks or months or years to get an accurate assessment of trait vagal tone that in turn would allow for assessing the link with trait self-esteem. In any event, investigating triat vagal tone seems more complicated than investigating state vagal tone. Thus linking it to other constructs also seems more complicated.

The connection between trait self-esteem and trait vagal tone may be further complicated because trait self-esteem also appears more difficult to investigate and link to other constructs than state self-esteem. Trait self-esteem may be defined not only by its level, but by other characteristics such as its stability and contingencies. Thus, if trait self-esteem promotes trait vagal tone, then these various facets of trait self-esteem should also affect trait vagal tone. Hence the relationship between trait self-esteem and trait vagal tone seems complicated by trait self-esteem's various components. In sum, both trait self-esteem and trait vagal tone appear more complicated to investigate and measure than state self-esteem and state vagal tone. As a consequence, investigating links between trait self-esteem and triat vagal tone becomes more complicated, albeit certainly possible.

We should note that this model connecting state self-esteem with state vagal tone, and connecting trait self-esteem with trait vagal tone, does not mean that these trait constructs are unrelated to these state constructs. Clearly trait self-esteem has implications for state self-esteem, and so we would predict that trait self-esteem has similar implications for state vagal tone, and also for primary threat responses. For example, if trait self-esteem makes state self-esteem and state vagal tone more resilient, then by way of affecting these state constructs, trait self-esteem should predict people's buffer from primary threats. Thus, we do not link the state constructs to primary threat, and the trait constructs to secondary threat, to suggest that both state and trait constructs will not predict both primary and secondary threat responses. We specify these links to suggest what should be the clearest links and predictions.

STUDY 1

To begin to test our model we first sought to test the clearest prediction we can derive, that state self-esteem should match up with state vagal tone, or in other words that changes in state self-esteem should affect corresponding changes in state vagal tone. Increasing or decreasing a person's state of symbolic security should increase or decrease their immediate physiological security as indexed and provided by state vagal tone. To test this prediction we devised an experiment. In Study 1 we monitored state vagal tone and manipulated state self-esteem using positive and negative personality feedback. We predicted that vagal tone would vary with changes in self-esteem—that a boost to state self-esteem would increase vagal tone and that a hit to state self-esteem would decrease vagal tone. We also measured self-esteem covertly with the Implicit Association Test (IAT; Greenwald, McGhee, & Schwartz, 1998) both before and after the feedback to assess the effectiveness of the feedback.

In addition to this primary purpose, this study allowed us to test other auxiliary hypotheses. For one, the study allowed us to examine whether pre-existing individual differences in trait self-esteem or baseline vagal tone prior to the feedback would moderate state self-esteem and state vagal tone responses to the feedback. If high trait self-esteem makes state self-esteem more resilient, then in high trait self-esteem people we might observe tempered state self-esteem decreases and tempered vagal tone decreases in response to negative feedback. In addition, if high tonic vagal tone indexes physiological security, then in high vagal tone people we might observe tempered state self-esteem decreases and state vagal tone decreases in response to negative feedback.

This study should also serve to address alternative hypotheses about the nature of vagal tone put forth in literature. One alternative to the self-esteem hypothesis suggests that vagal tone indexes attentional resources, or attention regulation abilities (e.g., Hansen, Johnsen, & Thayer, 2003). Administering the self-esteem IAT both before and after feedback will allow us to examine this hypothesis as compared to the self-esteem hypothesis. If this attention regulation hypothesis is correct and vagal tone indexes attention regulations resources first and foremost, then increases in vagal tone should predict an increased ability to override positive-self associations, and consequently lower self-esteem IAT scores. Conversely, the self-esteem hypothesis predicts that increases in vagal tone should predict higher self-esteem IAT scores—faster associations between self and good words than self and bad words.

Method

Participants

Fifty-six introductory psychology students participated in exchange for partial course credit. Screening prior to the experiment excluded those with epilepsy, heart problems, pacemakers, taking prescription drugs (except birth control pills), or using psychotropic drugs or illicit substances. In addition, we excluded four participants from the analyses because during the debriefing they expressed strong suspicion about the validity of the personality feedback. Therefore, the results are based on fifty-two participants.

Procedure

All participants completed the Rosenberg Self-esteem Scale (RSES; Rosenberg, 1965) during a mass screening in the beginning of the semester. In the experimental sessions, we tested participants individually. The experimenter greeted participants upon entering the laboratory, led them to a sound dampened chamber in which they would remain for the duration of the experiment, and provided the cover story to explain the purported purpose of the study. Thus, the participants were blind to the study's true purpose, that we wished to manipulate self-esteem, monitor self-esteem with reaction time computer tasks, and monitor the heart and autonomic nervous system.

The experimenter told participants that the study was about how the two sides of the brain interact and what this might mean for people's personalities. The experimenter then told participants that to investigate this they would wear sensors on their left and right temples and on their left and right arms. The sensors on their arms "can help measure activity in the brain, basically because the left side of the body is connected to the right side of the brain, and the right side of the body is connected to the left side of the brain." Further, the experimenter explained that they would engage in computer tasks using their left and right hands. These tasks it was told, would help assess left and right brain communication because "categorizing with the left hand always makes the right side of the brain more active, but might make the left side active too, depending on how the two sides of the brain interact or communicate". The experimenter then told participants that in order to investigate how personality interacts with this type of brain communication, we compiled a personality report from the psychological questionnaires filled out in the mass survey at the beginning of the semester.

After the “study overview”, the experimenter prepared the participants for the EKG recording. After this preparation the experimenter told participants that recording signals accurately necessitates periodically re-calibrating the equipment while the participants sit quietly with hands on their lap and feet on the floor. Further, the experimenter explained that they would begin at this point with 4-5 minutes of re-calibration. The experimenter then exited the chamber. In actuality, this time was not for re-calibration but for taking an EKG recording. We hoped that leading participants to believe the time was for re-calibration and not for physiological recording would encourage them to think naturally.

After the first EKG recording period, the experimenter re-entered the chamber and instructed the participants to begin the left-right computer tasks. These were a series of IATs, designed to measure the strength of people’s associations between various variables. The first IAT was intended to familiarize participants with the IAT and also served as a non-self-esteem relevant comparison IAT. The second task, based on work by Greenwald and Farnham (2000), was meant to assess self-esteem. Specifically, the task measured the strength of associations between the self and positive or negative words, relative to associations between other people and those positive and negative words. With this measure we hoped to acquire an index of self-esteem less influenced by self-report problems such as impression management, demand characteristics, self-deception, and defensive self-enhancement (Greenwald & Farnham, 2000).

After these tasks the experimenter entered the chamber and told participants there would be a break before the second set of computer tasks. The experimenter continued that during the break they could take a look at their personality report compiled from the mass survey questions. The experimenter also added that because the laboratory acquired that information from them, the lab was required to offer this report, and that participants “usually say it’s pretty accurate and find it interesting to look at.” The experimenter then left the room, ostensibly to print out the report, and asked participants again to sit quietly to make re-calibrating later easier. The experimenter recorded 2-3 minutes of EKG data and then re-entered the chamber to give the personality report to the participants.

The personality report served as the vehicle for our main independent variable—the self-esteem manipulation. Some participants received a very positive report, whereas others received a negative report (see Appendix A for reports). At the top of the feedback form, to add to its credibility, we printed the participant’s name, gender, and the mass testing date. Below was one of two paragraphs, 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 positive feedback, for instance, 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 negative feedback 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 reports were in presented in folders in order to keep the experimenter blind to the feedback condition.

Once given, the experimenter left the room for 90 seconds in order to allow the participants to view the report in private. Then the experimenter entered the chamber to take the folder and report and to instruct participants to sit still for 2-3 minutes during re-calibration. The experimenter then took a third EKG recording. Next the experimenter re-entered the chamber to begin participants on the second set of computer tasks, described as similar to the first set of task and given again to get a more stable reading. The first task was the same neutral IAT from before. The second task was the same self-esteem IAT from before. The third task was an anxiety IAT, adapted from Egloff and Schmukle (2002). The fourth task was a computerized RSES adapted to measure state self-esteem. Lastly participants worked on the Watson et al. (1988) PANAS. They rated how they felt "right now, at the present moment" by selecting a number between 1 (very slightly or not at all) and 5 (extremely) for each of twenty words. The words were *interested, distressed, excited, upset, strong, guilty, scared, hostile, enthusiastic, proud, irritable, alert, ashamed, inspired, nervous, determined, attentive, jittery, active*, and *afraid*.

