Title
Vagal Reactivity and Compassionate Responses to the Suffering of Others

Author
Stellar, Jennifer Ellen

Publication Date
2013

Peer reviewed|Thesis/dissertation

Vagal Reactivity and Compassionate Responses to the Suffering of Others

By

Jennifer Ellen Stellar

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Psychology

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Dacher Keltner, Chair
Professor Kaiping Peng
Professor Iris Mauss
Professor Robb Willer

Fall 2013

Abstract

Vagal Reactivity and Compassionate Responses to the Suffering of Others

by

Jennifer Ellen Stellar

Doctor of Philosophy in Psychology

University of California, Berkeley

Professor Dacher Keltner, Chair

Theoretical and empirical work suggest that the vagus nerve supports social behavior, promoting communication, social engagement, coping or self-soothing in social situations, and the initiation of socially supportive behavior (e.g. Porges, 2003). Guided by this thinking, I predict that the experience of compassion in response to the suffering of others is associated with greater vagus nerve activation. I test this hypothesis across four studies in which participants witnessed others suffer while I recorded physiological measures including a non-invasive index of vagal activity called respiratory sinus arrhythmia (RSA), heart rate, respiration, and skin conductance. Participants exhibited greater RSA activity during the compassion induction compared to a neutral control (Study 1), another positive emotion (Study 2), and a prosocial emotion that lacked the presence of suffering (Study 3). Increases in RSA activity during the experience of compassion were accompanied by decreases in heart rate and occasionally by increases in respiration, but not changes in skin conductance. In Study 4, RSA activity during the compassion induction correlated positively with continuous self-reports of compassion and perceptions of participants' compassion by coders. This work suggests that compassion engages the vagus nerve, facilitating this prosocial response to others' suffering.

Acknowledgements

First, I would like to thank the chair of my dissertation committee and my graduate mentor, Dacher Keltner. His guidance and mentorship has instilled in me a deep appreciation for the scientific search for truth and the ability of psychological research to answer fundamental questions about human nature. I am truly honored to have had the chance to learn from such an important figure in the field and hope that I can continue in his tradition of inspired and innovative research. I would also like to thank Robb Willer, Kaiping Peng, and Iris Mauss for their thoughtful comments on my dissertation and for being devoted, kind, and caring mentors. I could not have completed this work without my fellow graduate students and the Berkeley Social Interaction Laboratory who have taught me so much and supported me throughout my time at Berkeley. I would also like to thank my research assistants who worked tirelessly to help collect this data and who provide me with daily inspiration and motivation. Lastly, thank you to my husband, my largest supporter and biggest source of strength and support.

Vagal Reactivity and Compassionate Responses to the Suffering of Others

Humans are a social species with strong affiliative and cooperative inclinations. In support of this claim, specific neurophysiological systems appear to facilitate prosocial intentions and behaviors. Neuropeptides such as oxytocin increase social bonding (Carter, Williams, Witt, & Insel, 1992) and trusting behavior (Kosfeld, et al., 2005), genes like the Arginine Vasopressin 1a receptor (AVPR1a) are associated with greater altruistic responding (Knafo, et al., 2007), and specific brain regions such as the anterior insula and rostral anterior cingulate cortex enable individuals to empathize with others (Singer, et al., 2004).

The Polyvagal Theory developed by Porges (2001; 2007) asserts that within the autonomic nervous system the vagus nerve supports social behavior, promoting communication, prosocial engagement with others, the utilization of social support to cope with negative affect, and socially supportive behaviors. Building on this theory, I examine whether the experience of compassion engages the vagus nerve. Compassion is an affiliative emotion that encourages social communication and is characterized by powerful social connection. It motivates social engagement, allowing individuals to actively cope with the distress associated with seeing others suffer, and initiates caretaking behavior. Although there is considerable overlap between the functions of the vagus nerve and the characteristics of compassion, no one has examined whether compassion is associated with vagal activity. These findings would offer a new perspective on physiological reactivity to suffering because increases in vagal activation would suggest that the body is calming down or relaxing in response to suffering, which may promote caretaking behaviors. I hypothesize that the experience of compassion increases parasympathetic domination over the heart through greater vagus nerve activity. I predict that vagal activation will be unique to the experience of compassion, and not positive or prosocial emotions more generally because compassion promotes social engagement in the face of stress.

The Vagus Nerve: Anatomy, Measurement, and Function

The vagus nerve is the tenth cranial nerve. It extends from the brain stem farther than any other cranial nerve, innervating the Cricothyroid and other major muscles in the larynx, the Salpingopharyngeus, Palatopharryngeus, and pharyngeal constrictor muscles in the pharynx and esophagus, as well as the Levator veli palatine and Palatoglossus muscles in the palate, before travelling down into the heart and digestive organs involved in peristalsis. Recent research suggests the vagus nerve also functions to control immune response by regulating cytokine production (Rosas-Ballina, 2011).

Vagal activation is primarily measured through its influence upon heart. In order to obtain a non-invasive index of vagal activity as it originates in the nucleus ambiguus and projects to the sino-atrial node of the heart, researchers examine heart rate variability (HRV) or respiratory sinus arrhythmia (RSA). During respiration, as one inhales, vagus nerve innervation of the heart naturally reduces, resulting in heart rate acceleration; during exhalation vagus nerve innervation of the heart increases, leading to heart rate deceleration. HRV captures this variability in heart rate over time. RSA captures the variability in heart rate that is specifically associated with the respiration cycle, and is thought to be a better indicator of vagal activation (Berntson & Cacioppo, & Quigley, 1993). HRV is not an ideal measure of vagus nerve activity because it is influenced by both parasympathetic and sympathetic systems (Mendes, 2009). Therefore, researchers use a frequency domain technique to estimate HRV by examining it within different frequency bands using a Fourier transformation so vagal influence can be isolated. HRV that occurs in the high frequency band from .15 to .4 Hz (cycles per second), the typical frequency range of normal adult respiration, is thought to represent vagal influence. Low frequency HRV utilizes a low frequency band of 0.04 to 0.15 Hz and is influenced by the sympathetic and parasympathetic system. This method for obtaining high frequency HRV makes it equivalent to RSA. RSA, the focus of this paper, can be determined through multiple methods including the aforementioned use of a bandpass filter to isolate specific frequencies of heart rate activity associated with vagus control, spectral analysis, or a time-domain peak valley method (Beauchaine, 2001; Grossman & Taylor, 2007). When measuring HRV or RSA the question of whether respiration should be controlled for is heavily debated. Some researchers argue that respiration rate in psychological studies has a negligible impact on RSA (Denver & Porges, 2007), whereas others argue decreases in respiration reduce RSA, but do not change cardiac vagal activation, decreasing the validity of RSA as an index of vagal activity (Grossman & Taylor, 2007). Therefore, in our analyses I present RSA before and after including respiration as a covariate.

The vagus nerve is a major component of the parasympathetic branch of the autonomic nervous system (Beauchaine, 2001). In contrast to the sympathetic system, which is associated with high arousal states (e.g. threat, aggression, stress, fear, etc.) the parasympathetic system is primarily concerned with more restorative processes that take place during times of rest (Berntson, et al., 1993). In most cases these two systems are thought to work antagonistically within the heart such that greater parasympathetic efference to the heart is associated with less sympathetic control over the heart and vice versa. Greater sympathetic activation promotes increases in heart rate and greater parasympathetic activation leads to decreases in heart rate. In keeping with this analysis, the vagus nerve inhibits the sino-atrial node or the pacemaker for the heart. The vagus nerve chronically innervates the heart, maintaining the average adult heart rate at a pace of sixty to eighty beats per minute. Blocking all vagal efference to the heart results in a natural stable heart pace of 100 beats per minute, which would be unhealthy for humans to maintain (Sherwood, 2004). Individuals vary in their chronic vagal activation, referred to in the literature as vagal tone, which represents the constant level of stimulation that the vagus nerve exerts upon the heart (Berntson, Cacioppo, & Quigley, 1993; Oveis et al., 2009). Vagal tone is typically assessed in the absence of specific stimuli, during a baseline or resting task, and represents a relatively stable individual difference measure.

In addition to chronic levels of activation of the vagus nerve, temporary changes in vagal activity, or vagal reactivity, occur in response to stimuli in the environment (Berntson, et al., 1993). Vagal reactivity, the focus of this paper, can be defined either by decreases in vagal activation, called vagal withdrawal or suppression, or by increases in vagal activation. Vagal withdrawal occurs when vagal efference to the heart decreases, which is manifested in noticeable increases in heart rate (Frazier, Strauss & Steinhauer, 2004). In this case the sympathetic system gains greater control over the pace of the heart, which increases the body's metabolic output to meet challenges in the environment (Porges, 1995). In keeping with this claim, past research has documented a pattern of vagal withdrawal to different types of stressful tasks (e.g. Mezzacappa, Kelsey, Katkin, & Sloan, 2001). For instance, Mezzacappa and colleagues (2001) found that participants exhibited decreases in HRV during a challenging mental arithmetic task and the Stroop test compared to baseline. Similarly, a stressful speech task where participants had 3-5 minutes to prepare a speech that would be rated by others, led to decreases in high frequency HRV compared to a two minute relaxation baseline in adults (Souza, 2007) and in a sample of adolescents (Hollenstein, McNeely, Eastabrook, Mackey, & Flynn, 2012). The cold face test, where a very cold compress is applied to the cheeks is a common laboratory stressor, which is reliably associated with vagal withdrawal (Hilz, et al., 1999; La Marca et al., 2011).

Research has also documented that vagal withdrawal is part of an adaptive response to negative emotional stimuli (Porges, 1995). In one study, participants exhibited reduced RSA activity while watching three negative film clips (fear, surprise, and sadness) compared to a baseline immediately preceding each film clip (Frazier, et al., 2004). In addition, participants who were instructed to choose a worrisome topic and worry about it showed decreased RSA compared to a short baseline period (Fisher & Newman, 2013). It is also thought that a lack of vagal withdrawal to negative emotional situations may predict a more pernicious course of depression (Rottenberg, Salomon, Gross, & Gotlib, 2005). Depressed participants who showed greater RSA withdrawal when watching a sad film clip compared to a baseline were more likely to recover from their depression in a follow-up assessment. Importantly, vagal withdrawal may be associated with emotional arousal regardless of valence as they found reduced RSA activity in response to both negative and positive film clips (Frazier et al., 2004). Overall, these findings suggest that negative situations that are cognitively, physically or emotionally arousing promote reduced vagal activation, which mobilizes energy resources necessary to meet temporary environmental challenges.

Increases in vagal activation in response to an environmental stimuli presentation reflect the vagus nerve exerting greater control over the heart and are often accompanied by decreases in heart rate. Whereas vagal withdrawal often occurs in response to stressful situations, increases in vagal activation are seen during contexts characterized by a calming of the body, coping with negative affect, and positive engagement with the environment. These findings fit within the broader claims that the parasympathetic system is active during restorative, restful, and safe contexts (Berntson, et al., 1993). Across multiple studies, researchers have demonstrated that participants experience greater RSA activation when meditating compared to a control (Krygier, 2013; Kok, et al., 2013) or other activities such as listening to an audio book or sitting while relaxing one's muscles (Ditto, Eclache, & Goldman, 2006). Researchers argue that the vagus nerve is part of a soothing affect system, demonstrating that participants lower on anxious attachment who performed a Compassion-Focused Imagery (CFI), where they imagined receiving support from another person showed increases in HRV (Rockliff, Gilbert, McEwan, Lightman & Glover, 2008). These participants also showed decreases in cortisol, a hormone released by the adrenal cortex, which suggests a down-regulation of stress-related physiological systems. In addition, certain contexts where individuals actively attempt to soothe or cope with negative affect through regulating their negative emotions lead to increases in vagal activation. Participants instructed to suppress or reappraise their emotional responses while describing a disgusting clip to another participant experienced larger increases in RSA activity compared to a neutral film clip, than individuals who were given no instructions to regulate their emotions (Butler, Wilhelm & Gross, 2006). In addition, in the still face paradigm, mothers instructed to regulate their response to their infants by suppressing their emotional expression while their infants expressed distress, showed an increase in RSA activity compared to a baseline where infants played with a toy (Oppenheimer, Measelle, Laurent, & Ablow, 2013). Vagal activation also appears to co-occur with greater positive engagement with the physical environment. For instance, increases in RSA among infants while attending to pictures or toys compared to when they were sitting in a seat predicted coders' ratings of their positive engagement with objects measured as sustained attention, active interaction, and positive signaling (Bazhenova, Plonskaia, & Porges, 2001).

