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Feeling Good: Autonomic Nervous System Responding in Five Positive Emotions

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Although dozens of studies have examined the autonomic nervous system (ANS) aspects of negative emotions, less is known about ANS responding in positive emotion. An evolutionary framework was used to define five positive emotions in terms of fitness-enhancing function, and to guide hypotheses regarding autonomic responding. In a repeated measures design, participants viewed sets of visual images eliciting these positive emotions (anticipatory enthusiasm, attachment love, nurturant love, amusement, and awe) plus an emotionally neutral state. Peripheral measures of sympathetic and vagal parasympathetic activation were assessed. Results indicated that the emotion conditions were characterized by qualitatively distinct profiles of autonomic activation, suggesting the existence of multiple, physiologically distinct positive emotions.

Keywords: positive emotion, evolutionary psychology, autonomic nervous system, psychophysiology

From William James (1884, p. 190), who proposed that "bodily changes follow directly the perception of the exciting fact, and our feeling of the same changes as they occur IS the emotion," to Antonio Damasio (1999, p. 51), who wrote that "emotions use the body as their theater," many theorists have commented on the role of physiological changes controlled by the autonomic nervous system (ANS) in emotional experience. The autonomic aspects of emotion are thought to serve important adaptive functions, preparing the body for an appropriate behavioral response to the eliciting situation (Cannon, 1915; Frijda, 1986; Lang, 1985; Tooby & Cosmides, 2008). Many negative emotions involve increased activation of the sympathetic branch of the ANS (see Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000 for a review), which generally facilitates physical exertion needed for "fight or flight."

To the extent that different emotion-eliciting situations call for different behavioral responses, however, qualitatively different profiles of autonomic responding are expected to occur. In particular, those who posit the existence of multiple, functionally distinct "discrete" emotions predict some degree of emotion-specific autonomic patterning (e.g., Ekman, 1992; Tooby & Cosmides, 2008). For example, overall vascular resistance and blood flow to the hands are greater during anger than during fear (Cacioppo et al., 2000; Ekman, Levenson, & Friesen, 1983; Levenson, 1992), and disgust appears to involve an increase in parasympathetic activation as well as some degree of sympathetic activation (Rozin, Haidt, & McCauley, 1999). Although controversy still exists regarding the extent of autonomic differentiation among negative emotions, and the findings of individual studies have been mixed, major reviews of this literature typically point to some degree of specificity (e.g., Cacioppo et al., 2000; Friedman, 2010; Kreibig, 2010), especially when subtypes of major emotion categories are considered (Kreibig, 2010).

Much less is known about autonomic responding in the positive emotions. This lack of attention is consistent with the historical underrepresentation of positive emotions in psychological research, and with the still-common perception among theorists that positive emotions have fewer implications for evolutionary fitness, are less differentiated, and have less distinct impact on motivation and behavior than is true of the negative emotions (noted by Fredrickson, 1998, 2001). The present study aims to help correct this imbalance by examining and comparing the autonomic nervous system aspects of five positive emotions.

Positive Emotion Psychophysiology: Conflicting Messages

Some studies have examined the autonomic aspects of positive emotion, but these send conflicting messages. On one hand, many studies suggest that positive emotion involves little or no change in ANS activation. Early studies comparing "happiness" with several negative emotions found that happiness led to minimal cardiovascular and electrodermal change, relative to anger, fear, and sadness (e.g., Ekman et al., 1983; Levenson, Ekman, Heider, & Friesen, 1992; Levenson, 1992). Based upon a meta-analysis of existing research, Cacioppo and colleagues (2000) concluded that positive emotions were characterized by less autonomic reactivity than the negative emotions, likely reflecting a lesser degree of motivational output.

Other studies suggest that positive emotion is associated with increased physiological arousal. In particular, studies using comedy film clips to elicit amusement have documented changes in skin conductance, heart rate, and/or other cardiovascular measures consistent with increased sympathetic nervous system activation

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(e.g., Christie & Friedman, 2003; Demaree, Schmeichel, Robinson, & Everhart, 2004; Giuliani, McRae, & Gross, 2008; Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005). Other studies have observed signs of sympathetic activation associated with "happiness" or "joy" (e.g., Neumann & Waldstein, 2001; Tsai, Chentsova-Dutton, Freire-Bebeau, & Przymus, 2002). Recently, researchers have emphasized that sympathetic activation in positive emotions may reflect increased motivational engagement, and have documented signs of sympathetic activation in participants receiving positive feedback on a challenging task (e.g., Kreibig, Gendolla, & Scherer, 2010).

Still other research suggests that positive emotions have the opposite effect, reducing cardiovascular arousal. Several studies have documented an "undoing effect" of experimentally elicited amusement and contentment, finding that these emotions speed recovery from arousal associated with negative emotion (e.g., Fredrickson & Levenson, 1998; Fredrickson, Mancuso, Branigan, & Tugade, 2000). This might be due to withdrawal of sympathetic activation, but increased parasympathetic activation could also explain the effect. It has been proposed that positive emotions associated with social bonding, in particular, are characterized by enhanced activation of the vaso-vagal branch of the parasympathetic nervous system (Porges, 1997). Oveis and colleagues (2009) found that high tonic/resting respiratory sinus arrhythmia was associated with higher levels of dispositional positive affect, and a few studies have observed increases in vagal parasympathetic activation during exposure to pleasant stimuli (e.g., Matsunaga et al., 2009; McCraty, Atkinson, Tiller, Rein, & Watkins, 1995). Still, the extent to which specific positive emotion states are characterized by increased parasympathetic activation is quite uncertain.

Limitations of Prior Research

Prior studies of autonomic responding in positive emotion have a number of limitations. This is partly because many of these studies were not designed to study the autonomic aspects of positive emotion per se, but instead targeted some other psychological process (e.g., the effects of suppressing behavioral expression; emotion response system coherence). First, many studies do not include a neutral control condition against which the positive emotion condition(s) can be compared (e.g., Ekman et al., 1983; Levenson et al., 1992; Neumann & Waldstein, 2001; Tsai et al., 2002; Vrana, 1993). Emotion induction methods may themselves have effects on autonomic responding, and any effects of the actual emotion will be layered on top of these (Christie & Friedman, 2003). In particular, studies using stimuli such as photographs, film clips, or audio recordings need to account for the "orienting effect" when assessing the effects of emotion (Bradley, 2009; Sokolov, 1990; Stekelenburg & van Boxtel, 2002).