Once these tasks were finished, the experimenter again entered the chamber to ask participants to sit quietly for re-calibration. Electrocardiogram signals were recorded for 2-3 minutes and the experimenter then re-entered the chamber to administer a paper and pencil questionnaire presented as an "exit questionnaire". This form consisted of 2 parts. First participants answered five questions on 9-point scales. The first three were filler questions about participants interest in the computer tasks, the clarity of the instructions, and their comfort in the testing chamber. The fourth and fifth questions were “How accurately do you think the personality feedback described you?” and “How did the personality feedback make you feel about yourself?”

Materials and Apparatus

EKG hook-up and recording

To prepare for the physiological recording, the experimenter gently abraded the skin just below each elbow on the inside of the arm, and on both temples. The experimenter then applied conductive gel to four silver-silver chloride electrodes and affixed these with adhesive collars to the four abraded locations. The electrodes affixed to the arms served as the leads, and the electrode on the left temple served as a ground. The electrode on the right temple simply served to bolster the cover story—that we were investigating how the two halves of the brain interact. The electrode leads were plugged into a BioPac AC amplifier and the EKG signal, sampled at 500 Hz and amplified 500 times, was recorded using Acknowledge software.

IATs

We used three IATs, all administered on a PC computer. The IAT measures the strength of associations between constructs. The first one served to familiarize participants with the IAT and also as served as a non self-esteem IAT for purposes of comparison with the self-esteem IAT that would follow. It measured the associations of happy and not-happy with delicious and not-delicious categories. To do so, the IAT assesses how quickly participants categorize happy with delicious words (the positive categories) and not-happy with not-delicious words (the negative categories), compared to how quickly participants categorized happy with not-delicious words (a positive and negative category) and not-happy with delicious words. The logic of the IAT is that the degree to which people can more quickly categorize happy with delicious and not-happy with not-delicious, or the more slowly they categorize happy with not-delicious and not-happy with delicious, the stronger their associations between happy and delicious and between not-happy and not-delicious.

This happy-delicious IAT was administered both prior to and after participants received the personality feedback. It consisted of five blocks of trials. In each trial participants were presented with a word in the middle of the computer screen asked to categorize it to the right or left by pressing the “5” key or “A” key, respectively. The side to which a given word was to be categorized depended on the category it belonged to and the specific instructions for that block. In the first block, consisting of 20 trials, participants were presented with delicious and not-delicious words (delicious words: delicious, appetizing, yummy, tasty; not-delicious words: stale, spoiled, rancid, rotten). They categorized delicious words to the left and not-delicious words to the right. In the second block, consisting of 20 trials, participants were presented with happy and not-happy words (happy words: joy, laughter, gleeful, optimism, merry, cheerful; not-happy words: depressed, despair, gloom, pessimism, sobbing, misery). They categorized not-happy words to the left and happy words to the right. These two blocks served as preparation for the first critical test block, the third block of 40 trials in which participants were presented with words in all four categories. They categorized delicious and not-happy words to the left and not-delicious and happy words to the right. In the fourth block, another preparation block of 20 trials, participants were presented only with happy and not-happy words, but now categorized happy words to the left and not-happy words to the right. The fifth block consisting of 40 trials served as the second critical test block and as in the third block, participants were presented with all four categories of words. This time, however, participants categorized delicious and happy words to the left and not-delicious and not-happy words to the right. By measuring how quickly people perform the trials in the third block (when associating happy with delicious) relative to how quickly people perform the trials in the fifth block (when associating happy with not-delicious) we estimate the relative strength of people's associations between happy and delicious.

As mentioned, participants completed this practice IAT both before and after receiving the personality feedback. Following both practice IATs, participants completed self-esteem IATs. Adapted from Greenwald and Farnum (2000), participants completed 7 blocks of trials. In the first blocks (20 trials) participants received "self" words (self, me, mine, my, I) and "other" words (other, them, their, theirs, they) and categorized self words to the left and other words to right. In the second block (20 trials) participants received "positive" words (terrific, success, valued, loved, good) and "negative" words (terrible, failure, worthless, despised, bad) and categorized negative words to the left and positive words to the right. In the third block (20 trials) participants received words from all four categories and categorized self and negative words to the left and other and positive words to the right. The fourth block (40 trials) was a repetition of the third block but longer and served as the first critical test block. In the fifth block (20 trials), another preparation block, participants received positive and negative words but this time categorized positive words to the left and negative words to the right. In the sixth block (20 tirals) participants were presented with all four categories, but this time categorized self and positive words to the left and other and negative words to the right. In the seventh block (40 trials), the second critical test block, the task was identical to the sixth block though longer. By measuring how quickly people performed the trials in the seventh block (when associating self and positive words) relative to how quickly people performed the trials in the fourth block (when associating self and negative words) we can assess how strongly people associated themselves with positive and negative relative to associations between these constructs and others. Thus, this IAT allows us to index self-esteem.

After the second self-esteem IAT, completed after the personality feedback, participants completed an Anxiety IAT, adapted from Egloff and Schmukle (2002). This procedure was almost identical to the procedure for the self-esteem IAT, except that participants associated "me" words (me, I, my, self) and "others" words (others, them, your, they) with "anxiety" words (anxious, afraid, nervous, fearful) and "calmness" words (calm, relaxed, balanced, restful). Thus, as in the self-esteem IAT, the critical blocks (of 40 trials) were the fourth and seventh blocks in which participants categorized me and anxious words together and me and calmness words together, respectively. By measuring how quickly people performed the trials in the seventh block (when associating me and calmness words) relative to how quickly people performed the trials in the fourth block (when associating me and anxiety words) we could assess how strongly people associated themselves with calmness and anxiety relative to associations between these constructs and others.

Results and Discussion

Data Reduction

Vagal tone

We applied a low pass digital filter, using a cutoff frequency of 50 Hz, to the raw EKG data. For each recording period, we then estimated interbeat intervals (IBI) with a peak detection algorithm, and manually corrected artifacts by measuring the IBI values from the original EKG series. Next, using CMet software (Allen, 2004), we indexed vagal tone by two methods for each of the recording periods. We produced RSA by log transforming the heart period variability in the high frequency band (.12-.4 Hz), that of respiration. We also produced pNN50 scores by calculating the proportion of consecutive interbeat intervals that differed by more than 50 milliseconds. We report analyses with both these indices separately because they correlated less strongly than is usually the case. In the present study, RSA and pNN50 scores correlated at .80, whereas other work suggests that these two indices of vagal tone generally correlate at over .85 (Allen, 2003). Further, in the present study it appeared they often related differently to the other variables.

IATs

We computed the practice happy-delicious IAT scores by first subtracting the mean reaction time latency for the third happy/not-delicious block from the mean latency for the fifth happy/delicious block. Higher scores therefore indicated stronger associations between happy and delicious, the two positive constructs, relative to incongruent happy and not-delicious constructs. Following Greenwald, Nosek, and Banaji (2003), we transformed these raw scores by dividing them by the standard deviation of the latencies in both these blocks. This transformation, the *D* measure, corrects for differences in variability between the test blocks.

We computed the self-esteem IAT scores similarly by subtracting the mean latency for the fourth self/negative test block from the seventh self/positive test block. We then derived the *D* measure by dividing this score by the standard deviation of the latencies in both the blocks. Higher scores indicated greater self-esteem, or stronger associations between the self and positive words (and/or weaker associations between the self and negative words) relative to the strength of associations between others and positive and/or negative words.

We computed the anxiety IAT scores by subtracting the mean latency for the fourth me/anxiety block from the seventh me/calmness test block. As in the other IATs, we derived the *D* measure by dividing this score by the standard deviation of the latencies in both the blocks. Higher scores indicated greater calmness, or stronger associations between the self and calmness words (and/or weaker associations between the self and anxiety words) relative to the strength of associations between others and calmness and/or anxiety words.

Rosenberg self-esteem scale

Participants completed the trait RSES during a mass screening survey conducted prior to the experimental session. Participants rated ten statements on a scale from 1 to 4.

We reverse scored the appropriate items and then averaged all the items form the trait self-esteem score. Participants also completed a state RSES after receiving the personality feedback. As with the trait measure, we reverse scored the appropriate items and then computed the mean of all the items.

Mood

We averaged the 10 negative items and 10 positive items from the abridged PANAS to generate an index of negative mood and of positive mood.

Manipulation Check: The Effect of Feedback on Self-esteem

We were able to assess the impact of the personality feedback on self-esteem in several ways. We measured the effects on the question presented as part of the exit questionnaire, "How did the personality feedback make you feel about yourself?", on pre to post feedback changes in self-esteem IAT scores, and on pre to post changes in RSES scores. These measures did not correlated with one another significantly, though the relationships between the self-reported effect of feedback and IAT change scores approached significance, $r = -.20$, $p = .14$. The more participants reported that the feedback led them to feel good about themselves, the more self-esteem IAT scores tended to increase from pre to post feedback. We also examined the relationship between baseline RSES scores and baseline SE IAT scores. We found no relationship, $r = 0$, $p > .95$.