This research reveals several lines of evidence that are in keeping with Porges' Polyvagal Theory (2001) and its specific claims about vagal withdrawal and activation. I have seen that vagal withdrawal tends to covary with responses to stressful stimuli. By contrast, there is select evidence indicating that vagal reactivity is associated with calming, regulating distress, and social engagement. These findings set the stage for the present investigation of the relationship between vagal reactivity and compassion.

The Polyvagal Theory: A Foundation for the Vagus Nerve and Compassion

The Polyvagal theory posits that there were three major stages to the development of autonomic nervous system (Porges, 2001; Porges, 2007). The first and earliest stage of autonomic development was the evolution of the dorsal vagus in jawless fish and Chondrichthyes (fish with cartilaginous skeletons). The dorsal vagus, or unmyelinated vagus, originates in the dorsal motor nucleus in the brain stem and was a primitive system geared at eliciting immobilization by stimulating certain behaviors such as feigning death and passive avoidance of predators. In a second stage of evolution the sympathetic system emerged in Osteichthyes (fish with bone skeletons) and amphibians. These organisms were the first to have both parasympathetic (dorsal vagus) and sympathetic autonomic influence over the heart, providing inhibitory and excitatory innervation of the heart, respectively. The sympathetic system allowed organisms to mobilize for more active avoidance of predators by increasing heart rate and preparing the body for action. Within this second stage was the development of the adrenal medulla in reptiles. This development enhanced the sympathetic system by permitting faster and more regulated release of epinephrine and norepinephrine, which enhanced cardiac output during mobilization. The third and final stage of development that occurred with the advent of mammals was the appearance of the ventral vagus, or myelinated vagus, which originates in the nucleus ambiguus in the brain stem (see Porges, 2001, for chart of development of autonomic influences over the heart).

This theory generates critical hypotheses about the function of the ventral vagus. Porges argues that these systems are activated hierarchically based on how recently they evolved. The role of the dorsal vagus nerve in mammals became minimal, leaving the ventral vagus and sympathetic system to provide primary influence over the sino-atrial node of the heart. Porges argues that the ventral vagal retains primary influence over the pace of the heart and the sympathetic system activates only when heart rate changes due to ventral vagal withdrawal are insufficient to meet environmental challenges. When inhibited, the ventral vagal system allows for greater sympathetic control over the heart without requiring direct activation of sympathetic or adrenal system, resulting in more rapid mobilization to environmental stressors without the metabolically-costly direct activation the sympathetic system. Porges does claim, however, that sustained stress will lead to direct sympathetic activation. Increases in the ventral vagal influence on the heart, on the other hand, facilitate quick engagement or re-engagement with the environment, decreasing metabolic output in order to self-soothe and produce calm states, which promote social engagement and bonding with others. Given this analysis of the development and anatomy of the autonomic nervous system, Porges claims that the ventral vagus can be thought of as a physiological substrate of social engagement behaviors.

Anatomical connections of the ventral vagus nerve, findings from clinical populations, and empirical work support Porges' analysis, demonstrating that the vagus nerve promotes social communication, social engagement behaviors, the use of social support to cope with stressors, and the initiation of socially supportive behaviors. The vagus nerve shares connections in the nucleus ambiguus with surrounding areas that facilitate social communication such as facial muscles required for expression, muscles involved in nodding the head (a behavior strongly associated with perceptions of social engagement with others), orienting of the head and gaze toward others, the laryngeal and pharyngeal muscles responsible for talking and vocalizing, and the part of the middle ear that extracts human voice from other sounds in the environment (Porges, 2001). In keeping with this claim about vagus nerve activation and communication, Butler and colleagues (2006) found that participants with higher baseline RSA were rated as more emotionally expressive when discussing a negative film clip with another person, as measured by coders ratings of participant's grimaces, frowns, and looks of disgust, annoyance, frustration and negative verbal statements. The vagus nerve also appears to be sensitive to social contact, or touch, an understudied medium of social communication. In support of this claim, participants who received non-noxious touch exhibited greater vagus nerve activation, whereas those who received painful touch experienced greater sympathetic activation (Uvnäs-Moberg, 2006).

The vagus nerve has also been linked to greater prosocial or positive social engagement with others. Evidence supporting the role of the vagus nerve in social engagement almost exclusively comes from studies that measure of vagal tone, not reactivity, but these studies provide indirect support for the consequences of temporary increases in vagal activation in promoting social engagement. In clinical samples, children diagnosed with autism, a mental health condition associated with deficits in social communication and engagement with others, demonstrate particularly low baseline cardiac vagal tone compared to healthy controls (Ming, Julu, Brimacombe, Connor, & Daniels, 2005; Porges, 2007). On the other end of the spectrum, individuals who show high risk for mania, which is characterized by the extreme experience of positive emotion and a heightened sense of connection with others, exhibit very high baseline HRV (Gruber, Johnson, Oveis & Keltner, 2008). In a sample of healthy children baseline RSA correlated with ratings of children's social engagement and competence by their teachers (Eisenberg et al., 1995). Similarly, adults with higher resting RSA reported greater social connectedness to others at the beginning of a nine-week study, and increases in reports of social connectedness over the course of study correlated with increases in resting RSA, controlling for RSA at the beginning of the study (Kok & Fredrickson, 2010). Vagal tone predicts greater higher scores on social components of personality such as extraversion and agreeableness (Oveis, et al., 2009) and is associated with perceptions of greater prosociality by others (Kogan & Oveis, et al., 2013). In situations where participants were given the chance to rate how trustworthy others were after watching videos of them, a curvilinear relationship emerged whereby targets with higher vagal activity, although not extremely high levels, were rated as more trustworthy and chosen more often as partners in a future task requiring trust and cooperation. Dysregulation of the vagus nerve may be associated with unhealthily low levels of social engagement, which may in part account for the health problems associated with social isolation (Knox & Uvnäs-Moberg, 1998).

Vagal activity may be particularly critical in facilitating social engagement during negative contexts, allowing individuals to actively cope or down-regulate negative affect and promoting perceptions of safety. Empirical work suggests higher vagal tone allows individuals to more effectively utilize social support in negative contexts and initiate socially supportive behaviors directed toward others. Participant's resting RSA was associated with greater self-reported use of socially engaged coping styles such as social support seeking during negative situations and was associated with social acceptance and social integration (Geisler, Kubiak, Siewart, & Weber, 2013). In a follow-up study, a 28-day assessment with random experience sampling revealed that participants' resting RSA positively predicted the use of social support seeking, and negatively predicted the use of more socially disengaged strategies such as accepting the negative event or avoiding it. In a laboratory study individuals with strong RSA reactivity to a elicitor, designated as high in vagal regulatory control, subsequently showed reduced stress-related sympathetic system activation, when social support was made available in the form of an encouraging and supportive experimenter compared to a non-supportive experimenter (Wolff, Wadsworth, Wilhelm, & Mauss, 2012). These findings are in keeping with a study by Schwerdtfeger and Schlagert (2011), who found an interaction between perceptions of available support and the presence of a familiar (support condition) or unfamiliar figure (no support condition) in predicting HRV during a stressful public speech task. Participants high in perceived available support showed greater HRV and lower HR during the stressful task when they were in the support condition compared to the no support condition, whereas there were no effects of condition for those low on perceived available social support. These results suggest that the perceived availability of social support engages the vagal system promoting a reduced cardiovascular response to stress. As further evidence of this claim, participants who imagined receiving social support from another person experienced increased vagal activity compared to a baseline, but only if they had a more secure attachment style (Rockliff, Gilbert, McEwan, Lightman & Glover, 2008).

Vagal tone may also interact with attachment systems to reinforce social support giving. In discussions between mothers and adolescents about positive and negative topics, adolescent's with high resting RSA and low attachment anxiety demonstrated the greatest empathic responsiveness, measured as accuracy of detecting their mothers' emotions and concordance of the adolescents' and mothers' emotions. Indirect evidence can also be found from a study with oxytocin. Fathers who were administered oxytocin intra-nasally, compared to a placebo, had increases in RSA during play with their 5-month olds accompanied by increased touch, positive vocalizations directed at the infant, and latency to the first initiation of social gaze (Weisman, Zaoory-Sharon, & Feldman, 2012). These findings suggest vagal activation may facilitate social behavior towards others, especially supportive and caretaking behavior.

Porges' main argument that the vagus nerve represents a physiological substrate of social behavior generates predictions about its role in the experience of compassion. Compassion is defined as feeling concern for the suffering of another person coupled with the desire to alleviate that suffering (Batson, Duncan, Ackerman, Buckley & Birch, 1981; Eisenberg & Miller, 1987; Goetz, Simon-Thomas, & Keltner, 2010). Compassion is characterized by many of the same behaviors that the vagus nerve is thought to facilitate, such as increased social communication, social engagement behaviors, especially in a negative context where others are suffering, and social support giving. Compassion increases social communication such as facial expressions, nodding, gaze sharing, and social contact through touch (Goetz, et al., 2010), which originate in brain regions that are linked to the vagus nerve. Compassion leads to temporary increases in perceptions of similarity, closeness, and a power social connection to the sufferer (Campos et al., 2009; Oveis, et al., 2010). Finally, compassion also encourages caretaking and supportive behaviors aimed at soothing another's suffering (Batson, Duncan, Ackerman, Buckley, & Birch, 1981).

In light of this conceptual analysis, I propose that compassion will be associated with activation in the vagus nerve. Such compassion-related vagus nerve activation, I reason, will enable individuals to down regulate their negative response to another's suffering and engage socially with the sufferer, resulting in caretaking or socially supportive behaviors. Unlike, empathic distress in response to suffering, which motivates individuals to distance and become more self-focused, compassion promotes approach motivations and a greater other-focus (Eisenberg et al., 1989). Empathic distress is thought to represent an inability to cope with the suffering of another and may index a lack of resources to relieve that individual's suffering (Hoffman, 1981). Empathic distress activates the sympathetic system (i.e. increases in skin conductance) and hinders the experience of compassion by promoting competing motivations to escape the stressful situation (Batson, 1991). As a result, I hypothesize that the experience of compassion in response to suffering would be associated with increases in vagal activation.

A handful of studies on vagal tone suggest a potential link between compassion and vagal reactivity or greater vagal activation. In a longitudinal study measures of vagal tone correlated with trait measures of Agreeableness, a facet of personality associated with a tendency to be compassionate and cooperative (Oveis, et al., 2009). In studies with children baseline RSA predicted dispositional levels of sympathy and self-reports of sympathy in response to a film about another child in distress (Fabes, Eisenberg & Eisenbud, 1993). Eisenberg and colleagues (1996) found that children in third through sixth grade tended to nominate boys in their class with high baseline RSA as the most prosocial, though this effect did not generalize to girls. The vagus nerve has a primarily inhibitory role on the heart (Berntson, et al. 1993). Situations where individuals are suffering or in need reliably elicit heart rate deceleration in others (Eisenberg, et al, 1993, Stellar, Manzo, Kraus, & Keltner, 2011). Eisenberg and colleagues (e.g., 1991) have documented that compassion at the subjective and expressive level covaries with heart rate deceleration. Participants induced to feel compassion show decreases in heart rate from neutral state inductions, and the magnitude of the physiological response distinguishes between those who reported more or less compassion (Stellar, et al., 2011). Although this evidence must be interpreted carefully as the heart is innervated by both the parasympathetic and sympathetic systems, heart rate deceleration during compassion is a promising indicator of increased vagal activation.

The Specificity of Vagus Nerve Activation to Compassion

In the present research I study vagus nerve activation as it relates to a distinct emotion, compassion. Past work has been fruitful in linking emotions to changes in autonomic physiology (Ekman & Levenson, 1983), though the evidence that distinct emotions are marked by specific and unique patterns of autonomic physiology is mixed (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000). Emotions are defined by specific criteria: they are rapid in onset and brief in duration, involuntary, and centered around particular appraisals (Ekman, 1992). In the following studies I structure our methodology to meet these criteria so that I can ensure vagal activation is tied to the emotional experience of compassion. I measure RSA during the presentation of emotion-eliciting stimuli, rather than during a baseline or affectively laden task, that is not designed to elicit a specific emotion (e.g. public speaking task). I also present our stimuli for short periods, from two to four minutes on average, in order to capture the rapid onset and brief duration of the typical emotional experience.