Second, many prior studies assessed variables that limit detection of complex ANS responses by confounding the effects of multiple systems (Stemmler, Grossman, Schmid, & Foerster, 1991). For example, increased heart rate could be caused by an increase in β-adrenergic sympathetic influence, by withdrawal of vagal parasympathetic influence, or both. Because the physiological aspects of discrete emotions might involve profiles across multiple systems rather than change in a single system, the ideal study would include measures that help tease apart different aspects of sympathetic responding (e.g., effects mediated primarily by α-adrenergic, β-adrenergic, and/or cholinergic innervation), and distinguish these from the effects of parasympathetic responding.

Third, few studies have examined more than one positive emotion. Many studies have examined only "happiness" or "joy" as elicited by relived emotional experience, directed facial action, or imagining an eliciting situation (e.g., Collet, Vernet-Maury, Delhomme, & Dittmar, 1997; Ekman et al., 1983; Levenson et al., 1992; Sinha, Lovallo, & Parsons, 1992; Stemmler, 1989). Other studies have only examined amusement in response to a comedy film (e.g., Demaree et al., 2004; Guiliani et al., 2008; Mauss et al., 2005). Recently, a greater number of studies have included two positive emotions, often with contentment as a presumed low-arousal positive emotion (e.g., Stephens, Christie, & Friedman, 2010), but these also have important limitations. In some studies, researchers allowed participants to define the emotion constructs in a relived experience task, so that the content of the eliciting stimulus was not consistent across participants (e.g., Neumann & Waldstein, 2001; Tsai et al., 2002). In others, researchers examined physiological differences between participants who reported different positive emotions in the context of the same experimental task (e.g., Kreibig et al., 2010). Reports of yet other studies provide little detail about the content of experimental stimuli (e.g., Christie & Friedman, 2003; Stephens et al., 2010; Vrana, 1993). Although all of these studies offer valuable insight into the autonomic aspects of positive emotion, there is still a need for studies comparing autonomic responses to controlled stimuli targeting several specific positive emotions.

The Present Study

The present study examined the autonomic aspects of five positive emotions, as elicited experimentally using slides showing emotional images in a repeated-measures design.[1] Six peripheral measures of autonomic responding were assessed, allowing for some discrimination among different sympathetic and vagal parasympathetic mechanisms of physiological reactivity. The five positive emotion constructs were defined by identifying particular adaptive problems, the cues of a prototypical opportunity to solve each problem, and the functional behavioral response to each opportunity. These theoretical definitions formed the basis for hypotheses regarding autonomic responding, as well as for selecting emotion-eliciting stimuli. Fredrickson (1998, 2001) has proposed that positive emotions generally facilitate broadening attention and building resources, but she and others have also begun to offer functional accounts of several distinct positive emotions thought to facilitate appropriate responses to specific fitness-relevant opportunities presented by the environment (e.g., Fredrickson, 1998; Griskevicius, Shiota, & Neufeld, 2010; Shaver, Morgan & Wu, 1996; Shiota, Keltner, Campos, & Hertenstein, 2004; Shiota, Keltner, & Mossman, 2007).

[1] Contentment/serenity, while included in several prior studies of ANS responding in positive emotion, was not included on the present study. We agree that contentment may be a functionally distinct positive emotion. However, the postconsummatory aspect emphasized in functional definitions of this construct (e.g., Fredrickson, 1998; Griskevicius et al., 2009) made us wary of attempting to elicit it via photographs.

Anticipatory enthusiasm addresses the need for food and other material resources, and should facilitate the physical and cognitive effort needed to acquire such resources (Griskevicius et al., 2010). It is important that this definition of anticipatory enthusiasm differentiates it from sexual arousal, which is reasonably well characterized in the ANS literature (Kreibig, 2010). Anticipatory enthusiasm is experienced in response to cues of imminent reward, and has also been described as "wanting" by Berridge and Robinson (1995). A rich body of literature documents the dopaminergic neural network that appears to mediate the anticipation of reward (e.g., Depue & Collins, 1999; Knutson, Taylor, Kaufman, Peterson, & Glover, 2005), dubbed the "Seeking" system by Panksepp (1998). Prior research suggests that the anticipation of reward, as well as the motivation to pursue rewards and achieve important goals, is associated with increased cardiovascular arousal (e.g., Fowles, Fisher, & Tranel, 1982; Kreibig et al., 2010). Prior research also provides strong evidence of sympathetically mediated skin conductance responses during the anticipation of aversive stimuli (Bach, Daunizeau, Friston, & Dolan, 2010), and exposure to sexually arousing material (see Kreibig, 2010 for a review), although less is known about skin conductance responses to anticipated nonsexual rewards. As a result, we hypothesized that anticipatory enthusiasm would be accompanied by broad sympathetic activation.

Attachment love addresses the need for others' nurturance and protection, and has been described as the surge of love and trust experienced in response to an attachment figure (Griskevicius et al., 2010; Shaver et al., 1996). This emotion is thought to facilitate the passive acceptance of nurturance and attention, especially when one is vulnerable, or when a caregiver has returned from an absence (Shiota, Keltner, & John, 2006). Although parents and romantic partners have received the most research attention as attachment figures, humans may form attachments to others perceived as caregivers as well (Ainsworth, 1989). Prior research suggests that presence of and physical contact with close others helps alleviate HPA axis activation in times of stress (Carter, 1998; Hennessy, 1997), and it has been proposed that attachment love involves vaso-vagal parasympathetic activation (Porges, 1997). Thus, we hypothesized that attachment love would be accompanied by baseline-to-trial increase in respiratory sinus arrhythmia.

Nurturant love addresses the need to care for the young (Griskevicius et al., 2010; Shiota et al., 2006). Individuals displaying youth and helplessness are likely to elicit this response; ethologists have defined "cuteness" as a combination of physical characteristics (e.g., large head/body ratio; short, stubby limbs; large eyes, small nose, and tight clustering of facial features) and behavioral characteristics (e.g., clumsiness, attention-seeking) that serve as a mammalian cue for nurturance (Hildebrandt & Fitzgerald, 1979; Lorenz, 1971). It has been proposed that nurturant behavior draws on a broader appetitive motivational system that triggers sympathetic arousal (Bradley, 2009). Thus, we hypothesized that nurturant love would involve increased sympathetic activation, facilitating approach, and caregiving. Although increased vagal response might be involved in affectionate contact associated with nurturance (i.e., cuddling), a later "stage" of nurturant love, we did not expect this effect in participants viewing photographic images.