To examine the effect of feedback on self-esteem we first we analyzed the question from the exit questionnaire. We found support for the efficacy of the manipulation in a 2-way (feedback: positive vs. negative) ANOVA, $F\ (1, 52) = 104.87$, *p*

$< .01$. On a 9-point scale from "very bad" to "very good", participants receiving negative feedback reported it made them feel worse ($M = 4.0$, $SD = 1.33$) than participants receiving positive feedback ($M = 7.67$, $SD = 1.30$). Thus, this measure provided one clear indicator that the feedback had its intended effect on self-esteem.

Next we analyzed the effect of feedback on self-esteem IAT scores. We conducted a 2-way (feedback: positive vs. negative) X 2 (self-esteem IAT: pre-feedback vs. post-feedback) ANOVA with self-esteem IAT scores treated as a repeated measure. An interaction trend emerged, $F\ (1, 51) = 2.67$, $p = .11$. Further analysis using simple main effect tests suggested that in the negative feedback condition, self-esteem IAT scores were lower after the feedback ($M = .45$, $SD = .42$) than before the feedback ($M = .59$, $SD = .28$), $p = .08$. The self-esteem IAT scores in the positive feedback did not appear to change after the feedback ($M = .54$, $SD = .40$) as compared to before the feedback ($M = .50$, $SD = .36$), though the means were in the predicted direction. However, we did not expect a significant difference here in the positive feedback condition because we expected a general trend towards improved performance after the feedback due simply to practice. As one becomes more adept at the IAT, one should become better at overriding associations that lead to slower reaction times during incongruent test blocks. Thus, this practice effect should tend to decrease post feedback self-esteem scores, and consequently the bigger difference in self-esteem IAT scores after negative feedback than after positive feedback does not necessarily mean that the negative feedback impacted participants to a greater degree than the positive feedback. It may have been that the positive feedback stemmed the tendency for IAT scores to decrease with practice.

In addition, it is likely that positive and negative feedback have the opposite effect on non-self-esteem IAT performance in general. Positive feedback should generally relax people, improve cognitive flexibility, and consequently improve the ability to override pre-existing associations. Thus, positive feedback may generally decrease scores on the IAT and negative feedback may increase scores on the IAT, because higher scores indicate stronger associations or less ability to override the associations. If this is the case, the effects of feedback on the self-esteem IAT may have bee dampened by this tendency.

To help test this logic, we were able to examine the non-self relevant happy-delicious IAT. We conducted a 2 (feedback: positive vs. negative) X 2 (practice IAT: pre-feedback vs. post-feedback) ANOVA with the happy-delicious IAT treated as a repeated measures factor. Though no effects were significant, all *p*s $> .15$, the means were in the predicted direction. After positive feedback, happy-delicious IAT scores were lower ($M = 1.15$, $SD = .37$) than before the positive feedback ($M = 1.26$, $SD = .28$), indicating greater ability to override associations. After negative feedback, IAT scores were higher ($M = 1.19$, $SD = .31$) than before the feedback (M = 1.15, SD = .36), indicating that negative feedback increases the impact of associations on IAT scores, or that negative feedback decreases the ability to override associations on the IAT. Thus, the self-esteem IAT by feedback effect may have been dampened by this general trend for positive feedback to decrease IAT scores and for negative feedback to increase IAT scores.

Lastly we conducted a 2 (feedback: positive vs. negative) X 2 (RSES scores: pre-feedback vs. post-feedback) with RSES scores treated as a repeated measure. No effects emerged, thought the means were in the predicted direction, F (1, 46) = .55, $p > .40$. The pre-feedback RSES scores, however, were assessed weeks before the experiment, and so perhaps were not particularly sensitive for detecting changes due to the feedback. Further, the question that asked participants how the feedback made them feel about themselves indicated that the feedback did indeed affect explicit self-esteem.

Main Analyses

Effect of feedback on vagal tone

With the self-esteem IAT and self-report scores providing evidence for the validity of our self-esteem manipulation, we wished to assess our main hypothesis that the self-esteem manipulation would affect vagal tone such that a boost to self-esteem would increase vagal tone and a hit to self-esteem would reduce vagal tone. We analyzed the effects of the personality feedback on two indices of vagal tone, RSA and pNN50 scores. The first pNN50 analysis, a 2 (feedback: positive vs. negative) X 2 (pNN50: time 2, just prior to feedback vs time 3, just after feedback) repeated measures ANOVA, revealed an interaction trend, F (1, 49) = 2.23, $p = .14$. The direction of the means was as predicted. Negative feedback led to lower pNN50 scores at time 3 (M = 15.68, SD = 16.63) than at time 2 (M = 17.28, SD = 16.47). Positive feedback led to higher pNN50 scores at time 3 (M = 17.57, SD = 20.44) than at time 2 (M = 14.95, SD = 16.66), $p = .19$.

We also analyzed the effect of feedback on pNN50 scores at time 4 as compared time 2. This 2 (feedback) X 2 (pNN50: time 2 vs. time 4) repeated measures ANOVA revealed a marginal interaction, $F(1, 47) = 3.71$, $p = .06$. Simple main effect tests showed that negative feedback did not significantly affect pNN50 scores at time 4 (M = 16.79, SD = 16.28) as compared to time 2 (M = 17.43, SD = 16.60), $p = .70$. However, positive feedback led to significantly higher pNN50 scores at time 4 (M = 19.74, SD = 19.52) as compared to time 2 (M = 16.08, SD = 16.78), $p < .05$. See Appendix B for the complete set of pNN50 means by feedback condition. We conducted two identical analyses for RSA. Neither the time three 2 (feedback) X 2 (RSA: time 2 vs. time 3) ANOVA nor the time four 2 (feedback) X 2 (RSA: time 2 vs. time 4) ANOVA showed a feedback by RSA interaction, ps > .50.

Thus, only on the pNN50 index of vagal tone did we find the predicted change due to feedback. Perhaps the pNN50 is more sensitive to within subject changes. It utilizes a threshold and so may bring to the fore differences that RSA measurements do not detect. Indeed, though the mean RSA and pNN50 pre to post feedback change scores were similar, -.06 and -.96 respectively, the RSA change score standard deviation was much smaller than the pNN50 change score standard deviation, .61 versus 8.12. In addition, perhaps the pNN50 provided a better index of vagal tone in this study. The correlation between pNN50 scores and RSA scores appeared lower than should be the case. Outliers and/or noise from the EKG data might be one cause of such a discrepancy and the pNN50 is more resistant to the influence of these problems. Consequently, given this discrepancy between measures, we might trust the pNN50 more than RSA in the current study.

Correlations between self-esteem and vagal tone

To further test the relationship between state self-esteem and state vagal tone, we analyzed the correlations between self-esteem change and vagal tone change. Specifically, we correlated pNN50 change scores from time 2 to time 3 with self-esteem IAT pre to post feedback change scores, RSES pre to post feedback change scores, and the self-report item indicating how the feedback made participants feel about themselves. None of these correlations reached significance, *p*s > .1. However, we also correlated pNN50 change scores from time 2 to time 4 with the same self-esteem change indices. Here we found a significant positive correlation between pNN50 change and IAT change, $r = .36$, $p < .05$. We also found trends in the same direction between pNN50 change and RSES change, $r = .26$, $p = .09$, and between pNN50 change and how the feedback made participants feel about themselves, $r = -.21$, $p = .16$. In general, if self-esteem increased due to feedback, especially as indexed by the IAT, pNN50 scores tended to increase; if self-esteem decreased due to feedback, pNN50 scores tended to decrease.

Though RSA was not significantly affected by the feedback, we nevertheless examined the relationship between its pre to post feedback change and self-esteem change. Only the correlation between RSA change scores from time 2 to time 3 with RSES change scores reached significance, $r = .30$, $p < .05$. Increases and decreases in RSES self-esteem predicted corresponding increases and decreases in RSA scores.

None of the self-esteem indices correlated with each other, all *p*s > .10. RSA change scores from time 2 to 3 were correlated with pNN50 change scores from time 2 to

3, $r = .74$, $p < .001$, as were RSA and pNN50 change scores from times 2 to 4, $r = .43$, $p < .01$.

We also assessed the relationship between trait/baseline self-esteem and baseline vagal tone scores. Baseline pNN50 scores did not correlate with either baseline mass survey RSES scores, $r = -.17$, $p > .25$, or with the baseline pre-feedback self-esteem IAT scores, $r = -.03$, $p > .80$. Similarly, baseline RSA scores did not correlate with baseline mass survey RSES scores, $r = -.18$, $p > .20$. or with the baseline pre-feedback self-esteem IAT scores, $r = -.10$, $p > .5$. See Appendix 3 for full set of correlations between measures.