Importantly, I include stringent controls to ensure that changes in vagus nerve activation are not due to a broader dimension of emotional experience (e.g. valence) or closely related positive emotions (e.g., inspiration). Negative emotions are associated with vagal withdrawal; therefore one might expect positive emotions to be associated with vagal activation. At the tonic level, past work has demonstrated that greater resting RSA is associated with greater positive mood and dispositional optimism (Oveis, et al., 2009). However, in general research does not provide a clear picture of the effect that positive emotions have on vagal reactivity. Some studies find reductions in RSA in response to positive film clips (e.g. Frazer et al., 2004), whereas others find slight increases or no changes in RSA (e.g. Demaree, Pu, Robinson, Schmeichel, & Everhart, 2006). To more precisely characterize the relationship between vagal reactivity and positive emotion, I compare compassion to another positive emotion, pride. Pride falls within the same dimension of positive valence, but varies on its core appraisals and motivations. Compassion is characterized by appraisals of need, vulnerability, and weakness and promotes motivations to approach and care for others. Pride is a self-focused emotion, elicited when individuals feel responsible for a positive outcome; pride promotes a desire to distance oneself from weak others and feelings of dissimilarity from them (Oveis, Horberg, & Keltner, 2009). I predict that the experience of compassion, which promotes social engagement will promote greater vagal activation, whereas pride, which promotes social disengagement, will not.

To test the alternative hypothesis that vagal reactivity occurs during many prosocial emotions, and not just compassion, I compare compassion to inspiration. Although inspiration elicits warmth and tenderness, like compassion, it lacks appraisals of suffering. The vagus nerve appears to promote social engagement particularly in negative contexts, such as the suffering of others, which motivates coping to reduce negative affect, social engagement, and supportive behaviors. Comparing RSA during the experience of compassion to inspiration allows isolate suffering allows us to demonstrate the unique relationship between compassion and vagal activation and rule out the possibility that this relationship results from feelings of warmth and tenderness or inspiration. Overall, our study is the first to assess RSA during the experience of compassion and does so in manner that is in keeping with an affective approach to discrete emotions. In our studies measurement periods of RSA are brief, stimulus-tied, and properly controlled to isolate the unique effects of compassion as a discrete emotion with specific appraisals and motivations.

Present research

In Study 1 I tested whether RSA was greater in response to compassion-eliciting stimuli. I aimed, in Study 2, to eliminate the alternative explanation that increased RSA activity is associated with positive emotions more generally by comparing compassion to pride. In Study 3 I tested whether prosocial emotions were associated with greater RSA, by measuring RSA in response to compassion- and inspiration-inducing film clips. I hypothesize that appraisals of suffering are critical to greater vagal activation. As a result, I predicted that compassion would promote greater increases in RSA than inspiration. Across the first three studies I assessed the relationship between retrospective self-reports of compassion and RSA during the compassion induction. In Study 4, I examined whether vagal activity was associated with a group of compassion-related emotion words, continuous self-report measures of compassion during the compassion induction, coded perceptions of compassion, behaviors and self-reports of cognitions associated with compassion. In the following studies I also explored whether individual differences in prosocial inclinations interacted with RSA reactivity during the compassion inducing stimuli to predict self-reports of compassion.

Study 1

Study 1 aimed to demonstrate that compassion-inducing stimuli elicit greater RSA activity than a non-emotional control and that RSA activity during the compassion induction correlated with self-reports of compassion. Self-reports of compassion are likely to be influenced by social desirability concerns that could obscure the relationship between the experience of compassion and vagal activation. Therefore, I measured and controlled for individual differences in social desirability. I also explored whether vagal reactivity interacted with individual differences in prosociality to predict self-reported compassion.

Methods

Participants

Fifty-three (21 male, 32 female) undergraduates from a large west coast university participated in this study for credit in a psychology course.

Procedure

Participants arrived in the lab one at a time and were brought into an experiment room. Sensors were applied to the skin in a Lead II configuration to gather Electrocardiogram (ECG) and a belt was place on the torso to assess respiration frequency, which connected to the MP 150 data acquisition and analysis systems (Biopac systems, Inc.). Participants were given fifteen minutes fill out demographics and individual differences measures such as the Social Values Orientation, a measure of prosocial inclinations, and a Social Desirability measure. This time also allowed participants to acclimatize to wearing the physiological recording devices.

For our compassion induction participants watched a four-minute long video of a female student discussing the death of her grandfather. Participants were told the target in the video was a participant from a previous study, but in reality she was a confederate who had memorized a script created by the experimenter. The discussion focused on her grief and how she coped with the news of learning of his death. In addition to compassion, participants were asked how much they felt 14 other emotions after the compassion video (afraid/scared, angry, annoyed/irritated, anxious, contempt/disdain, enthusiastic/excited, disgusted/revolted, happy/joyful, inspired/impressed, relaxed/comfortable, sad, surprised/shocked, trust, warmth/tenderness) on a 10-point Likert scale from 1 (*not at all*) to 10 (*As much as I have ever felt*). After a few filler tasks participants then watched another four minute long video of that student recounting a nature documentary, which was also created by the experimenter and acted as the neutral comparison condition.

Physiological Measures.

Heart Rate. Electrocardiogram (ECG) recordings were sampled at 1 kHz and were gathered over the entire four minutes of the emotion induction. ECG signals were converted to beats per minute to obtain heart rate and aggregated to form mean heart rate scores for the entire four minutes and the initial minute and a half of the stimuli introduction. Artifacts in the signal (e.g. due to coughing, sneezing or movement) were corrected manually; this was done to less than 5% of all data files.

Respiration. Respiration signals were filtered directly as they were recorded with a low pass filter of 1 Hz and high pass filter of .05 Hz. A continuous measure of respiration rate was then obtained by transforming the data through the Biopac data acquisition program to breaths per minute. Respiration rate was then aggregated to form means over the four minutes and initial minute and a half of each video.

Vagal Activity. Vagal Activity was calculated using the analysis package in Biopac, which produces measures of Respiratory Sinus Arrhythmia (RSA), by scanning the ECG channel for the minimum and maximum RR intervals over during each respiration cycle. The average data was aggregated to form a mean over the four minutes and the initial minute and a half of the stimulus presentation.

Individual Difference Measures

Social Values Orientation. The Social Values Orientation Scale (SVO; Van Lange, 1999) assesses stable preferences egoism or altruism. It provides nine scenarios that ask participants to divide arbitrary points between themselves and another hypothetical person. Egoists are characterized by a preference for resource distributions that maximizes their own payoff (e.g. 540 points for the self, 280 points for the other), competitors are characterized by a preference for maximizing the relative payoff between themselves and other (e.g. 480 points for the self, 80 points for the other), and prosocials are characterized by a preference for maximizing the total payoff to themselves and others (e.g. 480 points for the self, 480 points for the other).

Social Desirability. The Marlow and Crowne Social Desirability Scale (Crowne & Marlow, 1960) is a 33-item scale where participants respond either true or false, to statements such as, *I have never deliberately said something that hurt someone's feelings* or *there have been times when I was quite jealous of the good fortune of others*. The scale assesses how willing participants are to answer these questions truthfully or whether they will lie in an effort to manage their self-presentation. As a result participants are given a total score of how susceptible they are to social desirability concerns.

Results and Discussion

To ensure that our compassion stimuli reliably elicited our target emotion I analyzed subjective reports of participants' emotions. Participants exhibited high levels of compassion in response to the student coping with the death of her grandfather (M = 7.19, SD = 1.63). Participants reported significantly more compassion than the next two most highly elicited emotions, sadness, (M = 6.23, SD = 2.34), t (52) = 4.27, p < .001, and warmth/tenderness, (M = 5.23, SD = 2.42), t(52) = 7.66, p < .001, which were the only two emotions with average self-reports greater than five.

Physiological Reactions. A repeated measures analysis revealed that participants exhibited a significant increase in RSA activity during the compassion condition (M =80.95, SD

= 35.58) compared to the neutral condition (*M* =73.35, *SD* =32.42), $F(1,52) = 4.04$, $p = .05$. Emotions are rapid in onset and brief in duration (Ekman, 1992). Therefore, I also examined the first minute and a half of RSA (the shortest acceptable duration to analyze RSA; Berntson, et al., 1993) because I anticipated participant's reactions to the compassion induction would be the strongest upon initially encountering the target's suffering. I found our effects were amplified when I examined this initial 1.5 minutes. RSA was significantly higher in the compassion condition (*M* =84.38, *SD* = 35.24), than the neutral condition (*M* =75.16, *SD* = 36.23), $F(1, 52) = 5.44$, $p = .02$. Compassion inducing stimuli elicited greater RSA activity than a neutral condition, and these effects were more pronounced in the initial stages of the stimulus presentation.

I also assessed respiration as a control (Denver & Porges, 2007; Grossman & Taylor, 2007). I found a decrease in respiration rate over the entire four minutes of the compassion video (*M* =18.30, *SD* = 4.63) compared to the neutral condition (*M* =19.06, *SD* = 3.84), $t(52) = 2.62$, $p = 01$. Controlling for respiration reduced the significance of our changes in RSA over the entire four minutes, $F(1, 51) = 1.93$, $p = .17$. However, respiration rate was not significantly different over the initial 1.5 minutes of the video presentation between the compassion (*M* =18.28, *SD* = 4.87) and neutral condition (*M* =19.07, *SD* = 3.84), $t(52) = 1.23$, *ns*. Therefore, it should not be necessary to control for respiration, but when it was entered as a covariate the differences in RSA between the two conditions in the first 1.5 minutes remained significant, $F(1, 51) = 4.10$, $p = .048$. I also explored whether the compassion induction elicited heart rate deceleration, which often accompanies compassionate responses (Stellar, et al., 2012). I did not find significant changes in heart rate in the compassion (*M* =78.72, *SD* = 8.94) condition compared to the neutral condition (*M* =78.01, *SD* = 8.56), $F(1, 52) = 2.73$, p =.11. Overall, I found a pattern of greater activation in response to compassion eliciting situations compared to a control. As I predicted, these effects were more pronounced in the first minute and a half of the video where individuals first encountered the suffering. Controlling for respiration did reduce the significance of our effects for RSA over the entire four minutes of the video, but not for RSA activation for the first minute and a half. Surprisingly, I did not find heart rate deceleration that is typical during the presentation of compassion stimuli.

I also wanted to know whether increases in RSA activity during the compassion clip would predict self-reports of the experience of compassion. I found no significant correlations between any of our self-reported emotions, including compassion, and RSA during the compassion video over the entire four minutes, controlling for respiration), nor the first 1.5 minutes, $r's \leq |.20|$, *ns*. The one exception was disgust, which was significantly negatively correlated with RSA over the four minutes of the video, $r = .-39$, $p =.004$. Controlling for participant's scores on our measure of social desirability did not improve the significance of any of these correlations, $r's \leq |.19|$, *ns*.

Interactions between physiology and individual differences. I found that vagal activity in response to the compassion-eliciting video interacted with our measure of prosociality to predict self-reported compassion, $\beta =.32$, $p = .02$ (see figure 1). Prosociality predicted compassionate responding for those high in vagal reactivity, $B = .96$, $t(48) =3.26$, $p = .002$, but not for those low in vagal reactivity, $B =-.05$, $t(48) =.02$, *ns*. As a result those with less egoistic tendencies who had high vagal reactivity responded with less compassion than with low vagal reactivity, $B = -.83$, $t(48) = 2.35$, $p = .02$.

Study 2

Although Study 1 provided initial support that compassion in response to suffering elicits greater vagal activation, Study 2 attempts to demonstrate this effect is specific to compassion and not part of a more general effect of positive emotion, by comparing compassion to pride. Compassion and pride vary on an important appraisal domain of self- versus other-focus that I believe is critical for vagal activation. Pride centers on appraisals of one's own strength and exceptionalism, which creates social distance between the self and others, whereas compassion focuses on appraisals of the vulnerability of others and creates perceptions of similarity (Oveis, et al. 2009). I use slides to elicit our target emotions to ensure our effects will generalize to other forms of emotionally-evocative stimuli. I hypothesize that compassion will elicit greater RSA activity compared to pride.