Amusement addresses the need to practice crucial physical and cognitive skills (Smith, 1982), and has been defined as the emotion experienced in response to opportunities for play (Griskevicius et al., 2010; Panksepp, 1998). Although rough-and-tumble physical play is the prototypical form, cognitive play and humor serve comparable skill-building purposes and may draw on closely related cognitive and physiological mechanisms (Pellegrini & Smith, 2005). In particular, theories of play emphasize the need to practice risky skills under safe circumstances, without time pressure or genuine threat (Smith, 1982). Prior research on autonomic aspects of amusement has produced inconsistent findings across a number of channels (Kreibig, 2010). Based on our theoretical definition of this construct, however, we predicted that amusement would be accompanied by signs of cardiovascular arousal (as observed in previous studies, e.g., Demaree et al., 2004; Guiliani et al., 2008; Mauss et al., 2005), and increased respiration rate, reflecting sympathetic activation and/or vagal withdrawal.

Finally, *awe* addresses our species' need to acquire and store information about the outside world. This emotion has been described as a response to novel, vast, complex stimuli not accounted for by one's current worldview (Keltner & Haidt, 1999; Shiota et al., 2007). Behaviorally, awe should facilitate orientation toward the stimulus and immobility; cognitive activity should reflect attentive sensory processing and accommodation (Shiota et al., 2007). A number of researchers have found that perception of and orienting toward novel features of the environment ("environmental intake") is associated with prolonged heart rate deceleration (Bradley, 2009; Graham, 1979; Lacey & Lacey, 1970), which may be due to increased parasympathetic activation and/or sympathetic withdrawal. Demaree et al. (2004) have also suggested that some kinds of intense cognitive effort are accompanied by sympathetic withdrawal. Thus, we hypothesized that awe would be accompanied by signs of parasympathetic activation and/or sympathetic withdrawal.

Method

Participants

Participants were 37 undergraduates enrolled in Psychology courses at Arizona State University. Mean age was 18.80 years ($SD = 1.32$), 76% of participants were female and 24% male, 57% were European American, 24% Latino/Latina, 11% African or African American, 5% Asian, and 3% Native American. Participants received $15 and one hour of course credit for their participation, plus an unexpected, additional $10 award during the Enthusiasm trial. Four additional participants completed the study, but their physiological data were unusable due to extreme sources of noise in the physiological signals (e.g., near-constant sneezing and coughing) or problems with sensor placement.

Procedure

The experimental protocol was approved by ASU's Office of Research Integrity and Assurance prior to data collection. Upon arrival at the laboratory participants completed informed consent procedures (including a verbal description of the procedures as well as a printed consent form), and sensors for physiological measurement were attached. The protocol included nine slide-viewing trials. Within each trial, participants viewed (a) an "X" on the monitor for a 60-s trial baseline, during which they were asked

to clear their minds of thoughts, feelings, and memories; and (b) six 15-s slides, for a total of 90 seconds. Slides were presented on a 42" LCD monitor, suspended on the wall eight feet from the participant. Participants were instructed to watch the slides carefully, and told that some slides might elicit positive, negative, or no emotions, but were not given any instructions for how to experience or control emotions they might feel. Participants were also asked to minimize movement and speech during the trials. E-prime was used to direct stimulus presentation, and also to embed "triggers" identifying the start of baseline and slide epochs of each trial in the physiology data files. After delivering trial instructions verbally, the experimenter left the room before each trial. At the end of each trial, the experimenter reentered the room to administer an emotional experience questionnaire. Participants were videotaped throughout the lab session with their knowledge and consent; audio-visual data are not used in the present analyses.

The neutral slides—images of household objects (e.g., office desk set, pile of telephone books) —were always used in the first trial. The order of the remaining trials was randomly determined for each participant. Data from the three negative emotion trials (sadness, fear, and disgust) are not used in the present analyses. People respond to money as a fundamental resource, so we used slides presenting a lottery-like game leading to an unexpected $10 reward to elicit anticipatory enthusiasm. The first slide presented five target numbers and the reward scheme, and subsequent slides showed an increasing set of "matching" numbers leading to the largest possible reward. In lieu of personalized attachment figures, images of caregiving childhood fictional characters (pretested for recognizability by this cohort, e.g., Big Bird, Papa Smurf) were used to elicit attachment love. Nurturant love slides showed baby animals (we anticipated that actual baby humans might elicit some anxiety in this college-age sample). Amusement slides showed "Far Side" cartoons. Awe slides showed panoramic views, following prior research documenting this prototypical awe elicitor (Shiota et al., 2007). All stimulus images were bitmap files approximately 300K pixels in size (e.g., 640 × 480). All images were brightly colored, and images for most trials were also fairly complex, showing a foreground figure against a background, or a complex background only (awe). Enthusiasm slides were somewhat less visually complex, as they primarily showed text, but these were also brightly colored.

Measures

Physiological data were collected using sensors and amplifying hardware supplied by Mindware, Inc., Biopac, and Medwave. Continuous ANS data were recorded using Biopac's Acquisition software throughout the laboratory session. Sampling frequency for all variables was 1000 Hz. In order to remove error and artifact (movement, sneezing, coughing, brief sensor displacement, etc.), all data were screened visually by the first author, blind to emotion condition, prior to further analysis. Six physiological variables were assessed:

Cardiac Interbeat Interval (IBI, in ms) has an inverse relationship with β-adrenergic sympathetic influence, and a positive relationship with vagal parasympathetic influence. Cardiac IBI was measured using a 3-lead configuration with disposable electrodes on the left rib cage and right clavicle, with the ground on the right rib cage. Signals were amplified using Mindware, Inc.'s Impedance Cardiography unit. Data were reduced into target epoch means using Mindware, Inc's Impedance Cardiography software module (version 2.51), which defines IBI as the time elapsed in milliseconds between R-peaks of the ECG signal, and averages these R-peaks across the target epoch. Maximum heart rate was set at 200 beats/min. (minimum IBI = 300 ms.) and minimum heart rate at 40 beats/min. (maximum IBI = 1500 ms.). The few IBIs outside this range were discarded when calculating epoch means.