It seems consistent with our analysis, though, that trait self-esteem less clearly predicts state vagal tone. Trait self-esteem should predict state vagal tone according to our analysis, but may vary in how it affects state vagal tone just as it seems to vary in how it affects state self-esteem. Perhaps better assessment of trait vagal tone and a more elaborate assessment of trait self-esteem would bring out this relationship between these two constructs. We might measure vagal tone in an environment more typical for the participant, or with repeated assessments over an extended period of time and/or across various situations. We might also measure other facets of trait self-esteem such as stability and contingencies.

Auxiliary Analyses

Self-esteem moderation

In addition to the above analyses, we examined the possibility that baseline measures of self-esteem may moderate the effects of feedback on vagal tone. To reduce the number of analyses we averaged pNN50 scores at times 3 and 4 and then analyzed the change scores between pNN50 at time 2 and this average of times 3 and 4. We did the same with RSA and then conducted a series of regressions. We (1) regressed the initial self-esteem IAT scores, feedback condition, and their interaction term onto pNN50 pre to post feedback change scores, (2) regressed mass survey RSES scores, feedback condition, and their interaction term onto pNN50 pre to post feedback change scores, (3) regressed the initial self-esteem IAT scores, feedback condition, and their interaction term onto RSA pre to post feedback change scores, and (4) regressed mass survey RSES scores, feedback condition, and their interaction term onto RSA pre to post feedback change scores.

Only this last analysis produced a significant interaction, $t = 3.05$, $p < .01$. Following Aiken and West (1991), a simple slopes analysis revealed that within the positive feedback condition, the lower people's self-esteem, the more their RSA scores tended to increase, $t = 3.04$, $p < .01$. From a different perspective, we examined the effect of feedback for those with low RSES scores (computed at 1 standard deviation below the mean). For these participants, positive feedback led to an increase in RSA scores, whereas negative feedback led to a decrease in RSA scores, $t = 2.37$, $p < .05$. However, for those with high RSES scores (computed at 1 standard deviation above the mean), negative feedback led to an increase in RSA and positive feedback led to a decrease in RSA, $t = -2.01$, $p = .05$. In other words, those with low self-esteem tended to show an increase in vagal tone after positive feedback and a decrease in vagal tone after negative feedback, as we would expect. Unexpectedly, however, those with high self-esteem tended to increase in vagal tone after the negative feedback and decrease in vagal tone after the positive feedback. This same analysis with pNN50 scores as the dependent measure, though not quite significant ($p = .07$) showed a similar pattern of means. Low RSES participants responded to the feedback in the predicted direction, whereas high RSES participants showed resistance to change, especially after positive feedback.

Perhaps one reason this effect emerged was because high self-esteem people found the negative feedback more farfetched or inaccurate, and consequently became focused on their positive qualities, boosting vagal tone. Conversely, perhaps the positive feedback was not positive enough for the high self-esteem people and consequently focused them on their shortcomings, decreasing vagal tone. Whatever the reason, if we assume that RSA and vagal tone index physiological security and equilibrium, this finding stands in contrast to what consistency theories (e.g., Swann & Read, 1981) would predict. They should predict that for low self-esteem people, negative feedback (consistent with their self-image) fosters equanimity and higher vagal tone, and that for high self-esteem people, positive feedback (consistent with their self-image) fosters equanimity and higher vagal tone.

Vagal tone moderation

We also examined the possibility that initial vagal tone measurements may moderate the effect of feedback on self-esteem change. Thus, in a series of analyses, we (1) regressed the initial pNN50 scores, feedback condition, and their interaction term onto RSES pre to post feedback change scores, (2) regressed the initial RSA scores, feedback condition, and their interaction term onto RSES pre to post feedback change scores, (3) regressed the initial pNN50 scores, feedback condition, and their interaction term onto self-esteem IAT pre to post feedback change scores, and (4) regressed the initial RSA scores, feedback condition, and their interaction term onto self-esteem IAT pre to post feedback change scores.

Only this last analysis produced a significant interaction, $t = 2.36$, $p < .05$. Further analysis revealed that RSA scores computed 1 standard deviation below the mean predicted a decrease in IAT self-esteem scores after negative feedback, $t = -2.84$, $p > .01$. However, RSA scores computed 1 standard deviation above the mean did not predict this decrease in self-esteem IAT scores after negative feedback, $t = .50$, $p > .6$. Thus, higher vagal tone tended to buffer people from self-esteem drops after negative feedback. Or conversely, low vagal tone participants seemed especially susceptible to the effects of the negative feedback on self-esteem.

We thought that perhaps differences in accuracy ratings might account for this effect—that higher RSA participants might rate the feedback as less accurate in the negative feedback condition and so be less affected by the feedback. Consequently, we regressed RSA scores, feedback condition, and their interaction term onto how accurately participants rated the feedback as describing them. No interaction effect emerged, $p > .15$, however, and the non-significant pattern suggested that low RSA participants found the negative feedback less accurate than high RSA participants. Thus accuracy ratings do not account for this buffering effect.

Mood analyses

We examined affect in response to the feedback both with explicit self-report and with an anxiety IAT. Examining self-report first, we conducted 2 (feedback: positive vs.

negative) ANOVAs on positive and negative mood as assessed with the PANAS. Participants completed the PANAS after the post-feedback IATs and RSES. This analysis showed no effect of feedback on positive mood, F (1, 50) = .008, $p > .9$. A marginal effect emerged for negative mood, F (1, 50) = 3.53, $p = .07$, such that the negative feedback led to greater negative mood (*M* = 1.62, *SD* = .49) than the positive feedback (*M* = 1.42, *SD* = .31). Given this marginal effect of feedback on negative mood, we examined whether mood mediated the effect of feedback on pNN50 change scores. However, negative mood predicted neither pNN50 change from time 2 to time 3 or from time 2 to time 4, *p*s > .1

Examining negative affect in a more subtle manner, we conducted a 2-way (feedback: positive vs. negative) ANOVA on the anxiety IAT scores, assessed after the post-feedback self-esteem IAT. No effects emerged, F (1, 51) = $p > .25$, and the pattern of means was such that after negative feedback the scores suggested less anxiety (*M* = .16, *SD* = .28) than after positive feedback (*M* = .07, *SD* = .34).

STUDY 2

Study 1 provided some support for the hypothesis that changes in state self-esteem affect corresponding changes in vagal tone. Specifically, we found a nearly significant effect for feedback on pNN50 pre to post feedback change scores, and in particular from time 2 to time 4. We also found that changes in self-esteem as measured by the IAT correlated with changes in pNN50 scores. However, our model suggests that self-esteem affects vagal tone because self-esteem provides security and because increased vagal tone secures our organism physiologically. We thus sought in Study 2 to more fully test this model by manipulating self-esteem as in Study 1 and by then exposing participants to the threat of painful electric shock in order to assess security from threat. We predicted, as we did in Study 1, that the self-esteem manipulation would affect vagal tone. We also predicted that both the self-esteem manipulation and corresponding changes in vagal tone would predict threat responding in anticipation of electric shock, such that positive feedback and increased vagal tone would predict less threat responding.

In addition to these basic predictions, if vagal tone changes due to the self-esteem manipulation indicate the effect of the self-esteem manipulation on bodily/physiological security, then these vagal tone changes may indicate the degree to which the manipulation protects from physiological sympathetic-related threat responding. Further, at the heart itself, vagal tone physically buffers sympathetic influence. Thus vagal tone at the heart should be the mechanism by which self-esteem buffers sympathetic influence on the heart. From this we can predict that the extent to which the self-esteem manipulation affects cardiac vagal tone determines, or mediates, the extent to which the feedback buffers from sympathetic threat responding at the heart. We used the Cardiac Sympathetic Index (CSI; Toichi, Sugiura, & Sengoko, 1997), extracted from the EKG signal, to assess this sympathetic activity.

In addition to including the threat of shock, Study 2 differed from Study 1 in its assessment of mood and self-esteem. A potential weakness of Study 1 was that we did not assess mood before the feedback. Thus, the mood measures were perhaps not as sensitive to the effects of feedback as the self-esteem and vagal tone indices. We therefore in Study 2 assessed mood using a short version of the PANAS both before and after feedback.

A couple factors may also have weakened the personality feedback effects in Study 1. First, we gave participants only ninety seconds to look at the feedback, perhaps not enough time for all participants to read it clearly to fully process it. Thus in Study 2 we gave participants three minutes to read the feedback. Second, another potential weakness in Study 1 is that the self-esteem IAT, though partially circumventing self-report problems, clearly allowed participants to link self words with good and bad words. Thus, participants though generally not reporting suspicion perhaps still were aware on some level that self-esteem was of interest in the study. Perhaps this dampened the effects of the personality feedback. For this reason, in Study 2 we assessed self-esteem both before and after the feedback using and implicit measure developed by Spalding and Hardin (1999). Using the same logic as the IAT, the measure primes participants subliminally with self or non-self words to assess reaction times to positive and negative words in a discrimination task. Thus, participants cannot consciously connect the self words with good and bad words.