Methods

Participants

Seventy-eight (19 male, 59 female) undergraduates participated in this study for credit in a psychology course.

Procedure

Participants arrived in the lab one at a time and were brought into an experiment room. Electrocardiogram (ECG) recordings from an Ambulatory Monitoring System (VU-AMS, The Netherlands) were gathered by applying sensors to the skin in a Lead II configuration. Participants were shown sets of slides that elicited compassion and pride while connected to the physiological device. Each set of slides was 1.5 minutes in duration and the order of presentation of the compassion and pride slides were randomized. Compassion slides included photographs of individuals who were suffering, (starving children, homeless individuals, injured animals, crying babies, etc.) whereas pride slides included photographs of the student's university and of national symbols. After watching each set of slides participants reported their compassion and pride along with six other emotions (anger, awe, enthusiasm/excitement, fear, sadness, and surprise) on a Likert scale of how much they experienced the emotions ranging from 0 (*not at all*) to 10 (*As much as I have ever felt*).

Physiological Measures.

Heart Rate. Recordings were sampled at 1 kHz and were gathered over the entire 1.5 minutes of the emotion induction. Artifacts in the signal (e.g. due to coughing, sneezing or movement) were corrected manually; this was done to less than 5% of all data files.

Vagal Activity. Vagal activity was indexed by high frequency heart rate variability (HRV), which was assessed by using cardiac metric software (CMET; Allen, Chambers, & Towers, 2007). RR intervals from the ECG channel over the 1.5 minutes of each induction were passed through a high frequency spectrum range (.12-.40Hz) to isolate the activity of the vagus nerve. These values are logged and therefore fall between one and ten.

Results and Discussion

First, I aimed to establish that our emotion manipulations elicited the target emotions of interest. Participants reported significantly higher levels of compassion towards the compassion eliciting slides (*M* = 6.31, *SD* = 1.83) than the pride slides (*M* = 2.09, *SD* = 2.13), $t(76)= 13.04$, $p < .001$. In addition, the pride slides evoked significantly more pride (*M* = 5.38, *SD* = 2.52) than the compassion slides (*M* = 0.55, *SD* = 1.09), $t(76)= 11.19$, $p < .001$ (see figure 2).

Physiological Reactions. In an examination of our main variable of interest, participants showed greater high frequency HRV activity while watching the compassion-inducing slides (*M* = 6.22, *SD* = 1.05) compared to the pride inducing slides (*M* = 6.05, *SD* = 1.02), $t(77)= 2.12$, $p = .04$. In addition, participants showed decreases in heart rate while watching the compassion-inducing slides (*M* =77.72, *SD* = 10.96) compared to the pride-inducing slides (*M* =80.99, *SD* = 11.60), $t(77)= 5.65$, $p < .001$. As in Study 1, there were no significant correlations between high frequency HRV and self-reported emotions, *r's* < .12, *ns*. Overall, I find that the experience of compassion elicits greater high frequency HRV activity and decreases in heart rate compared to the experience of pride.

Study 3

Theoretical and empirical work have suggested the vagus nerve facilitates social engagement behavior during negative contexts in an effort to cope in these situations and promotes support-giving behavior. In Study 3 I attempt to identify whether these processes are a critical components to vagal activation by comparing RSA activity during the experience of compassion to another socially engaging emotion that lacks these qualities, inspiration. Comparing RSA during compassion and inspiration also allows us to control for other prosocial responses such as warmth and tenderness and inspiration that are often also elicited during the experience of compassion, allowing us to isolate the unique influence of compassion.

I also collected an additional physiological measure, skin conductance level (SCL). SCL has been shown to index emotional arousal (Cuthbert, Bradley, & Lang, 1996), stress (Dawson, Schell, & Filion, 2000), and perceptions of threat (Mathews, Richards, & Eysenck, 1989). I had two reasons for including this measure. First, SCL is a purely sympathetic measure and will allow us to monitor sympathetic system arousal during our compassion inductions. Second, including SCL allows us to distinguish whether participants are feeling empathic distress versus compassion, both of which can occur when others are witnessed suffering (Batson, Fultz & Schoenrade 1987). Eisenberg and colleagues (1991) documented that a distressing film clip of another person in danger evoked greater SCL than a sympathy film clip (Eisenberg et al., 1991). In response to others' suffering, increases in SCL while listening to stories of another child in need were associated with greater feelings of distress, measured through expressions of distress, and with less prosocial responses, such as later helpful behavior towards the child in need (Fabes, et al., 1994). Employing skin conductance as an additional measure allows us solidify our claim that compassion is associated with increased activation of the parasympathetic system and ensure that our film clip is not evoking physiological responses associated with personal distress. I predict there will be changes in RSA during the film clip, but not in SCL. I also explore how individual differences in emotional empathy interact with vagal reactivity to predict self-reported compassion.

Methods

Participants

Seventy-four (33 male, 41 female) undergraduates participated in this study for credit in a psychology course.

Procedure

Participants arrived in the lab individually and were seated in front of a computer. Electrocardiogram (ECG) sensors were applied in a Lead II configuration, a respiration belt was placed on the participant's torso to measure the rate of inhalation and exhalation, and skin conductance was measured by passing a constant voltage (0.5 V) between disposable snap electrodes that were pre-gelled with isotonic gel and placed on the palmar surface approximately an inch apart. Participants filled out demographics information on the computer as well as an individual difference measure assessing trait emotional empathy using the interpersonal reactivity index (IRI; Davis, 1983).

Participants watched three two-minute long videos, which were meant to elicit compassion versus inspiration or a non-emotional control. These videos were presented in random order. As part of the compassion induction, participants were shown a video of children and their families who attend St. Jude's hospital where their children were receiving treatment for cancer. This video primarily covered footage of the parents discussing when they learned their child had cancer, the chemotherapy sessions that the children attended, and the outcomes of the cancer treatment. This compassion induction has been validated to successfully elicit compassion (Stellar, Manzo, Kraus, and Keltner, 2011). In inspiration video, participants were shown a video of a man carrying a sign saying free hugs and giving hugs to strangers on the street set to inspirational music, which elicited high levels of inspiration in participants (see the second column of Table 1 for most highly rated emotions). The neutral condition consisted of an instructional video on how to build a fence. In addition to compassion, participants were asked to list how much they experienced the same emotions as Study 1 from 1 (*not at all*) to 10 (*As much as I have ever felt*) after each video.

Individual Difference Measures.

The Interpersonal Reactivity Index. The Interpersonal Reactivity Index (IRI) is a 28-item questionnaire, which is broken into four subscales, two of which assess emotional responses to suffering—empathic concern, which is often equated to compassion or personal distress, which represents how stressed or upset they become at witnessing the suffering of others. I focused on the empathic concern, or compassion subscale which asks participants their agreement on a 5-point Likert scale ranging from *Does not describe me well* to *Describes me very well* to statements like *when I see someone being taken advantage of, I feel kind of protective towards them* and *I would describe myself as a pretty soft-hearted person.*

Physiological Measures.

Heart rate, respiration and RSA measures were gathered and cleaned for artifacts using the same methods as Study 1. In this study measures were gathered over the entire length of the emotion induction. In addition, continuous measures of unfiltered SCL signals were averaged over the entire two minutes of each video.

Results and Discussion

Subjective Emotion. There were significant differences in self-reports of compassion in response to the different conditions, $F(2,142) = 225.10$, $p < .001$, such that participants showed higher reports of compassion during the compassion condition ($M = 7.04$, $SD = 2.04$) compared to the neutral condition ($M = 1.35$, $SD = 1.33$), $F(1,71) = 469.22$, $p < .001$, and the inspiration condition, ($M = 4.90$, $SD = 2.51$), $F(1, 72) = 65.11$, $p < .001$. However, other prosocial emotions such as warmth/tenderness, inspiration, and trust, which provided potential explanatory power for vagal activation were more strongly elicited in the inspiration condition (see Table 1).

Physiological Reactions. A repeated measures analysis revealed significant differences in RSA activity in response to the compassion ($M = 83.99$, $SD = 31.61$), neutral ($M = 79.17$, $SD = 29.63$), and inspiration conditions ($M = 74.09$, $SD = 27.16$), $F(2,138) = 8.27$, $p < .001$. Participants showed greater RSA in the compassion condition compared to the neutral, $F(1,71) = 5.44$, $p = .02$, and inspiration conditions, $F(1,70) = 18.72$, $p < .001$. There were no significant differences in respiration between the compassion ($M = 18.21$, $SD = 3.45$), neutral ($M = 19.06$, $SD = 5.03$) and inspiration conditions ($M = 19.24$, $SD = 3.46$), $F(2,130) = 1.46$, ns, therefore I do not correct for respiration in our analyses. There were also differences in heart rate across the three conditions, $F(2, 138) = 24.05$, $p < .001$. In the compassion condition ($M = 73.42$, $SD = 9.41$) participants showed significantly slower heart rate compared to the neutral condition ($M = 75.71$, $SD = 9.85$), $F(1,71) = 41.73$, $p < .001$, and inspiration condition ($M = 74.83$, $SD = 9.43$), $F(1,70) = 20.67$, $p < .001$. Participants showed greater RSA, and lower HR in the compassion condition compared to the neutral or inspiration condition, but not differences in SCL or respiration. These analyses suggest that the compassion may be associated with greater RSA because it elicits social engagement in a negative context and motivates care-taking and socially supportive behaviors, unlike the inspiration clip.

RSA activity during the compassion video, controlling for resting RSA, did not significantly correlate with participants' self reports of any emotions, *r's* $\leq |.23|$, *ns*, including compassion. SCL during the compassion video, controlling for SCL during the neutral video, negatively correlated with self-reports of feeling disgust, $r = -.34$, $p = .004$, anger, $r = -.30$, $p = .01$, and annoyed $r = -.32$, $p = .006$, but not with any other emotions, *r's* $\leq |.23|$, *ns*. Adding SCL as a control variable in our analyses did not increase the strength of our correlations between RSA during the compassion video and self-reports of emotions.

Interactions between physiology and individual differences. Vagal reactivity in response to suffering interacted with individual differences in emotional empathy to predict self-reported compassion, $\beta = .23$, $p = .03$ (see figure 2). Individuals who showed high levels of vagal activity in response to suffering and scored high on emotional empathy reported marginally greater compassion compared to individuals with low vagal reactivity who were high on emotional empathy, $B = .78$, $t(66) = 1.78$, $p = .079$. In addition, among both groups emotional empathy predicted greater self-reported compassion, although it was more predictive for those who exhibited higher vagal reactivity to suffering $B = 1.59$, $t(66) = 4.77$, $p < .001$, than those with low vagal reactivity, $B = .59$, $t(66) = 1.96$, $p = .05$. These findings suggest that strong vagal activation in conjunction with prosocial inclinations promotes greater self-reports of compassion.

SCL did not interact with the IRI to predict self-reports of compassion, β =.23, *ns*, nor was SCL during the compassion video predicted by the interaction of RSA and IRI, β =.05, *ns*.

Study 4

Three studies have demonstrated that compassion-inducing stimuli are associated with greater RSA activity. However, the previous studies have been unable to demonstrate a robust relationship between RSA activity and participant's self-reports of compassion. Therefore, Study 4 attempts to demonstrate this link by using multiple methods to assess compassion as well as compassion-related cognitions and behavioral intentions. A lack of coherence between retrospective self-reports of subjective emotion and peripheral physiological response is common (Bonanno & Keltner, 2004; see Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005 for a review). Emotion reports collected after a stimulus presentation may not provide a fully accurate representation of the experience of an emotion. Fredrickson and Kahneman (1993) argue that retrospective reports of emotional situations suffer from biases such as duration neglect and are often derived from averaging the peak and end emotional intensity of the experience. These biases may be particularly problematic when attempting to establish a relationship to contemporaneous physiological responses. Therefore, in light of these concerns, in Study 4 I included other measures to avoid the biases inherent in retrospective emotion reporting. First, in addition to having participants report their levels of compassion after watching the video, I also included other compassion-related words drawn from Batson and colleagues (1995) empirical work measuring a similar construct—empathic concern. This composite aims to capture the broader construct of compassion and avoid the pitfalls of a single-item measure. Second, I collected online continuous measures of participant's compassion, relying on a technique pioneered by Levenson and Gottman (1983) where participants review an emotional stimulus while continuously rating their emotions. This method countervails biases in retrospective emotion reporting because emotional experience is assessed online. Third, trained coders rated their perceptions of participant's compassion while participants watched the compassion-inducing video and discussed it. Measures of observed compassion remove the social-desirability biases common in self-reports. Fourth, I gathered behavioral measures that assess more implicit levels of social engagement and prosocial behavior. These measures may be more strongly linked to physiological changes because the implicit measures are less controlled processes, and therefore less susceptible to social desirability concerns and impression management. Sixth, I measured cognitions that have been theorized (Goetz, et al., 2010) to be important for the experience of compassion in order to investigate whether changes in physiology may be more directly linked to these mechanisms than to compassion directly. Overall, these additional measures reduce the influence of traditional biases associated with socially desirable, retrospective single-item measures.