Cardiac Pre-Ejection Period (PEP, in ms), the time elapsed between the beginning of ventricular contraction and the opening of the aortic valve, shortens with increasing β-adrenergic sympathetic influence. Preejection period was measured using four leads with disposable electrodes placed at the base of the neck, the center of the clavicle, the xyphoid process, and on the spine approximately one inch inferior to the sensor on the xyphoid process (in addition to the ECG leads described above). Signals were amplified using Mindware, Inc.'s Impedance Cardiography unit. Data were reduced into target epoch means using Mindware, Inc's Impedance Cardiography software module (version 2.51), which creates a composite heartbeat across all valid beats in the target epoch, and calculates the time elapsed in milliseconds between the Q-point of the ECG signal (defined as the onset of the R-wave, or the point of maximum positive slope during the 65 milliseconds preceding the R-peak) and the B-point of the first derivative of the impedance signal (defined as 56% of the time elapsed from the R-peak of the ECG signal and the maximum value of dz/dt, the first derivative of the impedance signal) on this composite beat (Berntson, Lozano, Chen, & Cacioppo, 2004).

Skin Conductance Responses (SCRs) reflect brief bursts of sweat gland activity resulting from cholinergic sympathetic receptor stimulation. In the present study, SCRs were measured by passing a constant 0.5 V voltage between two electrodes attached to the palmar surfaces of the distal phalanges of the index and ring fingers of the nondominant hand. Signals were filtered and amplified by Biopac's GSR100C unit, with low-pass filtering at 10 Hz, high-pass filtering at DC, and a gain of 5 microSiemens. Valid SCRs were defined as increases of at least .05 microSiemens occurring during the slide set, and typically occurred immediately after a new slide was displayed on the monitor. The total number of valid SCRs during each slide viewing epoch were counted; skin conductance responses occurring less than 1 second after the first slide appeared, or immediately following a deep breath, were not included in the counts.[2]

Respiration Rate (in breaths per minute) generally increases with sympathetic influence and decreases with parasympathetic influence, although it is also under voluntary control. In the present study respiration rate was measured using an elastic belt with a tension-sensitive crystal; signals were filtered and amplified by Biopac's RSP100C unit with low-pass filtration set to 10Hz, high-pass at 0.5 Hz and DC, and a gain of 10. Epoch-level respiration rates were calculated using Mindware, Inc.'s HRV 2.51 analysis software.

Respiratory Sinus Arrhythmia (RSA) is the variability in IBI associated with the phases of breathing, increasing with greater

[2] Analyses examining baseline-to-trial change in tonic skin conductance level, rather than counts of skin conductance responses during the slides, produced the same results as in the current analyses.

vagal parasympathetic influence on the heart. In the present study, RSA was derived from the IBI series over the course of each epoch, using Mindware, Inc.'s HRV 2.51 analysis software. This program calculates RSA by subjecting the IBI series for each epoch to Fast Fourier Transform, and applying a Hamming window for the .12–.40 Hz frequency range of the resulting spectral distribution, which offers a reliable estimate of the extent of parasympathetic influence on the heart (Berntson, Cacioppo, Quigley, & Fabro, 1994). Spectral distributions of the respiration signals were also examined to ensure that integral power peaked within the .12–.40 Hz frequency range corresponding to the expected respiration rates for using RSA as a marker of parasympathetic activation. Trials with respiration rates outside the expected range were removed from analysis.

There is controversy in the literature over whether or not changes in RSA should be examined only after controlling for corresponding changes in respiration rate, which exerts an effect on RSA independent of vagal influence (e.g., Allen, Chambers, & Towers, 2007; Butler, Wilhelm, & Gross, 2006; Porges, 2007). For this reason, analyses of baseline-to-trial change in RSA were performed both directly on the change scores, and again controlling for the corresponding change in respiration rate. In the latter analyses, baseline-to-trial changes in RSA for each trial across the sample were regressed onto baseline-to-trial changes in respiration rate; unstandardized residuals were saved and used in a second set of hypothesis testing analyses.

Mean Arterial Pressure (MAP, in mmHg) increases with greater α-adrenergic influence, and is also affected both directly and via complex feedback loops by β-adrenergic influence and vagal parasympathetic influence. We measured MAP using Medwave's Vasotrac APM205A, which uses an elastic band on the wrist of the dominant arm, adjusts tension at 12-s intervals, and detects effects on pulse magnitude using a sensor at the pulse point of the wrist. Participants were asked to rest their dominant arm on the chair with the wrist facing up, in order to avoid putting pressure on the sensor.

All six measures were collected throughout the laboratory session. For all measures except SCRs, mean values were calculated for the baseline (while the "X" was on the screen) and slide-viewing epochs of each trial, and trial-level baseline-to-trial change scores were calculated from these means. These change scores were taken to represent reactivity to the slides, and used as the dependent variables in further analyses. Skin Conductance Responses were simply counted during the slide-viewing epochs of each trial.

Self-report measures of emotion. In addition to the ANS measures, participants' ratings of their emotional experience were collected at the end of each trial. Immediately after the last slide in each trial the experimenter entered the room, and asked participants to rate the intensity of their experience of 10 emotions, as felt while viewing the slides. Ratings were on a scale from 0 (did not feel that emotion at all) to 8 (strongest experience of that emotion ever). The 10 rated emotions were: Amusement, Anger, Awe, Contentment, Disgust, Enthusiasm/Excitement, Fear, Love/Attachment, Sadness, and Tenderness/Compassion.

Analyses

In the first stage of hypothesis testing, Multivariate Analysis of Variance in SPSS was used to examine the main effect of emotion condition on the set of ANS variables (excluding MAP). This analysis asks whether the several emotion conditions can be differentiated with respect to a linear composite of the ANS variables, but does not address differences between emotion conditions in terms of profile across ANS variables. This analysis included only the 28 participants providing complete IBI, PEP, SCL, respiration rate, and RSA data for all six trials. Mean arterial pressure was excluded from this analysis because eliminating participants with missing data for at least one of the six trials would have reduced the sample for the test to 11.[3]

A 6 [Emotion] × 5 [Physiological Measure] Repeated Measures Analysis of Variance was then used to confirm the omnibus effect of emotion condition on the set of physiological variables (main effect of Emotion condition), but also to assess the extent to which the emotion conditions led to qualitatively different profiles of ANS responding (Emotion condition × Physiological Measure interaction). Profiles across ANS variables are at least as important as linear composites of such variables in documenting possible differences among emotion conditions (e.g., Kreibig, Wilhelm, Roth, & Gross, 2007; Stemmler, 1989). The Greenhouse-Geisser correction of p was always applied to compensate for violations of sphericity.