Method

Participants

Seventy-eight introductory psychology students participated in exchange for partial course credit. As in Study 1, screening prior to the experiment excluded those with epilepsy, with heart problems, with pacemakers, taking prescription drugs (except birth control pills), or using psychotropic drugs or illicit substances. We excluded the data of seven participants because during the debriefing they expressed strong suspicion that the personality feedback was fake. This left seventy-one participants for analysis. In addition, two participants reported during debriefing that they did not believe they would be shocked and four participants discontinued the experiment when informed about the shocks (three in the negative feedback condition, one in the positive feedback condition). We therefore eliminated these participants from analyses involving threat responses to shock.

Procedure

The procedure for Study 2 was identical to Study 1 except for several key changes. First, in Study 2, we gathered two indices of sympathetic arousal to measure the strength of threat responding. We assessed electrodermal activity (EDA) from the fingertips, and Cardiac Sympathetic Index (CSI) scores derived from the EKG signal. Second, we used the subliminal reaction-time self-esteem measure developed by Spalding and Hardin (1999) instead of the self-esteem IAT. As with the IATs in Study 1, participants completed this measure both before and after receiving the personality feedback. Third, we followed the subliminal self-esteem measure each time with the

PANAS (Watson et al., 1988) presented on the computer. Fourth, we now gave participants 3 minutes instead of 90 seconds to look at the personality feedback.

The final difference between Study 2 and Study 1 was the inclusion of the threat of electric shock. After the second set of computer tasks (the second subliminal self-esteem measure and PANAS), the experimenter entered the chamber and explained to participants that “to keep testing this idea of how the left and right sides of the body and brain interact,” participants receive electrical impulses, “basically electric shocks”, sent through the electrodes attached to the left and right fingers. The experimenter further explained that a 3-minute baseline would first be recorded, and that after this period they would “receive a series of electrical impulses to the left and right hands at random intervals.” The experimenter warned participants that “they’ll hurt a bit, in fact, most people say it’s pretty painful, but they’re safe and won’t cause any tissue damage.” The experimenter then proceeded to set a timer on the computer screen that counted down to from 3 minutes to zero. This was to let participants know when the baseline ended and thus when they would ostensibly receive the electric shocks. With this timed countdown we hoped to increase the potential for anxiety, both during this anticipation period and at the end of the countdown.

After beginning the countdown timer, the experimenter exited the chamber and recorded a final 4-minute period of EKG and EDA. The experimenter marked the end of the 3-minute countdown to enable observation of EDA responses to the onset of the threat of shock. After the 4 minutes (3 of anticipation, 1 of expected shock) the experimenter entered the chamber to tell participants that the electrical generator was not yet ready. The experimenter gave participants an anxiety questionnaire “to get a better idea about how you’re thinking about the procedure,” ostensibly before the experiment would continue. The questions were adapted by Schmader and Johns (2003) from the Spielberger State Anxiety Scale (Spielberger, Gorsuch, & Lushene, 1970). Once participants completed the anxiety questionnaire, the experimenter revealed to them that they would not receive electric shocks and provided a full debriefing.

Materials and Apparatus

EKG and EDA hook-up and recording

The experimenter prepared the participants for EKG recording exactly as in Study 1. In addition, the experimenter prepared participants for EDA recording. To do so, the experimenter first placed adhesive collars on participants’ left-hand ring and middle fingers and on their right-hand middle finger, centered on the middle of the fingerprint. An adhesive collar was also placed on each of three electrodes. Electrode paste, free of air bubbles and composed of .05 M NaCl to simulate sweat, was applied to the surface of each electrode in order to facilitate contact between the electrodes and the skin. The adhesive collars, in addition to helping secure the electrodes to the fingers, also served to keep constant a 1.1 cm^2 contact area between the fingers and the electrodes. The electrodes were then adhered to the fingers by means of the adhesive collars, and tape was gently wrapped around each finger and its respective electrode to further immobilize the electrodes. The two electrodes on the left hand were connected to the BioPac and a constant voltage of .5 volts was applied through the electrodes in order to measure changes in skin conductance as measured in micro-seimens. We recorded these changes using Acknowledge software. The electrode on the right hand was attached only to bolster the cover story.

Subliminal self-esteem measure

We used Spalding and Hardin's (1999) subliminal self-esteem measure. Participants were presented in the center of the computer screen with positive and negative words, one at a time, and instructed to press the "5" key with the right index finger if the word was positive, or the "A" key with the left index finger if the word was negative. They were to make these judgements as quickly as possible without sacrificing accuracy. The words were *good*, *proud*, *superior*, *worthy*, strong, *winner*, *bad*, *ashamed*, *inferior*, *unworthy*, *weak*, and *loser*. A self-relevant or self-irrelevant subliminal prime preceded each positive or negative judgement word. The self-relevant words were *me* and *myself*. The self-irrelevant words were *two* and *manner*. The subliminal primes appeared for 17 milliseconds. They were preceded by random letter string masks lasting for 50 milliseconds, and followed by random letter string masks lasting for 100 milliseconds. Each subliminal prime was presented randomly 24 times, and paired twice with each of the twelve positive and negative judgement words. Thus, the measure consisted of 96 trials. This procedure was completed twice, once before receiving the personality feedback and once after receiving the feedback.

Rosenberg self-esteem scale

Participants completed the RSES during a mass screening session prior to the experimental session.

Mood

After each presentation of the subliminal self-esteem measure (both before and after feedback), participants completed an abridged version of the PANAS. They rated how they felt "right now, at the present moment" by selecting a number between 1 (very slightly or not at all) and 5 (extremely) for each of twenty words. The words were *interested, distressed, excited, upset, strong, guilty, scared, hostile, enthusiastic, proud, irritable, alert, ashamed, inspired, nervous, determined, attentive, jittery, active*, and *afraid*.

Results and Discussion

Data Reduction

Vagal tone

As in Study 1, we reduced the raw EKG signal to an IBI series and used CMet to produce pNN50 scores and RSA scores. In addition we used CMet to derive a third vagal tone index, the Cardiac Vagal Index (CVI; Toichi, Sugiura, & Sengoko, 1997). CVI scores are derived by log transforming the product of beat to beat variability and overall heart rate variability.

PNN50 scores correlated with RSA scores at .84, higher than in Study 1 and at approximately what other research indicates is to be expected (Allen, 2004). The alpha for these three standardized vagal tone indices was .95, and they generally related in a similar way with other variables. Thus, to simplify analyses, we collapsed the indices into one composite vagal tone index. To do so, we standardized each metric and then calculated their mean at each time period for each participant.

Sympathetic activity

Using CMet we derived an index of sympathetic activity, the Cardiac Sympathetic Index (CSI; Toichi, Sugiura, & Sengoko, 1997) from the first 100 IBIs of each recording period. This metric is derived by log transforming the ratio of overall heart rate variability to beat to beat variability. We limited the analyses to these first 100 IBIs for each period because our main hypothesis concerned the relationship between people's state buffer and their primary or initial threat responses. If one bases the CSI on too few IBIs, however, it cannot provide an accurate index of sympathetic activity. But Toichi et al. (1997) reported that basing the CSI on 100 IBIs still accurately predicts sympathetic influence on the heart.

In addition to this index, we recorded EDA, putatively controlled solely by the sympathetic nervous system (e.g., Dawson, Schell, & Filion, 2000). To assess sympathetic activity with EDA we computed (1) the average level of activity, and (2) the amplitude of the response to the possibility of electric shock. This was the response approximately at the junction of time 4 and time 5, as the computer screen timer reached zero.

Subliminal self-esteem measure

We first log transformed the reaction times (Spalding and Hardin, 1999). Separately for both self-irrelevant and self-relevant primes, we subtracted the average log-transformed latency for positive words from the average latency for negative words. Then we subtracted the difference score for self-irrelevant latencies from the difference score for self-relevant latencies. The higher this final self-esteem score, the more quickly participants responded to positive words relative to negative word when flashed self-relevant words than when flashed self-irrelevant words. Consequently, higher final scores should index higher self-esteem.

Mood

As in Study 1, we averaged the 10 negative items and 10 positive items from the PANAS to generate both an index of negative mood and of positive mood. In Study 2 we computed these negative and positive mood indices both before and after the personality feedback. Thus we had pre and post feedback indices of both negative and positive mood.

Manipulation Check: The Effect of feedback on self-esteem

We assessed the impact of our feedback manipulation on self-esteem in two ways. We analyzed responses to the question presented towards the end of the study that asked participants "How did the personality feedback make you feel about yourself?", and we analyzed pre to post feedback changes in subliminal self-esteem. These two measures did not correlate, $r = -.01$, $p > .9$. Baseline RSES scores and baseline subliminal self-esteem scores also showed no relationship, $r = -.01$, $p > .9$. See Appendix D for correlations between measures.