Participants

Ninety-four participants (26 male, 68 female) undergraduates participated in this study for credit in a psychology course. Five participants were produced physiology files with too many errors to use and were removed from all analyses leaving a total sample of 89 participants

Procedure

Participants arrived in the lab individually and were seated at a computer station in front of a mounted video camera. They were connected to the MP 150 data acquisition and analysis systems (Biopac systems, Inc.) through sensors applied to their skin in the same configuration as Study 3. Participants filled out demographics information on the computer as well as an individual difference measure assessing trait compassion using the Dispositional Positive Emotion Scale (Shiota, Keltner & John, 2006) and the Interpersonal Reactivity Index (Davis, 1983) as well as their altruistic orientation using the NEO Personality Inventory (Costa & McCrae, 1985) and Social Values Orientation (Van Lange, 1999).

Participants first watched a neutral film clip followed immediately by a compassion-inducing clip. These clips were the same as those used in Study 3. After the compassion-inducing video participants reported how much they felt the target emotion of compassion in addition to three other compassion-related states, including *moved, warmth/tenderness*, and *softhearted* from 1 (*not at all*) to 10 (*As much as I have ever felt*). These emotions were embedded within ten other emotions including *afraid, annoyed, angry, anxious, awe, contempt, disgust, inspired*, *sad*, and *wonder*. Afterward participants responded to a variety of statements that assessed participants' thoughts and views of the sufferer (see measures for statements).

The experimenter asked participants to summarize the video clip and discuss their reaction to it out loud, while the experimenter waited outside. Participants were given as much time as they wished to complete this activity. Participants were then given the opportunity to type any comments to the children at St. Jude's Hospital in an open ended response. They were told the comments would be collected at the end of the study and sent to the children. They were able to write as much as they wanted before moving on to the next activity.

The experimenter told participants they would be watching the same compassion-inducing video a second time, but that they would continuously report how much compassion they felt during their original viewing using a hand held sliding scale. Participants were asked to re-watch the video while making ratings of their compassion. I did not ask participants to make these rating the first time they watched the video because I wanted to avoid participant moving during collection of physiological data during the first video viewing, which creates artifacts in the physiological signals. In addition, making continuous ratings of compassion may have interfered with participant's spontaneous response to the emotional stimulus in the first viewing. Participants used a sliding scale device (TSD115 Variable Assessment Transducer by Biopac Systems), which provides continuous subjective responses to stimuli. The labels on the device were modified to range from that ranged from 1 (*I do not feel compassion at all*) to 10 (*I feel compassion very strongly*). Once participants reported they were comfortable using the scale without looking at it they placed it in their lap and watched the video, moving the scale in accordance with their levels of compassion. After re-watching this video participants were told they were done with the study, but were asked by the electronic survey if they would like to be redirected to the St. Jude's hospital webpage to learn more about the organization or see ways to help. Once they were done they called the experimenter back into the room and they were debriefed and released.

Individual Difference and Survey Measures.

Compassion. The Dispositional Positive Emotion Scale (DPES) is a validated self-report measure of the trait-like tendency to feel several distinct positive emotions including joy, contentment, pride, love, compassion, amusement, and awe (Shiota, Keltner & John, 2006; Stellar, et al. 2012). The compassion portion of this scale asks for individuals' agreement with five items ranging from *1* (strongly disagree) to *7* (strongly agree). Example statements include: I *am a very compassionate person* and *When I see someone hurt or in need, I feel a powerful urge to take care of them*. Participants also completed the empathic concern subscale of the Interpersonal Reactivity Index, which is described in Study 3.

Altruism. The NEO Personality Inventory (Costa & McCrae, 1985) assesses 5 facets of personality. The altruism subscale of the NEO is part of the larger Agreeableness facet of personality and gauges an individual's concern for the welfare of others. Participants are asked their agreement from 1 (*Strongly Disagree*) to 5 (*Strongly Agree*) to five statements such as *I love to help others* and *I am concerned about others*. Participants also completed the Social Values Orientation scale, which is described in Study 1.

Statements in response to film clip. Participants were asked their level of agreement from 1 (*Strongly Disagree*) to 7 (*Strongly Agree*) to 13 statements that aimed to assess the underlying mechanisms that explain why participants reported more or less compassion. These statements targeted particular cognitions that may reduce compassionate responding based of the theoretical work by Goetz and colleagues (2010). Statements targeted cognitions such that are associated with apathy: *I don't have the energy to get invested in the topic of this video* and *I see all kinds of suffering around me and it is hard to care about everything,* ($\alpha = .68$), feelings of helplessness: *There is nothing we can do to solve the problem of cancer, There is nothing I can do to help these children*, and *I felt helpless while watching this video (*$\alpha = .55$), a sense of being overwhelmed by one's emotions: *This video was too intense for me, I feel as if this was happening to me as I watched the video*, and *I was able to cope with my emotions while watching this video* (R; $\alpha = .71$), and a lack of ability to perspective-take (*It is hard to imagine how these children are feeling*). Other statements assessed mechanisms that may explain greater levels of compassion such as perceptions of similarity (*I feel as if I share many of the values and interests as these children*), deservingness (*These children deserve my help*), responsibility (*The children in this video were not responsible for what was happening to them*), and vulnerability (*The children in this video are vulnerable*).

Physiological Measures.

Heart rate, respiration, skin conductance and RSA were gathered in the same manner as Study 3. Continuous recordings of these measures were averaged over the entire length of the neutral and compassion film clips.

Coded Measures.

Two independent coders watched videos of the participants watching the compassion clip. The camera was oriented so that the videos of participants displayed their torso and head. Raters were instructed to answer two questions, *How much do you think this person felt compassion/sympathy?* and *How much do you think this person felt anxiety/distress?*, on 4-point Likert scales, *0* (Not at all), *1* (A little), *2* (Moderately), or *3* (Very Strongly). Coders were trained to look for facial and body expressions associated with compassion such as furrowing in the center of the brow, eyebrows pulled down flat and forward, lower face relaxed with the mouth sometimes opened or frowning, head and body oriented forward and vocalizations typically associated with sympathy (Eisenberg, et al., 1989). These expressions were in contrast to those of distress, which may manifest in the tightening of one's lips or biting of the lip and eyebrows that were lowered and pulled forward. Coders had a high reliably in their perceptions of participant's levels of compassion ($\alpha > .85$) and distress ($\alpha > .82$). After completing ratings for all participants, coders went back through all the videos and rated the participant's compassion ($\alpha = .85$) and anxiety ($\alpha = .66$) again, while the participants discussed the film.

Results and Discussion

As in Study 3, participants reported high levels of compassion in response to the compassion-inducing film clip (M =7.37, SD = 1.59). The compassion related states of warmth/tenderness (M = 6.26, SD = 2.13), moved (M = 6.66, SD = 2.27), and softhearted (M = 6.38, SD = 2.35) were also elicited at high levels. These four emotions showed a strong reliability (α= .87) and were aggregated into a compassion composite (M = 6.66, SD = 1.78) for future analyses.

Physiological Reactions. One participant was removed from the analyses of RSA because they had an RSA value during the compassion clip that was more than three standard deviations from the mean and two participants were removed from the heart rate analyses for this reason. A repeated measures analysis revealed significantly higher RSA activity in response to the compassion video (M =94.97, SD = 48.17) compared to the neutral video (M =88.33, SD =43.48), $F(1, 87) = 6.16$, $p = .015$. There were significant differences in respiration between conditions, $F(1,87) = 4.90$, p =.029, with slower respiration in response to compassion video (M =16.62, SD = 3.37) compared to the neutral video (M =17.11, SD = 3.28). Differences in vagal activation remained marginally significant when controlling for changes in respiration, $F(1,86) = 3.11$, p =.081. There were also differences in heart rate across the conditions, $F(1, 86) = 12.61$, $p = .001$. In the compassion condition (M =74.69, SD = 12.06) participants showed decreases in heart rate compared to the neutral condition (M =75.80, SD =12.45). There were no significant changes in SCL between the neutral (M =9.64, SD =5.93) and compassion conditions (M =9.94, SD = 6.05), $F(1, 88)= 1.55$, *ns*. Overall results suggest the compassion video was associated with increased RSA and reduced HR and respiration, but not changes in SCL.

The following analyses examine the relationship between RSA activation during the compassion clip and a variety of self-report, observed, cognitive, and behavioral measures. In all analyses when reporting these associations I always control for RSA activation during the neutral condition and changes in respiration.

Retrospective self-report measures. Like our past studies, RSA did not correlate significantly with participants' self reports of their compassion, $r = .03$, *ns*, but RSA was marginally significantly correlated with our compassion composite of emotions, $r = 0.18$, p =.09. SCL during the compassion video did not correlate with any self reports of emotions $|r\text{'s}| \leq .13$, *ns*, controlling for SCL during the neutral video. Adding SCL as a control variable in our analyses did not increase the strength of our correlations between RSA during the compassion video and self-reports of emotions.

Continuous measures of compassion. Data from participants' continuous rating of compassion was aggregated over the entire film clip to create a mean continuous compassion rating (M =6.37, SD = 1.56). There was a sizeable, though not extremely large, correlation between this continuous measure of compassion and the retrospective reports of at the end of the clip, *r* =.53, p < .001. RSA during the compassion clip was significantly correlated with participants mean continuous compassion rating, *r* =.23, *p* = .041. These results suggest that RSA is a predictor of the compassion as individuals are experiencing the emotion in the moment.

Coded measures of Compassion. Participants were given compassion and stress ratings by coders while they watched and they discussed the video. RSA during the compassion film clip were marginally correlated with coder ratings of compassion during the video, *r* = .18, *p* = .11, and significantly correlated with perceptions of compassion while discussing it, *r* =.14=.22, *p* = .055. Overall rated levels of compassion were calculated by averaging coders' ratings of participants' compassion during the video and while discussing it. These ratings were significantly correlated with RSA activity during the compassion induction, *r* =.23, *p* =. 038. RSA and rated stress were not correlated during the video, *r* =.14, *ns*, while participants discussed the video, *r* =.09, *ns*, nor a composite of the two, *r* =.13, *ns*. These results suggest that RSA during the compassion video is associated participant's perceived levels of compassion by others, but not stress.

Behavioral Measures. I gathered prosocial behavioral measures that gauge the participant's level of social engagement with and responsiveness to the sufferer. The number of seconds that participants discussed the compassion clip and their reaction to it (*M* = 68.73, *SD* =30.84) was skewed to the right. Given this skewed distribution, a natural logarithmic transformation was applied to normalize the data. RSA during the compassion clip did not predict the amount of time participants chose to talk, *r* = -.05, *ns*. When given an option to write to the children, the thirty-five participants chose to write nothing at all, receiving a word count of zero, (*M* = 18.57, *SD* = 21.92). Therefore, in order to normalize the distribution I performed a natural logarithmic transformation of the number of words after adding 0.5, an appropriate practice when data contain a moderate proportion of zeros and the distribution is skewed (Fox, 2008). RSA during the compassion clip did not predict the number of words participants wrote to the children of St. Jude's, *r* = .08, *ns*. These results suggest that RSA during the compassion clip was not associated with more implicit measures of engagement and connection to the victims. Thirty-one participants chose to visit the St. Jude's website at the end of the study. In a binary logistic regression, RSA during the film clip was not a significant predictor of whether participants chose to visit the St. Jude's website, *B*= -.01, *SE* = 01, *ns*.

Cognitions. RSA during the compassion film clip was marginally positively correlated with feeling emotionally overwhelmed and marginally positively correlated with perceptions that children were not responsible for their suffering as well as feeling similar to the children in the video (see Table 2 for specific correlations). These data do not support the claim that RSA during the compassion clip was more strongly associated with particular cognitions that promote compassion, rather than the experience of the emotion itself.