Next, overall differences among the Neutral and five positive emotion conditions in baseline-to-trial change scores for each ANS measure (for SCRs, counts during the trial) were assessed using a series of omnibus one-way repeated measures analyses of variance (ANOVAs). Again, the Greenhouse-Geisser correction of p was applied in each test to compensate for any violations of sphericity in the data. Each of these analyses included all participants with acceptable data on the target physiological variable for every emotion condition, including some not represented in the multivariate analyses, in order to maximize statistical power (see Table 2 for *N*s for each analysis). Omnibus ANOVAs were followed by t tests examining planned pairwise contrasts between the Neutral condition and each of the five positive emotion conditions, as well as exploratory t tests contrasting positive emotion conditions with each other. With the exception of MAP analyses, these t tests used only the participants included in the omnibus one-way ANOVAs.[4] Unusability of MAP data in some trials limited the sample with data for all trials to only 11 participants. Thus, t tests for MAP used all participants with data needed for a given pairwise test, in order to maximize statistical power.

Results

Manipulation Check

Mean ratings of experienced Enthusiasm/Excitement, Love/Attachment, Tenderness/Compassion, Amusement, and Awe while viewing the slide sets are reported in Table 1. Mean reports

[3] Unfortunately, MAP sensor recalibration (which takes place at regular intervals using the Vasotrac system) led to substantial loss of data during the baseline and/or slide-viewing epoch of at least one trial for many participants. As a result, only 11 participants had the necessary baseline and slide-epoch MAP data to calculate a change score for every trial, necessary for inclusion in the MANOVA.

[4] The pattern of findings observed using this approach is also produced by using all eligible subjects in the pairwise t tests (as for MAP), and when pairwise contrasts are limited to those reporting at least moderate levels of the target positive emotion in each contrast. The current approach was selected by virtue of simple graphical presentation.

Table 1
Self-Reported Emotional Experience, Means and Standard Deviations by Emotion Condition

Emotional Experience Rated	Emotion condition				
	Neutral	Enthusiasm	Attachment love	Nurturant love	Amusement	Awe
Enthusiasm/Excitement	.93 (1.74) $t_{vEnth} = -10.32$	5.54 (1.90)	3.25 (2.19) $t_{vEnth} = -5.52$	4.43 (2.70) $t_{vEnth} = -2.33$	3.64 (2.28) $t_{vEnth} = -3.87$	3.64 (2.70) $t_{vEnth} = -3.59$
Love/Attachment	.11 (.57) $t_{vAL} = -7.41$	.36 (1.19) $t_{vAL} = -6.56$	3.21 (2.18)	5.61 (1.77) $t_{vAL} = 5.71$	.43 (1.23) $t_{vAL} = -6.50$	2.04 (2.46) $t_{vAL} = -2.76$
Tenderness/Compassion	.32 (.90) $t_{vNL} = -14.93$	.32 (1.19) $t_{vNL} = -16.56$	2.96 (2.30) $t_{vNL} = -6.59$	5.93 (1.70)	.89 (1.69) $t_{vNL} = -14.06$	2.18 (2.47) $t_{vNL} = -8.02$
Amusement	1.71 (2.14) $t_{vAmu} = -10.99$	4.50 (2.35) $t_{vAmu} = -4.30$	4.29 (1.84) $t_{vAmu} = -5.80$	4.57 (2.08) $t_{vAmu} = -4.81$	6.14 (1.35)	1.89 (2.33) $t_{vAmu} = -9.90$
Awe	.46 (1.20) $t_{vAwe} = -12.97$	2.39 (2.60) $t_{vAwe} = -6.50$	1.18 (1.59) $t_{vAwe} = -9.28$	3.25 (2.52) $t_{vAwe} = -4.89$	1.61 (1.87) $t_{vAwe} = -8.88$	5.86 (1.98)

Note. All *t*-values contrasting ratings of the target emotion with ratings of the same emotion in other trials (e.g., ratings of Enthusiasm/Excitement in the Enthusiasm versus Neutral trial) are significant at the $p < .01$ level.

of all five positive emotions were less than 2.0 in the Neutral condition. The Anticipatory Enthusiasm slides elicited stronger reports of Enthusiasm ($M = 5.54$, $SD = 2.04$) than of any other positive emotion, and reported Enthusiasm was significantly higher in this condition than in any other emotion condition (see Table 1 for *t*-values associated with these differences).

The Attachment Love slides elicited moderately strong reports of Love/Attachment ($M = 3.22$, $SD = 2.36$), and reports of Love/Attachment were significantly higher in this condition than in the Neutral, Anticipatory Enthusiasm, Amusement, and Awe conditions. Reports of Love/Attachment were significantly higher in the Nurturant Love condition than in the Attachment Love condition; however, this is consistent with the colloquial use of the term "love" and was not taken to indicate invalidity of either of the "love" stimuli. Reports of Amusement were also moderately high in the Attachment Love condition, though significantly lower than in the Amusement condition.

The Nurturant Love slides elicited stronger reports of Tenderness/Compassion ($M = 5.49$, $SD = 2.08$) than of any other positive emotion, and reported Tenderness/Compassion was significantly higher in this condition than in any other emotion condition. The Amusement slides elicited stronger reports of Amusement ($M = 6.16$, $SD = 1.40$) than of any other positive emotion, and reported Amusement was significantly higher in this condition than in any other emotion condition. Finally, the Awe slides elicited stronger reports of Awe ($M = 5.62$, $SD = 2.028$) than of any other positive emotion, and reported Awe was significantly higher in this condition than in any other emotion condition. Thus, the manipulation check suggests that the target emotions were successfully elicited in each emotion condition, with the Attachment Love slides eliciting mild levels of amusement as well.

Hypothesis Testing

Results are summarized numerically in Table 2, and graphically in Figure 1. Multivariate Analysis of Variance in SPSS indicated that the main effect of Emotion Condition on the composite of IBI, PEP, SCR, Respiration Rate, and RSA was significant, $F(25, 675) = 2.64$, $p < .001$, indicating overall differences among the emotion conditions. The 6 [Emotion Condition] × 5 [ANS Variable] Repeated Measures ANOVA confirmed the main effect of Emotion Condition on the set of ANS variables, *Epsilon* = .851, $F(5, 135) = 2.75$, $p = .028$, and also detected a significant interaction between Emotion Condition and ANS Variable, *Epsilon* = .215, $F(20, 540) = 2.93$, $p = .021$, indicating qualitative differences among Emotion Conditions in the profiles of responding across ANS variables.[5] These effects remained significant when the analysis was performed using RSA change scores controlling for change in Respiration Rate: for main effect of Emotion Condition *Epsilon* = .852, $F(5, 135) = 2.72$, $p = .030$; for Emotion Condition × ANS Variable interaction *Epsilon* = .214, $F(20, 540) = 2.95$, $p = .021$.