Our first analysis, a 2-way (feedback: negative vs. positive) ANOVA on self-reported effects of the feedback revealed a significant effect, $F(1, 64) = 160.27$, $p < .001$. On a 9-point scale from "very bad" to "very good", participants receiving negative feedback reported that the personality profile made them feel worse about themselves (*M* = 3.49, *SD* = 1.67) than the participants receiving positive feedback (*M* = 7.71, *SD* = .86). This strongly indicated that negative feedback led participants to feel worse about themselves than positive feedback.

Next we analyzed subliminal self-esteem in a 2 (feedback) X 2 (pre-feedback subliminal self-esteem vs. post feedback subliminal self-esteem) ANOVA with subliminal self-esteem treated as a repeated measure. The interaction was not significant, F (1, 68) = .67, $p > .4$. However, the relationship between subliminal self-esteem scores before and after the feedback was inverse and nearly significant, $r = -.21$, $p = .07$. Thus, perhaps presenting this measure twice to participants generated problems with its reliability. Bosson et al. (2000), without a manipulation between administrations, also found low test-retest reliability using this measure ($r = .28$). Thus, in the present study it seems best to view this measure with substantial caution.

Main Analyses

Effect of feedback on vagal tone

After finding strong evidence on the self-report manipulation check that feedback was affecting self-esteem, we assessed the main hypothesis that feedback would affect vagal tone. To do so we conducted a 2 (feedback) X 2 (composite vagal tone: time 2 vs. time 3) ANOVA with vagal tone treated as a repeated measure. A significant interaction emerged, F (1, 68) = 5.85, $p < .05$. Simple main effects revealed a trend in the negative feedback condition such that vagal tone was lower during time 3 (*M* = -.24, *SD* = .74) than during time 2 (*M* = -.16, *SD* = .73), p = .18. Further, simple main effects showed that in the positive feedback condition vagal tone was higher during time 3 (*M* = .15, *SD* = 1.17) than during time 2 (*M* = .02, *SD* = 1.20), $p < .05$. Thus, in support of our main hypothesis, leading people to feel temporarily bad and good about themselves led to lower and higher vagal tone, respectively.

Next we analyzed the effect of feedback on vagal tone at time 4, during anticipation of shock, by conducting a 2 (feedback) X 2 (composite vagal tone: time 2 vs. time 4) ANOVA, with vagal tone treated as a repeated measure. Here we found no interaction—no effect for feedback on change in vagal tone, F (1, 63) = .02, $p > .60$. A main effect for time of vagal tone measurement emerged, however, F (1, 63) = 15.53, $p < .01$. It showed that vagal tone increased from time 2 (*M* = -.07, *SD* = .10) to time 4 (*M* = .22, *SD* = .93). This was contrary to what we expected given that during time 4 participants awaited the onset of electric shocks, a threat not present beforehand. Perhaps this general increase in vagal tone occurred as a response to counteract the threat. In addition, maybe this threat in the form of anticipation distracted participants enough from the feedback to eliminate its power. The effect of feedback was short lived and disappeared between times 3 and 4. Maybe, then, with either a stronger boost to self-esteem or a weaker and less consuming threat, we would see self-esteem continue its impact on vagal tone. See Appendix E for the complete set of vagal tone means by feedback condition.

Correlations between self-esteem and vagal tone

To further investigate the hypothesis that state self-esteem affects vagal tone, we analyzed the relationship between how much people reported the feedback affected their self-esteem and vagal tone change between time 2 and time 3. The significant correlation, $r = -.31$, $p = .01$, showed that the better the feedback led participants to feel about themselves, the more their vagal tone increased; the worse the feedback made them feel about themselves the more their vagal tone decreased. This provided further evidence that state self-esteem affects vagal tone.

Although subliminal self-esteem was unaffected by the feedback and appeared unreliable, we nevertheless analyzed the relationship between subliminal self-esteem change scores and vagal tone change from time 2 to time 3. The correlation approached significance, $r = .19$, $p = .11$, suggesting that changes in vagal tone and subliminal self-esteem varied together from pre to post feedback.

Mediation analyses

Given the effect of feedback on self-reported self-esteem due to feedback, the effect of feedback on vagal tone change, and also that self-reported self-esteem due to feedback predicted vagal tone change, we examined the possibility that this self-reported self-esteem mediated the effect of feedback on vagal tone change. To do so we regressed vagal tone change scores from time 2 to time 3 onto feedback. This essentially repeated the ANOVA conducted earlier. Feedback predicted vagal tone, $B = -.21$, $t = -2.42$, $p < .05$. Next we regressed the self-reported self-esteem due to feedback onto feedback. Also essentially repeating the earlier analysis using ANOVA, feedback predicted its self-reported effects on self-esteem, $B = 4.22$, $t\ (1, 64) = 12.66$, $p < .01$. We therefore showed in separate analyses that the independent variable predicted both the dependent variable and the mediator. To show mediation, however, when the dependent variable is regressed onto the mediator and independent variable simultaneously, the mediator must predict the dependent measure and decrease the independent measure's ability to predict the dependent measure (Baron & Kenny, 1986). Consequently we regressed vagal tone change scores onto feedback and onto self-reported self-esteem due to feedback. In this analysis we found no effect of self-reported self-esteem on vagal tone, $B = -.02$, $t = -.71$, $p = .48$. Similarly, the effect of feedback on vagal tone dropped below significance, B = -.12, $t = -.79$, $p = .43$. A Sobel test revealed that this drop was not significant, $z = -.71$, $p = .48$. Thus, we did not show mediation.

We though it possible that mediation might work the other way around—that vagal tone might mediate the effects of feedback on the self-reported self-esteem due to feedback. Thus, we simultaneously regressed self-reported self-esteem onto feedback and onto vagal tone change. However, vagal tone failed to predict self-reported self-esteem due to feedback, $p > .45$ and the effect of feedback on self-reported self-esteem remained significant, $B = 4.15$, $t = 11.76$, $p < .01$. Thus, we again did not show mediation.

Auxiliary Analyses

Self-esteem moderation

We examined whether either trait RSES scores or baseline subliminal self-esteem moderated the effect of feedback on vagal tone. We first examined RSES scores and regressed vagal tone change onto mass survey RSES scores, feedback condition, and the RSES by feedback interaction. We found no interaction, $p > .95$. We next examined baseline subliminal self-esteem and regressed vagal tone change scores onto baseline subliminal self-esteem, feedback condition, and the subliminal self-esteem by feedback interaction. We again found no sign of an interaction, $p > .60$.

We next examined whether RSES scores or baseline subliminal self-esteem moderated the effect of feedback on self-reported self-esteem due to feedback. To examine RSES scores, we regressed the self-reported effects of feedback onto RSES scores, feedback condition, and the RSES by feedback interaction. We found no interaction, $p > .85$. To examine baseline subliminal self-esteem, we regressed the self-reported effects of feedback onto baseline subliminal self-esteem, feedback condition, and the subliminal self-esteem by feedback interaction. Again we found no interaction, $p > .25$.

In sum, though we found evidence that trait self-esteem moderated of effects of feedback on vagal tone in Study 1, we found no evidence for this kind of moderation here in Study 2. The studies are very similar up to this point, so no obvious reason presented itself to explain this difference. One difference between studies, however, is the length of time the experimenter left participants alone with the feedback. Participants in Study 2 had the feedback for 3 minutes, twice as long as in Study 1. Perhaps this time extension allowed the feedback to sink in more, thus increasing the strength of the manipulation and decreasing the impact of the personality variable.

Vagal tone moderation

We examined whether baseline vagal tone might moderate the effect of feedback on self-reported self-esteem due to feedback. We therefore regressed self-reported self-esteem due to feedback onto feedback condition, vagal tone at time 1, and the feedback by vagal tone time 1 interaction. No interaction emerged, $p > .40$.

We also examined whether baseline vagal tone might moderate the effect of feedback on vagal tone change. We therefore regressed vagal tone change (from time 2 to time 3) onto vagal tone at time 1, feedback condition, and the vagal tone time 1 by feedback interaction. Again no interaction emerged, $p > .40$.