Interactions between physiology and individual differences. In a regression RSA during the compassion clip did not interact with individual differences in empathic concern (IRI), β =.04, *ns*, or dispositional compassion (DPES), β =-.15, *ns*, to predict self-reported compassion. Similarly, there was no significant interaction between RSA during the compassion condition and altruism as measured by the SVO, β =-.01, *ns*, or the NEO, β =.03, *ns.* SCL did not interact with any of these individual differences to predict self-reports of compassion, $|\beta$'s$| \leq .23$, nor was there any a pattern of significant interactions between RSA during the compassion condition and these four individual difference measures in predicting SCL, $|\beta$'s$| \leq .11$.[1]

Overall, RSA during the compassion clip was significantly associated with compassion using continuous online ratings, observed compassion, and marginally with a composite of compassion-related terms. These results suggest that stronger relationships between physiological and emotion can be obtained by using methods that minimize retrospective biases and social desirability concerns.

General Discussion

Our findings support the theoretical claims of the Polyvagal Theory that the vagus nerve may be a physiological system underlying social engagement behaviors. I demonstrate that the vagus nerve is associated with an emotion at the core of social engagement, compassion. Across four studies I find that compassion-inducing stimuli were associated with greater RSA activity. I ruled out a crucial alternative explanation that the vagus nerve is associated with positive emotions more generally by demonstrating greater increases in RSA activity during the experience of compassion, a socially engaging emotion, than pride, a socially distancing emotion. I also find greater RSA activity during compassion compared to another prosocial emotion, inspiration. These results suggest that the presence of suffering, which may initiate social engagement strategies and promote socially supportive behavior, is likely an active ingredient of compassion associated with increases in RSA. Increased RSA in response to suffering was also accompanied by HR deceleration and slower respiration rate in the majority of our studies, but not by changes in SCL. In Study 4 increases in RSA during the compassion clip were associated with higher self-reports of compassion when ratings are made online rather than retrospectively and greater perceptions of compassion by observers.

Our work reveals that the emotional suffering of others leads to greater parasympathetic activation (increases in RSA and decreases in HR and respiration), which is traditionally viewed as a characteristic of resting states or calming of the body. Past psychological work has suggested that the autonomic system is organized around responses to threats in the environment (Cacioppo, 1994). This psychological dimension has dominated the discourse on autonomic physiology, with a majority of studies assessing sympathetically mediated responses to stressors in the environment (Blascovich, Mendes, Hunter, & Salomon, 1999; Lazarus, Speisman, & Mordkoff, 1963; Obrist, 2007). Our work supports the theoretical accounts of Porges that an outward focus and engagement with others may be another critical organizing principle of autonomic physiology. These two dimensions, protecting the self and engaging with others are not necessarily mutually exclusive, but appear to activate different branches of the autonomic nervous system.

Increases in parasympathetic activation in response to suffering may be surprising because one might predict an individual would exhibit a stress response to the inherently negative situation of suffering. Indeed, recent work by Hein and colleagues (2011) has demonstrated changes in the sympathetic system measured by SCL increases, in response to witnessing others receive painful shocks predicted downstream prosocial behavior. However, differences in the types of suffering may be responsible for these different physiological responses. In the literature on empathy suffering often depicts others in physical pain, such as receiving shocks or stabbing a needle through a person's palm (Hein, et al., 2011; Singer, et al., 2004). Physical harm to another person may lead to a strong experience of vicarious distress, which would likely elicit a sympathetic-based stress response. Our work, on the other hand, focuses on emotional pain such as the loss of a loved one or coping with cancer, which I believe promotes compassion and accompanying RSA activation. Responses to emotional suffering may lead to a calming of the body that encourages approach, care, and the provision of social support for the sufferer. Future work should examine the effects of different types of suffering on observer's emotional and physiological responses.

Part of the parasympathetic response to the suffering of others may be due to changes in respiration. In conjunction with increases in vagal activation I found slower respiration during the compassion condition than comparison conditions in most studies. It may be that these changes in respiration are a meaningful component of the physiological experience of compassion and the vagal response more broadly. Research demonstrates a robust relationship between emotions and changes in respiration (for review see Boiten, Frijda, & Wientjes, 1994). Although respiration has never been examined for compassion, a similar emotion, sadness, has been associated with decreases in respiration rate (Averill, 1969; Rehwoldt, 1911) and greater respiration depth (Santibañez & Bloch, 1986). These decreases in respiration for sadness are in contrast to other negative emotions such as fear, distress, or anger, which increase respiration rate (Ax, 1953; Schacter, 1957). While our effects appear to be somewhat distinct from respiration it may be that deep breathing is a form of self-soothing that is part of the experience of compassion.

Increases in parasympathetic activation during compassion also have potential health benefits for those who experience of this emotion. The vagus nerve suppresses the HPA axis, a neuroendocrine circuit that activates the stress response (Bueno, et al., 1989). In addition, the vagus nerve helps control the immune response by regulating the expression of pro-inflammatory cytokines, which are released in response to emotional stressors and cause health problems when chronically elevated (Borvikova, et al. 2000). People with lower baseline vagal activity are more likely to suffer from diabetes, obesity, hypertension, and cardiovascular disease (Fukudo et al., 1992; Thayer & Lane, 2007), respiratory problems (Casale, 1987), and show slower recovery from medical procedures (Donchin, Constantini, Szold, Byrne, & Porges, 1992). The experience of compassion in response to suffering, especially in contrast to distress, may provide temporary boosts in vagal activity that compound over time to provide health benefits. Future work should examine whether there are vagally mediated long-term health outcomes to compassion.

Our work also has important implications for the measurement of emotions when collecting autonomic physiology. Across our four studies I were unable to find a robust correlation between compassion as a single item retrospective self-report and RSA activity during the compassion condition. These findings suggest that continuous recordings of emotional responding provide a potentially useful solution when examining relationships to physiology. In addition, our studies reveal that measuring physiological responses appears to be a fruitful method for capturing the experience of compassion compared to self-reports. Compassion is subject to socially desirability and impression management concerns. To make matters more complicated, these concerns differentially affect self-reports for men and women. Compassion is considered a more acceptable emotion for women than men (Plant, Hyde, Keltner, & Devine, 2000). In a review of the research on gender differences in empathy and sympathy Lennon and Eisenberg (1987) argue these differences are more a function of the method of measurement than a reflection of true internal states, noting much smaller gender effects in situations with less overt demand characteristics. The failure to reliably identify gender differences in empathy also extends to compassion's behavioral outcomes, prosocial behavior (for a review see Eagly & Crowley, 1986). Our past work supports this claim, finding that women typically report higher levels of compassion than men, despite having similar physiological responses. I attempted to measure self-reports of emotions anonymously and recorded participants' reactions to the video in a minimally invasive a manner, but measures that reduce social desirability concerns and minimize retrospective biases are critical when measuring physiological changes.

Conclusion

Compassion is considered a virtuous emotion at the core of moral systems and fundamental to prosociality. Although research has begun to better understand its subjective experience, little is known about how it physiological correlates. As psychological research attempts to understand the biological processes that underlie more complex emotions like compassion, researchers are challenged to discover and utilize new measures that provide greater insight into the body's inner workings. I argue that the vagus nerve becomes engaged during compassion, facilitating social engagement with others in need.

References

Allen, J. J. B. (2002). Calculating metrics of cardiac chronotropy: a pragmatic overview. *Psychophysiology*, *39*, 18.

Allen, J. J. B., Chambers, A. S., & Towers, D. N. (2007). The many metrics of cardiac chronotropy: A pragmatic primer and brief comparison of metrics. *Biological Psychology*, *74,* 243-262.

Averill, J.R. (1969) Autonomic response patterns during sadness and mirth. Psychophysiology, 5: 399-414.

Ax, A.F. (1953). The physiological differentiation between fear and anger in humans. *Psychosomatic Medicine*, *15*, 433-442.

Batson, C. D., Duncan, B. D., Ackerman, P., Buckley, T., & Birch, K. (1981). Is empathic emotion a source of altruistic motivation? *Journal of personality and Social Psychology*, *40*(2), 290.

Batson, C. D., Fultz, J., & Schoenrade, P. A. (1987). Distress and empathy: Two qualitatively distinct vicarious emotions with different motivational consequences. *Journal of Personality, 55,* 19-39.

Batson, C. D., Klein, T. R., Highberger, L., & Shaw, L. L. (1995). Immorality from empathy-induced altruism: When compassion and justice conflict. *Journal of personality and social psychology*, *68*(6), 1042.

Batson, C. D., Sager, K., Garst, E., & Kang, M. (1997). Is empathy-induced helping due to self–other merging? *Journal of Personality and Social Psychology, 73,* 495–509.

Batson, C. D., & Shaw, L. L. (1991). Evidence for altruism: Toward a pluralism of prosocial motives. *Psychological Inquiry, 2,* 107–122. doi:10.1207/s15327965pli0202_1

Bazhenova, O. V., Plonskaia, O., & Porges, S. W. (2001). Vagal reactivity and affective adjustment in infants during interaction challenges. *Child Development*, *72*(5), 1314-1326.

Beauchaine, T. P. (2001). Vagal tone, development, and Gray's motivational theory: Toward an integrated model of autonomic nervous system functioning in psychopathology. *Development and Psychopathology. Vol 13(2)*, 183-214.

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1993). Respiratory sinus arrhythmia: Autonomic origins, physiological mechanisms, and psychophysiological implications. *Psychophysiology*, *30*, 183–183.

Blascovich, J., Mendes, W. B., Hunter, S. B., & Salomon, K. (1999). Social" facilitation" as challenge and threat. *Journal of personality and social psychology*, *77*(1), 68.

Boiten, F. A., Frijda, N. H., & Wientjes, C. J. (1994). Emotions and respiratory patterns: review and critical analysis. *International Journal of Psychophysiology*, *17*(2), 103-128.

Bonanno, G., & Keltner, D. (2004). The coherence of emotion systems: Comparing “on-line” measures of appraisal and facial expressions, and self-report. *Cognition & Emotion*, *18(3),* 431–444.

Borovikova, L. V., Ivanova, S., Zhang, M., Yang, H., Botchkina, G. I., Watkins, L. R., ... & Tracey, K. J. (2000). Vagus nerve stimulation attenuates the systemic inflammatory response to endotoxin. *Nature*, *405*(6785), 458-462.

Butler, E. A., Wilhelm, F. H., & Gross, J. J. (2006). Respiratory sinus arrhythmia, emotion, and emotion regulation during social interaction. *Psychophysiology. Vol 43(6)*, *2006*, 612-622.