Turning to the one-way ANOVAs for each physiological measure, omnibus differences among the six emotion conditions were

[5] The Emotion Condition × Physiological Measure interaction is also significant in analyses using residual variability in trial-epoch means after controlling for baseline-epoch means as the index of reactivity, rather than baseline-to-trial change scores, $F(20, 540) = 3.356$, $p = .001$.

Table 2
Baseline and Trial Epoch Means and Standard Errors for ANS Measures, by Emotion Condition

	Neutral	Enthusiasm	Attachment love	Nurturant love	Amusement	Awe
IBI (n = 37)						
Baseline Mean (*SE*)	833.5 (23.4)	859.0 (21.5)	852.7 (22.1)	856.6 (24.1)	859.9 (23.4)	847.8 (23.0)
Trial Mean (*SE*)	851.3 (21.8)	859.1 (23.0)	848.1 (22.6)	856.3 (23.5)	874.0 (22.8)	862.1 (22.1)
t for BT Δ vs. Neutral		-1.85^{+}	-2.88^{**}	-2.14^{*}	$-.45$	$-.44$
PEP (n = 35)						
Baseline Mean (*SE*)	101.1 (1.4)	102.9 (1.1)	103.1 (1.1)	102.8 (1.2)	103.1 (1.1)	102.2 (1.1)
Trial Mean (*SE*)	101.5 (1.3)	102.5 (1.3)	103.1 (1.2)	103.4 (1.2)	102.9 (1.2)	103.6 (1.1)
t for BT Δ vs. Neutral		-1.36	$-.68$	.65	$-.92$	2.86^{**}
SCRs (n = 35)						
Trial Mean (*SE*)	1.71 (.42)	3.74 (.64)	1.89 (.39)	1.46 (.38)	1.94 (.36)	1.29 (.32)
t vs. Neutral		4.44^{**}	.51	-1.04	.81	-1.23
Respiration rate (n = 32)						
Baseline Mean (*SE*)	14.37 (.53)	13.91 (.61)	13.91 (.59)	13.75 (.58)	13.78 (.56)	13.34 (.62)
Trial Mean (*SE*)	14.59 (.49)	15.22 (.48)	14.94 (.60)	15.34 (.38)	15.69 (.46)	14.94 (.51)
t for BT Δ vs. Neutral		1.77^{+}	1.69	2.60^{*}	3.51^{**}	3.02^{**}
RSA (n = 29)						
Baseline Mean (*SE*)	6.81 (.22)	7.12 (.24)	7.11 (.22)	6.99 (.24)	6.93 (.20)	7.11 (.22)
Trial Mean (*SE*)	6.90 (.22)	6.67 (.23)	6.79 (.24)	6.80 (.25)	6.95 (.20)	6.71 (.24)
t for BT Δ vs. Neutral		-2.55^{*}	-2.74^{*}	-1.85^{+}	$-.41$	-2.34^{*}
MAP						
N for emotion	23	21	20	18	17	19
Baseline Mean (*SE*)	86.87 (2.8)	84.20 (2.6)	84.46 (2.8)	84.52 (2.6)	86.34 (3.6)	80.88 (2.4)
Trial Mean (*SE*)	86.19 (2.8)	85.21 (2.6)	82.98 (2.8)	84.97 (2.6)	82.83 (3.0)	80.27 (2.6)
t for BT Δ vs. Neutral		1.76^{+}(df = 20)	$-.12$ (df = 19)	.82 (df = 17)	$-.35$ (df = 16)	$-.11$ (df = 18)

Note. IBI = Cardiac Interbeat Interval in ms; PEP = Cardiac Pre-Ejection Period in ms; SCRs = number of valid Skin Conductance Responses during trial only; RSA = Respiratory Sinus Arrhythmia in ms^2; MAP = Mean Arterial Pressure in mmHg.
$^{+}p < .10$. $^{*}p < .05$. $^{**}p < .01$.

statistically significant for change in IBI [*Epsilon* = .822, $F(5, 180) = 2.68$, $p = .032$], number of SCRs [*Epsilon* = .614, $F(5, 170) = 10.98$, $p < .001$], and change in Respiration Rate [*Epsilon* = .840, $F(5, 155) = 2.62$, $p = .035$], and approached significance for change in PEP [*Epsilon* = .456, $F(5, 170) = 2.87$, $p = .056$]. The six conditions also differed significantly on change in RSA [*Epsilon* = .775, $F(5, 140) = 2.88$, $p = .027$], although this omnibus effect ceased to be significant after controlling for change in Respiration Rate [*Epsilon* = .694, $F(5, 140) = .36$, *ns*]. Omnibus differences among emotion conditions were not significant for change in MAP [*Epsilon* = .661, $F(5, 50) = 1.04$, *ns*]. Relative to baseline, Neutral slides led to modest and nonsignificant increases in IBI and PEP and decrease in MAP, a small number of SCRs, and no effect on Respiration Rate or RSA— effects consistent with the orienting response.

Compared with responses to the Neutral stimuli, Anticipatory Enthusiasm led to a significantly greater number of SCRs, $t = 4.44$, $p < .001$. Number of SCRs during the Enthusiasm slides was also significantly greater than during the Attachment Love, $t = 3.72$, $p = .001$, Nurturant Love, $t = 4.49$, $p < .001$, Amusement, $t = 4.05$, $p < .001$, and Awe slides, $t = 4.44$, $p < .001$. Differences of the Anticipatory Enthusiasm from the Neutral condition on three other physiological measures also approached significance: smaller increase in IBI, $t = -1.85$, $p = .072$, greater increase in respiration rate, $t = 1.77$, $p = .087$, and increase in MAP, $t = 1.76$, $p = .094$. The increase in MAP also distinguished Anticipatory Enthusiasm from Amusement, $t = 2.16$, $p = .048$. Anticipatory Enthusiasm led to a decrease in RSA that differed significantly from change in RSA during the Neutral slides ($t = -2.55$. $p = .017$). However, this effect was no longer significant after controlling for baseline-to-trial change in Respiration Rate. Similarly, change in RSA differed significantly between the Enthusiasm and Amusement trials, $t = 2.74$, $p = .011$, although this effect was no longer significant after controlling for changes in respiration.