Mood analyses

We first examined the effects of feedback on negative mood. We conducted a 2 (feedback) X 2 (negative mood: pre-feedback vs. post-feedback) ANOVA with negative mood as a repeated measure. An interaction emerged, $F(1, 61) = 5.00$, $p < .05$, suggesting that after positive feedback, negative mood was lower ($M = 1.44$, $SD = .32$) as compared to before the feedback ($M = 1.65$, $SD = .38$), $p < .01$. The means for negative mood pre and post feedback, however, showed negative mood also lower after the negative feedback ($M = 1.48$, $SD = .49$) as compared to before the feedback ($M = 1.52$ $SD = .43$), albeit insignificantly lower, $p = .46$. Given this significant interaction, however, we examined whether change in negative mood mediated the effect of feedback on vagal tone change. We regressed vagal tone change scores onto the pre to post change in negative mood, and onto feedback. Feedback remained a significant predictor of vagal tone, $B = .21$, $t = -2.28$, $p < .05$. Negative mood failed to predict vagal tone, $B = .12$, $t = .83$, $p > .40$. Thus, change in self-reported negative mood did not mediate the effect of feedback on vagal tone change.

To examine positive mood we conducted a 2 (feedback) X 2 (positive mood: pre-feedback vs. post-feedback) ANOVA with positive mood as a repeated measure. The interaction did not emerge, $p > .4$.

Threat Analyses

Effects of feedback/self-esteem on threat

Participants between times 3 and 4 were told they would receive electric shocks. During time period 4, therefore, participants waited under threat in anticipation of the shock period quickly approaching. To assess the impact of feedback on the response to this threat we first analyzed CSI scores at time 4 as compared to baseline CSI scores at time 1. Specifically, we conducted a 2 (feedback: negative vs. positive) X 2 (CSI scores: time 1 vs. time 4) ANOVA with CSI scores treated as a repeated measure. A marginal interaction emerged, F (1, 63) = 3.74, $p < .06$. Computing simple main effects tests, participants who received negative feedback evidenced higher CSI scores at time 4 (M = 2.88, SD = .84) than during baseline (M = 2.44, SD = .96), $p < .05$. However, participants who received positive feedback showed no such increase in CSI scores from time 4 (M = 2.44, SD = .76) as compared to baseline (M = 2.56, SD = 1.05). Consistent with this effect, a correlation showed that the more self-reported self-esteem due to feedback, the lower CSI scores at time 4, $r = -.24$, $p < .05$. Thus, as predicted, our state self-esteem boost in the form of positive feedback buffered people from primary sympathetic threat responding.

We also analyzed the effect of feedback on self-reported anxiety during threat of shock. The 2-way (feedback) ANOVA showed no difference in self-reported anxiety as a function of personality feedback, $F(1, 64) = .67$, $p > .4$. Consistent with this analysis, a correlation showed no relationship between self-reported self-esteem due to feedback and self-reported anxiety, $r = .06$, $p = .64$. Considering the timing of the anxiety self-report measure presented approximately four minutes after the induction of threat, and given the hypothesis that state self-esteem should most readily predict primary threat responses (responses in close temporal proximity to the threat) and less readily predict secondary threat responses, we might expect this null effect.

EDA analyses were limited in power due to an equipment malfunction (the total n dropped to forty-two), and the remaining data was sometimes not clearly interpretable. Thus we focused solely on CSI scores as our method for assessing sympathetic responding to threat.

Effects of vagal tone on threat

Or analysis posits that vagal tone buffers from sympathetic threat responses. Thus, we should see higher vagal tone predict subsequent sympathetic threat responding. To assess this we correlated vagal tone scores at time 3 with CSI scores at time 4. A significant effect emerged, $r = -.39$, $p > .01$, showing that higher vagal tone levels at time 3 predicted less sympathetic activity at time 4. This supports the theorized relationship between parasympathetic and sympathetic nervous systems.

Mediational analyses

We found that the self-esteem feedback and vagal tone buffered people from sympathetic threat, but our analysis in addition suggests that state vagal tone might mediate the effects of feedback on sympathetic threat responding. To examine this possibility, we first regressed our dependent measure, CSI scores at time 4, onto our independent measure, feedback. As shown earlier, a significant effect emerged such that positive feedback led to less sympathetic threat responding as compared to negative feedback, $B = -.44$, $t = -2.21$, $p < .05$. We next regressed our potential mediator, vagal tone at time 3, onto feedback. Also as shown earlier, a marginal effect emerged such that positive feedback led to greater vagal tone than negative feedback, $B = .41$, $t = 1.84$, $p < .07$. Third, we regressed CSI scores at time 4 onto both feedback and vagal tone at time 3. Vagal tone remained a significant predictor of CSI scores, $B = -.30$, $t = -2.95$, $p < .01$, while the effect of feedback dropped below significance, $B = -.30$, $t = -1.58$, $p = .12$. A Sobel test conducted to examine this drop in the ability of feedback to predict CSI scores did not reach significance, $t = 1.56$, $p = .12$. Thus, it appears vagal tone may only in part mediate the effect of feedback on sympathetic threat responding.

GENERAL DISCUSSION

Across both studies we found evidence that manipulating state self-esteem with personality feedback affected state changes in vagal tone. In Study 1 only pNN50 scores responded to the feedback. However, noise and/or outliers in the EKG data may have reduced the validity of RSA scores to a greater degree than pNN50 scores (Burr et al., 2003; Toichi, Sugiura, Murai, & Sengoku, 1997). And the lower correlation between the two measures in Study 1 than in Study 2 suggests that noise and/or outliers may have been a factor. In Study 2, across all vagal tone indices, positive feedback led to higher vagal tone than negative feedback. Additionally supporting our basic hypothesis, we found correlations between self-esteem IAT change and vagal tone change in Study 1, and between self-reported effects of the feedback on self-esteem and vagal tone change in Study 2. Thus, the evidence suggests that state self-esteem affects state vagal tone.

Our analysis also posits that vagal tone promotes security from threat at a physiological level, and that self-esteem promotes vagal tone because it provides security to human beings. Thus to assess this model we threatened participants in Study 2 with the promise of electric shock and examined if both state self-esteem and state vagal tone buffered people from sympathetic threat responding. As predicted, we found that the self-esteem manipulation predicted sympathetic responding closely following the introduction of the threat. Specifically, boosting state self-esteem with positive feedback eliminated the sympathetic threat response observed in those presented with negative feedback. Also as predicted, vagal tone levels just prior to threat predicted less sympathetic threat responding. However, the evidence that vagal tone mediated the effect of feedback on sympathetic responding appeared more ambiguous.

Perhaps one explanation for why we failed to see this mediation fully stems from difficulty in measuring vagal tone. Error measurement can inhibit mediation effects from emerging (Baron & Kenny, 1986) and our measures of vagal tone are approximations based on the variability in heart rate within the frequencies of breathing. Thus it may be that with more precise techniques for assessing vagal tone will come too a more precise ability to test for mediation. Similarly, we might think about more powerful ways to manipulate and measure self-esteem. For example, we can perhaps manipulate self-esteem better by taking into account how TMT and related theories (e.g., Symbolic Interactionist Theory) posit people acquire self-esteem. These theories suggest that a particularly important source of self-esteem is feedback from others who are important for one’s worldview. This suggests that we might strengthen our self-esteem manipulation by making it clear to participants that the experimenter knows the content of the feedback, and also by bolstering the extent to which the participants value the experimenter’s opinions.

Implicit Self-esteem and Vagal Tone

Further work might investigate other methods for measuring self-esteem. We employed two “implicit” measures of self-esteem in the belief that they would tap the type of self-esteem that is important for vagal tone. However, they proved of only limited value in predicting vagal tone. But perhaps different implicit measures would fair better. There seems a good deal of variation in the growing list of implicit self-esteem measures

(Bosson, Swann, & Pennebaker, 2000), and it seems reasonable to hypothesize a link between implicit self-esteem and vagal tone. Implicit self-esteem in principle should index the symbolic sense of security that is below people's consciousness and so under less conscious control. Similarly, vagal tone is generally under non-conscious or automatic control. Of course, this implicit sense of symbolic security may also be reflected in conscious and more controlled thoughts, and reciprocally, conscious thought surely has implications for people's implicit sense of self-esteem. But given the predominantly automatic nature of the autonomic nervous system it would seem that its more direct connection be with more automatic and implicit forms of self-esteem.

Perhaps one difficulty, however, with using implicit self-esteem measures for this research endeavor is ambiguity about whether implicit self-esteem measures indicate state self-esteem or trait self-esteem. As is evident in Studies 1 and 2, implicit self-esteem measures do change and so might tap state self-esteem. But still they are not necessarily meant to measure state self-esteem and so may fall short when used for this task. Perhaps then we can develop an implicit self-esteem measure designed to better tap state self-esteem. Maybe it is possible to prime people to think more about immediate circumstances (versus life generally) while completing implicit self-esteem measures. This may be important considering the specific hypotheses laid out related to state and trait self-esteem, state and trait vagal tone, and primary and secondary threat responses.