Caccioppo, J.T. (1994). Social Neuroscience: Autonomic, neuroendocrine, and immune responses to stress. *Psychophysiology*, *31*(2), 113-128.
Cacioppo, J. T., Berntson, G. G., Larsen, J. T., Poehlmann, K. M., & Ito, T. A. (2000). The psychophysiology of emotion. *Handbook of emotions*, *2*, 173-191.
Cacioppo, J. T., & Sandman, C. A. (1978). Physiological differentiation of sensory and cognitive tasks as a function of warning, processing demands, and reported unpleasantness. *Biological Psychology*, *6*(3), 181-192.
Campos, B., Shiota, M. N., Keltner, D., Gonzaga, G., Goetz, J. L., & Shin, M. (2009). *Amusement, awe, contentment, happiness, love, pride, and sympathy: An empirical exploration of positive emotions in language, internal experience, and facial expression.* Unpublished manuscript.
Cannon, W. B. (1927). The James-Lange theory of emotions: A critical examination and an alternative theory. *The American Journal of Psychology*, *39*(1/4), 106-124.
Carter, C., Williams, J. R., Witt, D. M., & Insel, T. R. (1992). Oxytocin and Social Bonding. *Annals of the New York Academy of Sciences*, *652*(1), 204-211.
Cialdini, R. B., Brown, S. L., Lewis, B. P., Luce, C., & Neuberg, S. L. (1997). Reinterpreting the empathy–altruism relationship: When one into one equals oneness. *Journal of personality and social psychology*, *73*(3), 481.
Costa, P. T., Jr., & McCrae, R. R. (1985). The NEO personality inventory manual. Odessa, FL: Psychological Assessment Resources.
Crowne, D. P., & Marlowe, D. (1960). A new scale of social desirability independent of psychopathology. *Journal of Consulting Psychology*, *24*(*4*) 349-354.
Cuthbert, B. N., Bradleym, M. M., & Lang, P. J. (1996). Probing picture perception: Activation and emotion. Psychophysiology, 33(2), 103-111.
Davis, M. H. (1983). Measuring individual differences in empathy: Evidence for a multidimensional approach. *Journal of Personality and Social Psychology; Journal of Personality and Social Psychology*, *44*(1), 113.
Dawson, M. E., Schell, A. M., & Filion, D. L. (2000). The electrodermal system. *Handbook of psychophysiology*, *2*, 200-223.
Demaree, H. A., Pu, J., Robinson, J. L., Schmeichel, B. J., & Everhart, D. E. (2006). Predicting facial valence to negative stimuli from resting RSA: Not a function of active emotion
Denver, J. W., Reed, S. F., & Porges, S. W. (2007). Methodological issues in the quantification of respiratory sinus arrhythmia. *Biological Psychology*, *74*(2), 286-294.
Ditto, B., Eclache, M., & Goldman, N. (2006). Short-term autonomic and cardiovascular effects of mindfulness body scan meditation. *Annals of Behavioral Medicine*, *32*(3), 227-234.
Donchin, Y., Constantini, S., Szold, A., Byrne, E. A., & Porges, S. W. (1992). Cardiac vagal tone predicts outcome in neurosurgical patients. *Critical care medicine*, *20*(7), 942-949.
Eagly, A. H., & Crowley, M. (1986). Gender and helping behavior: A meta-analytic review of the social psychological literature. *Psychological Bulletin*, *100*(3), 283.
Eisenberg, N., Fabes, R. A., Bustamante, D., Mathy, R. M., Miller, P. A., & Lindholm, E. (1988). Differentiation of vicariously induced emotional reactions in children. *Developmental Psychology, 24,* 237-246.
Eisenberg, N., Fabes, R. A., Miller, P. A., Fultz, J., Shell, R., Mathy, R. M., & Reno, R. R. (1989). Relation of sympathy and personal distress to pro-social behavior: A multimethod study. *Journal of Personality and Social Psychology, 57*, 55-66. doi: 10.1037/0022-

3514.57.1.55
Eisenberg, N., Fabes, R. A., Karbon, M., Murphy, B. C., & et al. (1996). The relations of children's dispositional prosocial behavior to emotionality, regulation, and social functioning. *Child Development. Vol 67(3)*, (1996), 974-992
Eisenberg, N., Fabes, R. A., Murphy, B., Maszk, P., Smith, M., & Karbon, M. (1995). The role of emotionality and regulation in children's social functioning: A longitudinal study. *Child development*, *66*(5), 1360-1384.
Eisenberg, N., Fabes, R. A., Schaller, M., Miller, P., Carlo, G., Poulin, R., Shea, C., et al. (1991). Personality and Socialization Correlates of Vicarious Emotional Responding. *Journal of Personality and Social Psychology, 61(3),* 459-470.
Eisenberg, N., & Miller, P. A. (1987). The relation of empathy to prosocial and related behaviors. *Psychological Bulletin, 101,* 91-119.
Ekman, P. (1992). Are there basic emotions? *Psychological Review*. *99*, 550-553.
Ekman, P., Levenson, R. W., & Friesen, W. V. (1983). Autonomic nervous system activity distinguishes among emotions. *Science*.
Fabes, R. A., Eisenberg, N., & Eisenbud, L. (1993). Behavioral and physiological correlates of children's reactions to others in distress. *Developmental Psychology*, *29*(4), 655.
Fabes, R. A., Eisenberg, N., Karbon, M., Bernzweig, J., Lee Speer, A., & Carlo, G. (1994). Socialization of children's vicarious emotional responding and prosocial behavior: Relations with mothers' perceptions of children's emotional reactivity. Developmental Psychology, 30(1), 44.
Fisher, A. J., & Newman, M. G. (2013). Heart rate and autonomic response to stress after experimental induction of worry versus relaxation in healthy, high-worry, and generalized anxiety disorder individuals. Biological Psychology, 93(1), 65–74. doi:10.1016/j.biopsycho.2013.01.012
Fox, J. (2008). Applied regression analysis and generalized linear models. Los Angeles, CA: Sage.
Frazier, T. W., Strauss, M. E., & Steinhauer, S. R. (2004). Respiratory sinus arrhythmia as an index of emotional response in young adults. *Psychophysiology. Vol 41(1)*, (2004), 75-83.
Fredrickson, B. L., & Kahneman, D. (1993). Duration neglect in retrospective evaluations of affective episodes. *Journal of personality and social psychology*, *65*(1), 45.
Galinsky, A. D., Maddux, W. W., Gilin, D., & White, J. B. (2008). Why It Pays to Get Inside the Head of Your Opponent The Differential Effects of Perspective Taking and Empathy in Negotiations. *Psychological Science*, *19*(4), 378-384.
Goetz, J. L., Keltner, D., & Simon-Thomas, E. (2010). Compassion: An evolutionary analysis and empirical review. *Psychological Bulletin*, *136*(3), 351-374. doi: 10.1037/a0018807
Graham, J., & Haidt, J. (2011). Sacred values and evil adversaries: A moral foundations approach. *The Social Psychology of Morality: Exploring the Causes of Good and Evil. New York: APA Books*. Hrdy, S. H. (1999). *Mother Nature: A history of mothers, infants, and natural selection*. New York: Pantheon.
Grossman, P., Stemmler, G., & Meinhardt, E. (2007). Paced respiratory sinus arrhythmia as an index of cardiac parasympathetic tone during varying behavioral tasks. *Psychophysiology*, *27*(4), 404-416.

Grossman, P., & Taylor, E. W. (2007). Toward understanding respiratory sinus arrhythmia: Relations to cardiac vagal tone, evolution and biobehavioral functions. *Biological Psychology. Vol 74(2)*, 263-285.

Gruber, J., & Johnson, S. L. (2009). Positive Emotional Traits and Ambitious Goals among People at Risk for Mania: The Need for Specificity. *International Journal of Cognitive Therapy, 2(*2*)*, 176-187.

Haidt, J., & Joseph, C. (2004). Intuitive ethics: How innately prepared intuitions generate culturally variable virtues. *Daedalus*, *133*(4), 55-66.

Hein, G., Lamm, C., Brodbeck, C., & Singer, T. (2011). Skin conductance response to the pain of others predicts later costly helping. *PloS one*, *6*(8), 22759.

Hilz, M. J., Stemper, B., Sauer, P., Haertl, U., Singer, W., & Axelrod, F. B. (1999). Cold face test demonstrates parasympathetic cardiac dysfunction in familial dysautonomia. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 276(6), R1833-R1839.

Hollenstein, T., McNeely, A., Eastabrook, J., Mackey, A., & Flynn, J. (2012). Sympathetic and parasympathetic responses to social stress across adolescence. Developmental Psychobiology, 54(2), 207–214. doi:http://dx.doi.org/10.1002/dev.20582

Keltner, D. (2009). *Born to be good: The science of a meaningful life*. New York: W. W. Norton & Company.

Keltner, D., & Haidt, J. (2001). Social functions of emotions. In T. Mayne & G. A. Bonanno (Eds.)*, Emotions: Current issues and future directions.* New York: Guilford Press. (pp. 192-213).

Keltner, D., Horberg, E. J., & Oveis, C. (2006). “Emotions as Moral Intuitions.” In J. P. Forgas (Ed.), *Affect in thinking and social behavior* (pp. 161-175). New York: Psychology Press.

Knafo, A., Israel, S., Darvasi, A., Bachner-Melman, R., Uzefovsky, F., Cohen, L., ... & Ebstein, R. P. (2007). Individual differences in allocation of funds in the dictator game associated with length of the arginine vasopressin 1a receptor RS3 promoter region and correlation between RS3 length and hippocampal mRNA. *Genes, Brain and Behavior*, *7*(3), 266-275.

Knox, S. S., & Uvnäs-Moberg, K. (1998). Social isolation and cardiovascular disease: an atherosclerotic pathway? *Psychoneuroendocrinology*, *23*, 877-890.

Kogan, A., Oveis, C., Gruber, J., Mauss, I. B., Shallcross, A. J., Impett, E., Sitrin, S., Flythe, M., van der Lowe, I., Hui, B., Cheng, C, & Keltner, D. (2013). Cardiac vagal tone and prosociality: A test of Aristotle’s principle of moderation. *Journal of Personality and Social Psychology*.

Kok, B. E., Coffey, K. A., Cohn, M. A., Catalino, L. I., Vacharkulksemsuk, T., Algoe, S. B., ... & Fredrickson, B. L. (2013). How Positive Emotions Build Physical Health Perceived Positive Social Connections Account for the Upward Spiral Between Positive Emotions and Vagal Tone. *Psychological science*.

Kok, B.E. & Fredrickson, B.L. (2010). Upward spirals of the heart: Autonomic flexibility, as indexed by vagal tone, reciprocally and prospectively predicts positive emotions and social connectedness. *Biological Psychology, 85*, 342-346

Kosfeld, M., Heinrichs, M., Zak, P. J., Fischbacher, U., & Fehr, E. (2005). Oxytocin increases trust in humans. *Nature*, *435*, 673-676.

Krygier, J. R., Heathers, J. A., Shahrestani, S., Abbott, M., Gross, J. J., & Kemp, A. H. (2013). Mindfulness Meditation, Well-being, and Heart Rate Variability: A Preliminary Investigation into the Impact of Intensive Vipassana Meditation. *International Journal of Psychophysiology*.

La Marca, R., Waldvogel, P., Thörn, H., Tripod, M., Wirtz, P. H., Pruessner, J. C., & Ehlert, U. (2011). Association between Cold Face Test‐induced vagal inhibition and cortisol response to acute stress. Psychophysiology, 48(3), 420–429. doi:http://dx.doi.org/10.1111/j.1469-8986.2010.01078.x

Lazarus, R. S., Speisman, J. C., & Mordkoff, A. M. (1963). The relationship between autonomic indicators of psychological stress: Heart rate and skin conductance. *Psychosomatic Medicine; Psychosomatic Medicine*.

Lennon, R., & Eisenberg, N. (1987). Gender and age differences in empathy and sympathy. *Empathy and its development*, 195-217.

Levenson, R. W., & Gottman, J. M. (1983). Marital interaction: physiological linkage and affective exchange. *Journal of personality and social psychology*, *45*(3), 587.

Mathews, A., Richards, A., & Eysenck, M. (1989). Interpretation of homophones related to threat in anxiety states. Journal of Abnormal Psychology, 98(1), 31.

Mauss, I.B., Levenson, R.W., McCarter, L., Wilhelm, F.H., & Gross, J.J. (2005). The tie that binds? Coherence among emotion experience, behavior, and physiology. *Emotion, 5,* 175–190.

Mendes, W. B. (2009). Assessing autonomic nervous system activity. Methods in social neuroscience, 118-147.

Mezzacappa, E. S., Kelsey, R. M., Katkin, E. S., & Sloan, R. P. (2001). Vagal rebound and recovery from psychological stress. *Psychosomatic Medicine*, *63*(4), 650-657.

Mikulincer, M., & Shaver, P. R. (2005). Attachment security, compassion and altruism. *Current Directions in Psychological Science*, *14*, 34-38. doi: 10.1111/j.0963-7214.2005.00330.x

Ming, X., Julu, P. O., Brimacombe, M., Connor, S., & Daniels, M. L. (2005). Reduced cardiac parasympathetic activity in children with autism. *Brain and Development*, *27*(7), 509-516.

Obrist, P. A., Gaebelein, C. J., Teller, E. S., Langer, A. W., Grignolo, A., Light, K. C., & McCubbin, J. A. (2007). The relationship among heart rate, carotid dP/dt, and blood pressure in humans as a function of the type of stress. *Psychophysiology*, *15*(2), 102-115.

Oppenheimer, J. E., Measelle, J. R., Laurent, H. K., & Ablow, J. C. (2013). Mothers' vagal regulation during the Still-Face Paradigm: Normative reactivity and impact of depression symptoms. Infant Behavior & Development, 36(2), 255–267. doi:http://dx.doi.org/10.1016/j.infbeh.2013.01.003

Oveis, C., Cohen, A. B., Gruber, J., Shiota, M. N., Haidt, J., & Keltner, D. (2009). Resting respiratory sinus arrhythmia is associated with tonic positive emotionality. Emotion, 9(2), 265.