Attachment Love led to a decrease in IBI that differed significantly from the Neutral condition, $t = -2.88$, $p = .007$, as well as from the Amusement condition, $t = -2.49$, $p = .017$ and the Awe condition, $t = -2.22$, $p = .033$. Change in PEP during Attachment Love did not differentiate it from the Neutral condition, but did differ significantly from that in Awe, $t = -2.15$, $p = .039$. Number of valid SCRs observed during Attachment Love was significantly lower than during Enthusiasm, as reported above. Attachment Love also led to a decrease in RSA that differed significantly from change in RSA during the Neutral slides ($t = -2.74$. $p = .011$). However, this effect was no longer significant after controlling for baseline-to-trial change in Respiration Rate. No other differences between Attachment Love and other emotion conditions were significant.

Nurturant Love led to a decrease in IBI, $t = -2.14$, $p = .040$ and increase in Respiration Rate, $t = 2.60$, $p = .014$ that differed significantly from the Neutral condition. Change in PEP during Nurturant Love did not differentiate it from the Neutral condition, but did differ significantly from that in Awe, $t = -2.19$, $p = .036$. Number of valid SCRs observed during Nurturant Love was significantly lower than during Enthusiasm, as reported above. Nurturant Love also led to a marginally significant decrease in RSA compared with change in RSA during the Neutral slides ($t = -1.85$. $p = .075$). However, this effect disappeared after controlling for baseline-to-trial change in Respiration Rate. No other

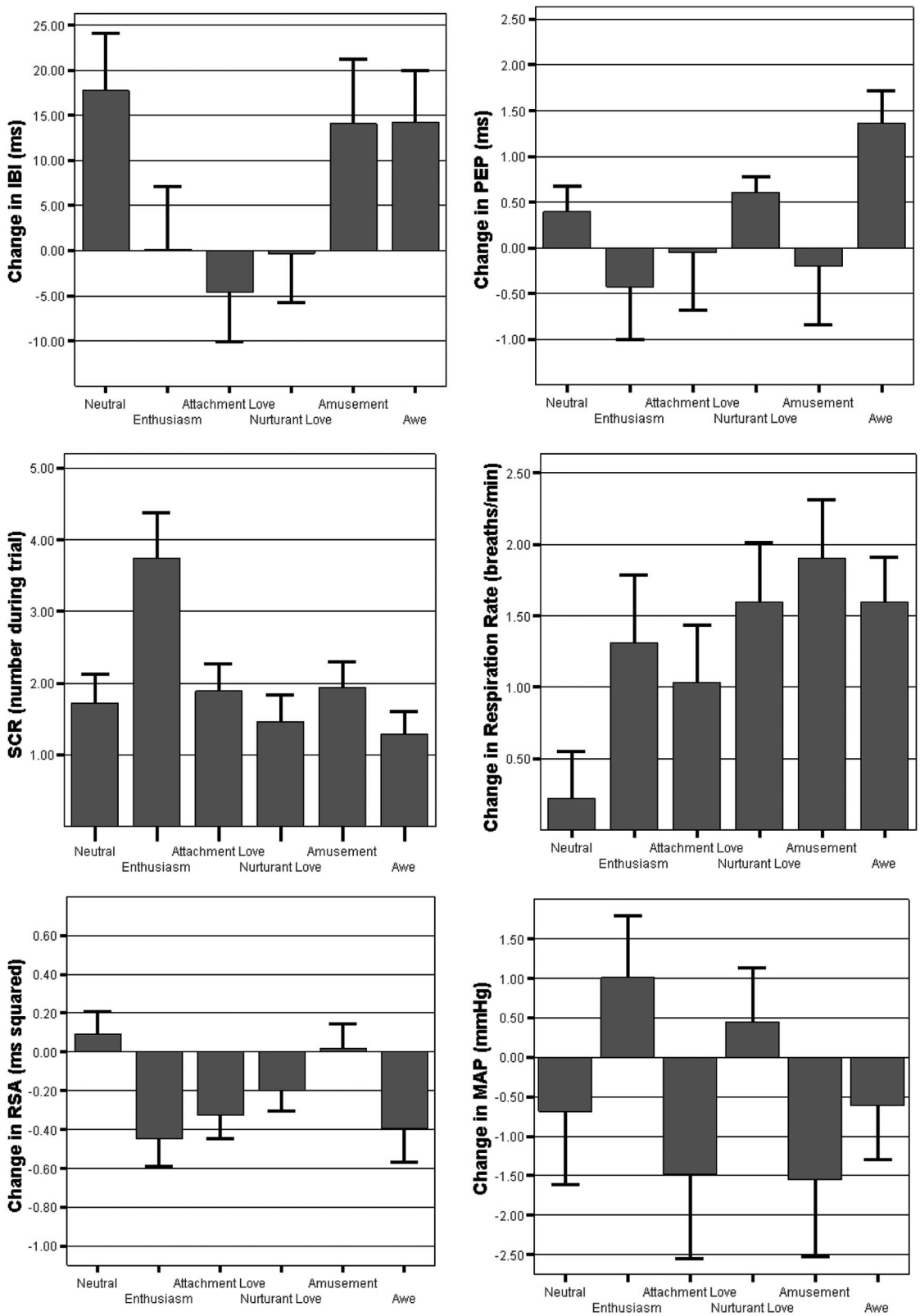

Figure 1. Baseline-to-Trial Changes in ANS Variables, by Emotion Condition *Note*: Error bars represent standard errors around the observed mean.

differences between Nurturant Love and other emotion conditions were significant.

The baseline-to-trial increase in IBI did not significantly distinguish Amusement from the Neutral condition, but did distinguish it from Attachment Love, as reported above. Change in PEP during Amusement also did not differentiate it from the Neutral condition, but did differ significantly from that in Awe, $t = -2.65$, $p = .012$. Number of valid SCRs observed during Amusement did not differ significantly from Neutral, but was greater than during Awe, $t = 2.09$, $p = .044$, and less than Anticipatory Enthusiasm (as reported above). Amusement led to a significantly greater increase in Respiration Rate than the Neutral condition, $t = 3.51$, $p = .005$. Also as reported above, change in RSA differed significantly between the Enthusiasm and Amusement trials, although this effect was no longer significant after controlling for changes in respiration. The decrease in MAP observed during Amusement did not distinguish it significantly from the Neutral condition, but did distinguish it significantly from Anticipatory Enthusiasm, as reported above. No other differences between Amusement and other emotion conditions were significant.