State and Trait

Specifically, we have posited that the state buffers—state self-esteem and state vagal tone—should most readily predict primary responding to threat. The trait buffers—

trait self-esteem and trait vagal tone—should most readily predict secondary threat responses. We assessed primary threat responding using the CSI in Study 2, but this provided us with an index of sympathetic activity gathered from over a minute of data. Other indexes of threat responding might therefore be more amenable to assessing primary threat in its relation to state self-esteem and state vagal tone. For example, EDA provides an index of sympathetic activity that can reflect meaningful changes occurring over the course of several seconds. Or perhaps even more clearly capable of indicating primary threat responses, eyeblink startle should allow for assessing threat responding with very little chance for secondary appraisals or enacting coping strategies. Given what appear to be fewer complications in assessing both state buffers and primary threat responding as compared with trait buffers and secondary threat responding, it seems future research might first be directed towards these constructs. With this foundation we should be better equipped to then integrate trait and secondary threat constructs.

For example, we might begin to assess the relationship between trait self-esteem and trait vagal tone by measuring vagal tone over prolonged periods of time, perhaps with ambulatory equipment. We could then compare better with standard trait self-esteem measures such as the RSES. We might also compare with other indices of trait self-esteem, such as that acquired in a way paralleling the assessment of triat vagal tone, by repeatedly measuring state self-esteem over a period of days or weeks. Or we might think about "capabilities", the degree and frequency of changes people are capable of, as an important component of trait self-esteem and trait vagal tone (Wallace, 1966). Kernis' work (e.g., Kernis, Grannemann, & Barclay, 1989) investigating stability of self-esteem suggests one method for assessing a person's potential for ups and downs, and we might in parallel observe the variability of state vagal tone over a prolonged period. Or we might observe people's potential for vagal tone change in the lab using various tasks intended to elicit extreme responses. Perhaps these indicators of trait self-esteem and trait vagal tone correspond and in turn predict secondary or more long term sympathetic-related threat responses. Based on the work of Kernis and colleagues we might hypothesize that more stable and less volatile self-esteem and vagal tone predict better coping and reduced secondary threat responses.

Physical Health

Yet another avenue for future research should be deeper investigations into implications for physical health. The present research posits a strong link between self-esteem and the parasympathetic nervous system, arguably the dominant branch of the autonomic nervous system. 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 paper—that vagal functioning inhibits the body's emergency or threat systems, which left unchecked can deteriorate the body and lead to disease and contribute ultimately to death.

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., Menkes et al., 1989; Kamarck et al., 1997;

Krantz & Manuck, 1984). By controlling and dampening these sympathetic stress responses, then, vagal tone should protect the heart from disease (Jennings & Follansbee, 1985). Indeed, research links lower heart rate variability and lower RSA to greater hardening of artery walls and to sudden heart arrhythmia that can lead to cardiac arrest (Jennings, van der Molen, Somsen, Graham, & Gianaros, 2002; Chamberlain, 1978; Kent, Smith, Redwood, & Epstein, 1973; Hinkle, Carver, & Plakun, 1972).

Research has also recently suggested 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 various 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. And 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 diseases include rheumetoid arthritis, Crohn's disease, lupus, diabetes, and sepsis. Evidence linking these issues to vagal tone is beginning to emerge, and for example showed that vagal tone predicted higher mortality rates due to sepsis (e.g., Yien et al., 1997). We might in future research then examine our hypotheses by observing in single studies the path between self-esteem and cardiovascular and immune system health and by examining populations with cardiac and immune system disease. We could then more strongly advocate that avenues for effectively protecting people from both potentially lethal heart complications and from immune system diseases should more seriously include a consideration of self-esteem.

In addition to these implications for health, this research was designed to further test the TMT perspective on self-esteem and to broaden the theory to specify connections with the autonomic nervous system. That this work connects self-esteem to an important physiological buffer of threat (the parasympathetic nervous system) suggests the accuracy of the TMT-proposed function of self-esteem. In other words, the evidence that self-esteem affects a physiological threat-buffer provides more data that indeed self-esteem can function to secure our organism and protect people from threat. Further, the more the theory can accurately represent reality, the more useful it should be. The more accurate, the more we can draw useful implications from the theory for the real world, whether they be relevant to mental health, physical health, or to social problems such as prejudice and aggression.

APPENDIX A

Negative Personality Evaluation:

You display a tendency to doubt yourself and your ability to succeed; you are concerned about whether others like and admire you. While you do have some personality strengths, your personality weaknesses affect your life to a much greater extent. Your sexual adjustment has presented more than the usual amount of problems. You may feel insecure and this can often hinder being productive. Though you like to think that the decisions you make are the correct ones, you sometimes have serious doubts as to whether you have made the right decision or done the right thing. Furthermore, you have trouble thinking creatively and in novel ways, and are concerned about your ability to solve problems. Thus, you often rely on others rather than thinking independently. Nevertheless, your social intelligence is adequate and you generally show an ability to solve basic life problems. You are sometimes extroverted and sociable, but also have more troubles than you would like interacting with others. Given your personality traits, there's a good chance that you do not accept your limitations, and that many of your aspirations are unrealistic. It is likely that these characteristics will continue to solidify later on in life.

Positive Personality Evaluation:

You genuinely like yourself and believe in your ability to succeed. You are self-sufficient and while you may feel you have some personality weaknesses, your personality strengths affect your life to a much greater extent. Your sexual adjustment has presented less than the usual amount of problems. You have a great deal of inner security and this helps you be productive. However, at times you have serious doubts as to whether you have made the right decision or done the right thing. Your creativity enables you to solve many problems. Thus, you pride yourself on being an independent thinker and are open to new opinions and viewpoints. Although you are generally extroverted, affable, and sociable, you also have the capacity to enjoy and fully utilize the time you have to yourself. Given your personality traits, there’s a good chance that even your most ambitions aspirations are realistic, although bringing them to fruition will require focus and persistence.

APPENDIX B

Study 1 pNN50 scores by condition. Higher pNN50 scores indicate higher vagal tone

	Feedback			
	Negative		Positive	
Time	*M*	*SD*	*M*	*SD*
Time 1 (baseline)	14.84	16.06	14.59	19.58
Time 2 (pre-feedback)	17.28	16.47	14.95	16.66
Time 3 (post feedback)	15.68	16.63	17.57	20.44
Time 4 (shock anticipation)	16.79	16.28	19.74	19.52

APPENDIX C

Study 1 correlations among variables

Variable	1	2	3	4	5	6	7	8	9
1. RSES 1	-----								
2. RSES 2	+.29*	-----							
3. SE IAT 1	+.00	.00	-----						
4. SE IAT 2	-.10	.00	+.37*	-----					
5. Feed Felt	+.05	+.19	-.23*	+.03	-----				
6. pNN50 1	-.17	-.23	-.03	+.03	+.12	-----			
7. pNN50 2	-.12	-.21	-.11	-.08	+.09	+.94*	-----		
8. pNN50 3	-.18	-.13	-.11	+.05	+.18	+.90*	+.84*	-----	
9. pNN50 4	-.26	-.18	-.03	+.12	+.18	+.95*	+.90*	+.89*	-----

Note: * $p < .05$
RSES: Rosenberg Self-esteem Scale; SE: Self-esteem; Feed Felt: Participant ratings of how the feedback made them feel about themselves; pNN50: Vagal Tone index.

APPENDIX D

Study 2 correlations among variables

Variable	1	2	3	4	5	6	7	8	9	10
1. RSES	-----									
2. Feed Felt	+.15	-----								
3. VT 1	+.06	+.08	-----							
4. VT 2	+.10	+.09	+.91*	-----						
5. VT 3	+.11	+.19	+.91*	+.93*	-----					
6. VT 4	-.14	+.05	+.81*	+.81*	+.82*	-----				
7. CSI 1	-.03	+.00	-.75*	-.68*	-.72*	-.63*	-----			
8. CSI 2	-.03	-.06	-.67*	-.62*	-.67*	-.55*	+.77*	-----		
9. CSI 3	+.01	-.04	-.63*	-.61*	-.63*	-.56*	+.78*	+.82*	-----	
10. CSI 4	+.03	-.13	-.52*	-.41*	-.46*	-.56*	+.60*	+.61*	+.63*	-----

Note: * $p < .05$
RSES: Rosenberg Self-esteem Scale; Feed Felt: Participant ratings of how the feedback made them feel about themselves; VT: Vagal Tone; CSI: Cardiac Sympathetic Index.

APPENDIX E

Study 2 vagal tone scores by feedback condition

	Feedback			
	Negative		Positive	
Time	*M*	*SD*	*M*	*SD*
Time 1 (baseline)	-.17	.85	-.12	1.18
Time 2 (pre-feedback)	-.12	.76	-.08	1.08
Time 3 (post feedback)	-.22	.73	+.02	1.01
Time 4 (shock anticipation)	+.20	.74	+.28	1.06

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