Oveis, C., Horberg, E. J., & Keltner, D. (2010). Compassion, pride, and social intuitions of self-other similarity. *Journal of Personality and Social Psychology*. *98*, 618-630. doi: 10.1037/a0017628

Plant, E. A., Hyde, J. S., Keltner, D., & Devine, P. G. (2000). The gender stereotyping of emotions. *Psychology of Women Quarterly*, *24*(1), 81-92.

Porges, S. W. (1995). Cardiac vagal tone: A physiological index of stress. Neuroscience & Biobehavioral Reviews, 19(2), 225–233. doi:10.1016/0149-7634(94)00066-A
Porges, S. W. (2001). The polyvagal theory: phylogenetic substrates of a social nervous system. *International Journal of Psychophysiology*, *42*(2), 123-146.
Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology. Vol 74(2)*, 116-143.
Rainville, P., Bechara, A., Naqvi, N., & Damasio, A. R. (2006). Basic emotions are associated with distinct patterns of cardiorespiratory activity. *International Journal of Psychophysiology*, *61*(1), 5-18.
Rash, J. A., & Prkachin, K. M. (2013). Cardiac vagal reactivity during relived sadness is predicted by affect intensity and emotional intelligence. *Biological psychology*, *92*, 106-113.
Rehwoldt, F. (1911). Uber respiratorische Affektsymptome. *Psychol. Studien*, *7*, 141-195.
Rockliff, H., Gilbert, P., McEwan, K., Lightman, S., & Glover, D. (2008). A pilot exploration of heart rate variability and salivary cortisol responses to compassion-focused imagery. *Journal of Clinical Neuropsychiatry*, *5*, 132–9.
Rosas-Ballina, M., Olofsson, P. S., Ochani, M., Valdés-Ferrer, S. I., Levine, Y. A., Reardon, C., ... & Tracey, K. J. (2011). Acetylcholine-synthesizing T cells relay neural signals in a vagus nerve circuit. Science, 334(6052), 98-101.
Rottenberg, J., Salomon, K., Gross, J. J., & Gotlib, I. H. (2005). Vagal withdrawal to a sad film predicts subsequent recovery from depression. *Psychophysiology. Vol 42(3)*, 277-281.
Ruch, W. (1995). Will the real relationship between facial expression and affective experience please stand up: The case of exhilaration. *Cognition & Emotion*, *9*(1), 33–58.
Santibañez-H, G. and Bloch, S. (19861 A qualitative analysis of emotional effector patterns and their feedback. *Journal of Biological Sciences*, *21*, 108-116.
Schachter, J. (1957) Pain, fear, and anger in hypertensives and normotensives. *Psychosomomatic Medicine*, *19*, 17-29.
Sherwood, L. (2004). Human physiology: from cells to systems.
Singer, T., Seymour, B., O'Doherty, J., Kaube, H., Dolan, R. J., & Frith, C. D. (2004). Empathy for pain involves the affective but not sensory components of pain. *Science*, *303*(5661), 1157-1162.
Souza, G. G. L., Mendonça-de-Souza, A. C. F., Barros, E. M., Coutinho, E. F. S., Oliveira, L., Mendlowicz, M. V., et al. (2007). Resilience and vagal tone predict cardiac recovery from acute social stress. *Stress: The International Journal on the Biology of Stress. Vol 10(4)*, *2007*, 368-374.
Stellar, J. E., Feinberg, M., & Keltner, D. (2012). *Egoism and the Boundaries of Compassion*. Unpublished manuscript.
Stellar, J. E., Manzo, V. M., Kraus, M. W., & Keltner, D. (2012). Class and compassion: Socioeconomic factors predict responses to suffering. *Emotion, online first publication*. doi: 10.1037/a0026508
Stock, S., & Uvnäs-Moberg, K. (2008). Increased plasma levels of oxytocin in response to afferent electrical stimulation of the sciatic and vagal nerves and in response to touch and pinch in anaesthetized rats. Acta physiologica scandinavica, 132(1), 29-34.
Thayer, J. F., & Lane, R. D. (2007). The role of vagal function in the risk for cardiovascular disease and mortality. *Biological psychology*, *74*(2), 224-242.
Trivers, R.L. (1971). The evolution of reciprocal altruism. *Quarterly Review of Biology, 46*,

35-57.
Uvnäs- Moberg, K. (2006). Physiological and endocrine effects of social contact. *Annals of the New York Academy of Sciences*, *807*(1), 146-163.

Van Lange, P. A.M. (1999). The pursuit of joint outcomes and equality in outcomes: An integrative model of social value orientation. *Journal of Personality and Social Psychology, 77,* 337-349.

Weisman, O., Zagoory-Sharon, O., & Feldman, R. (2012). Oxytocin administration to parent enhances infant physiological and behavioral readiness for social engagement. Biological psychiatry.

Wilhelm, F. H., Grossman, P., & Coyle, M. A. (2004). Improving estimation of cardiac vagal tone during spontaneous breathing using a paced breathing calibration. *Biomedical Sciences Instrumentation*, *40*, 317-324.

Wolff, B. C., Wadsworth, M. E., Wilhelm, F. H., & Mauss, I. B. (2012). Children's vagal regulatory capacity predicts attenuated sympathetic stress reactivity in socially supportive contexts: Evidence for a protective effect of the vagal system. *Development and Psychopathology, 24,* 677-689

Zahn-Waxler, C., Friedman, S. L., & Cummings, E. M. (1983). Children's emotions and behaviors in response to infants' cries. *Child Development*, *54*(6), 1522–1528.

Zak, P. J., Stanton, A. A., & Ahmadi, S. (2007). Oxytocin increases generosity in humans. *PLoS One*, *2*(11), e1128.

Zaki, J., Weber, J., Bolger, N., & Ochsner, K. (2009). The neural bases of empathic accuracy. *Proceedings of the National Academy of Sciences*, *106*(27), 11382-11387.

Footnotes

[1] RSA during the compassion condition did interact with NEO Altruism to predict SCL during the compassion condition, $\beta = .13$, but this finding did not replicate for our second measure of altruism, SVO, therefore it is unclear whether it is a robust effect.

Table 1. *Mean levels of emotions reported after the compassion and inspiration video in Study 3.*

	Compassion Video	Inspiration Video
	Mean (SD)	
Compassion	7.04 (2.04)	4.90 (2.51)
Warmth	5.27 (2.80)	6.62 (2.49)
Inspiration	4.35 (2.61)	6.07 (2.76)
Trust	4.11 (1.76)	5.26 (2.49)

Note. All means are significantly different by condition at $p < .001$.

Table 2. *RSA predicted by different cognitions in Study 4.*

	RSA
Apathy	0.04
Helpless	-0.07
Emotionally overwhelmed	0.22†
Trouble perspective taking	0.06
Responsibility	0.21†
Vulnerability	0.06
Deservingness	0.16
Similarity	0.21†

Note. All correlations in the RSA column are controlling for RSA during the neutral video and changes in respiration.
† $p \leq .08$.

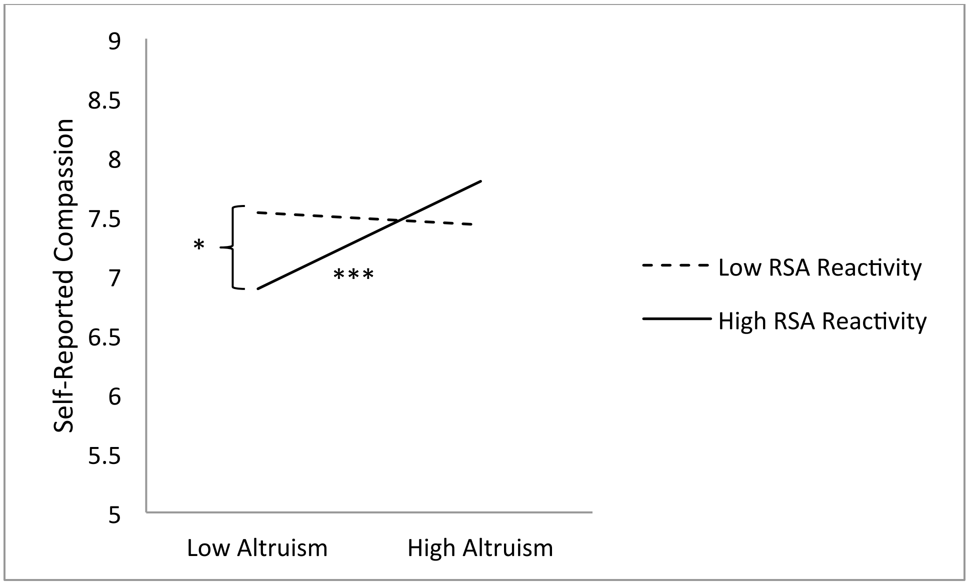

Figure 1. Interaction between RSA reactivity during the compassion induction and Altruism predicting self reported compassion in Study 1. Both measures include participants 1 SD below and 1 SD above the mean.
* $p < .05$
***$p < .001$

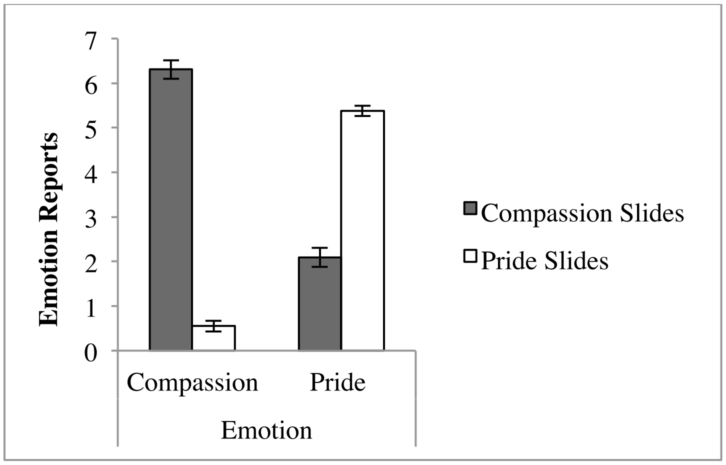

Figure 2. Elicitation of compassion and pride during compassion and pride slides in Study 2.

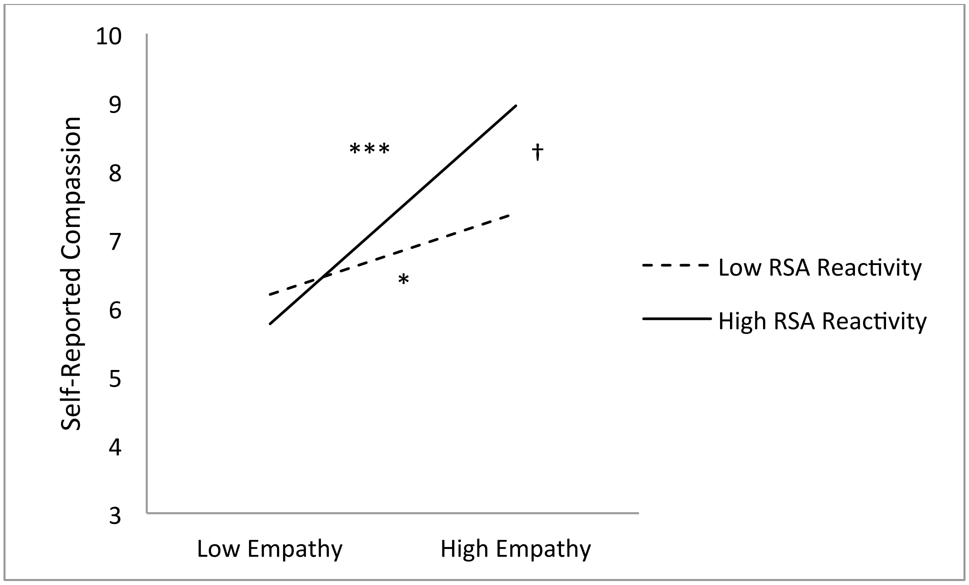

Figure 3. Interaction between RSA reactivity and empathy predicting self reported compassion in Study 3. Both measures include participants 1 SD below and 1 SD above the mean.
† p <.001
***p <.001