Awe did not lead to a change in IBI that differed significantly from the Neutral condition, although it did differ significantly from Attachment Love on this measure as described above. Awe led to a lengthening of PEP that differed significantly from the Neutral condition, $t = 2.86$, p .007, as well as from each of the other four positive emotion conditions, as described above. Awe involved fewer SCRs than did Anticipatory Enthusiasm and Amusement, as reported above. Awe led to an increase in Respiration Rate that distinguished it from the Neutral condition, $t = 3.02$, $p = .005$, but not the other positive emotions. Awe also led to a significant decrease in RSA compared with the Neutral slides ($t = -2.34$. $p = .075$). However, this effect disappeared after controlling for change in Respiration Rate. No other differences between Awe and other emotion conditions were significant.

Discussion

The current study offers evidence of differences in autonomic nervous system responding associated with multiple positive emotions. We detected significant overall differentiation among six emotion conditions—five positive, one neutral—not only in terms of a main effect on the set of physiological measures used in the study, but also in the profile of responding across measures. This suggests that ANS responses associated with the emotions in this study differed not only as a matter of degree, but also as a matter of kind. Moreover, we observed omnibus univariate differences among the emotion conditions on four ANS variables (IBI, PEP, SCRs, and Respiration Rate), and also differentiated each of the five positive emotions from the neutral control on at least one variable. This differentiation at the level of individual physiological measures is compelling, even compared to the many studies successfully contrasting multiple negative emotions using multivariate approaches. We believe that the degree of differentiation observed in the present study reflects our strict definition of the positive emotion constructs in theoretical terms, specifying the distinct fitness-enhancing function of each, and using that function to guide stimulus selection.

Physiological changes during anticipatory enthusiasm, thought to facilitate active pursuit of material rewards, were consistent with the hypothesized broad increase in sympathetic activation. In contrast, the lengthening of PEP associated with Awe was consistent with the hypothesized withdrawal of sympathetic influence—at least the β-adrenergic component—and directions of change in other variables (with the exception of respiration rate) were also consistent with this interpretation. The relatively shortened IBI associated with Attachment Love, combined with nonsignificant decreases in PEP and MAP, somewhat resembles the "challenge pattern" identified by Tomaka, Blascovich, Kibler, and Ernst (1997). This may suggest an increase in β-adrenergic, but not α-adrenergic, aspects of sympathetic influence. This effect differs from the increase in vagal parasympathetic activation we had predicted, but might well facilitate effortful approach toward a still-distant attachment figure. Nurturant Love was associated with relatively shortened IBI and increased respiratory rate, but no sign of reduced arterial pressure, and other variables offered few clues to the mechanism behind this increase in "arousal." Finally, amusement did not lead to the hypothesized increase in cardiovascular arousal. While this finding is inconsistent with effects observed in a number of other studies, it is consistent with studies of the "undoing" effect of amusement and other positive emotions (e.g., Fredickson et al., 2000). Methodological differences may well explain this inconsistency, a subject to be explored in future research.

A great deal more work is still needed to fully characterize the ANS aspects of particular positive emotions. The present study examined 90-s "snapshots" of autonomic responding associated with one stage of each emotion, as elicited by theoretically relevant photographs. In some cases, the physiological aspects of particular emotions may be best characterized by sequences of responding rather than a single stage, and our study would not have detected such effects. For example, the enhanced vagal parasympathetic activation we predicted for attachment love might be observed during actual reunion with an attachment figure (especially physical contact or "cuddling"), whereas detection of and approach toward such a figure involves the increased β-adrenergic influence observed in this study. It is also possible that the nature of ANS responding in a particular emotion depends to some degree on the way that emotion is elicited. The present study would not be able to detect such moderator effects.

Nonetheless, the present study offers strong added support for autonomic differentiation among some positive emotions, and thus adds to the evidence for the existence of multiple functionally distinct positive emotion constructs. We do not claim that the five emotions in the present study are the only positive emotions, and in fact studies using other methodologies offer some evidence for additional constructs (e.g., Griskevicius, Shiota, & Neufeld, 2010; Shiota et al., 2006; Tracy & Robins, 2004). It is also plausible that, as some have argued, positive emotion space is not organized into "discrete" categories at all, but rather reflects interaction among several continuous dimensions (e.g., Feldman Barrett & Russell, 1998; Scherer, 2001). These data do, however, add to the growing body of literature showing that positive emotion is not a single, unidimensional phenomenon. Furthermore, the data are not well explained by models of emotion that limit differentiation to high- versus low-arousal states. Most of the positive emotions in this study (except awe) elicited some increase in "arousal," but more specific physiological changes varied from emotion to emotion in ways that likely reflect different underlying autonomic mecha-

nisms. Prior studies have found that different experimentally elicited positive emotions have distinct effects of the processing of persuasive messages (Griskevicius, Shiota, & Neufeld, 2010); and on the attractiveness of specific consumer products (Griskevicius, Shiota & Nowlis, 2010). Other studies have found that different positive emotion dispositions show different patterns of correlation with core aspects of personality (Shiota et al., 2006). The present study documents qualitative differences among five positive emotions at the physiological level as well.

The present study does have a number of limitations. As noted earlier, our methods only captured brief snapshots of each positive emotion state—the point at which the eliciting stimulus is detected visually. Also, we elicited the target emotions using the same visual images for all participants. This inevitably leads to some loss in personal impact—especially for attachment love stimuli. Further, studies using event-related potential and startle response outcomes often find that simple figure-ground images convey hedonic content more effectively than complex scenes (e.g., Bradley, Hamby, Löw, & Lang, 2007). The inclusion of awe as one of the target emotions in the present study necessitated more complex images, but this might have diluted hedonic impact. Additional studies of these phenomena should use other elicitation methods, including film clips (which are likely to be more potent), and relived experiences (which will be more personal). Finally, losses of data in some ANS variables (particularly MAP) mean that null effects should be treated with the usual caution.

Despite these limitations, the present findings suggest that positive emotions still deserve greater attention than they have received from emotion research. Recent years have seen great advances in research on the global functions and characteristics of positive emotion (e.g., Fredrickson, 2001; Fredrickson & Branigan, 2005; Johnson & Fredrickson, 2005; Tugade & Fredrickson, 2004). Still, we have investigated the spectrum of positive emotions far less carefully than that of negative emotions. Distinct positive emotion constructs can be defined in functional/evolutionary terms, and these theoretical definitions are just as useful in generating empirical hypotheses as is true of the negative emotions. In failing to examine the depth and complexity of positive emotions, we lose a great opportunity to understand the depth and complexity of our own nature.

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