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Respiratory sinus arrhythmia as an index of emotional response in young adults

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Abstract

The relationship between respiratory sinus arrhythmia (RSA) and valence and arousal remains unclear. In the present study, the associations between emotion responses and tonic or task-related changes in RSA were assessed. Specifically, the sensitivities of changes in interbeat interval, RSA, and skin conductance to the valence and arousal values of emotional stimuli were examined. This study also explored the association between tonic RSA and subjective, expressive, and physiological emotional responses. Response measures were collected from 56 adults during baseline and film-viewing periods. Tonic RSA was not significantly related to any of the response measures. Increased skin conductance and decreased RSA were associated with arousal independent of valence. Interbeat interval was related to affective valence and not arousal. These findings suggest that RSA may be a useful adjunct to skin conductance measures in assessing emotional arousal.

Descriptors: Respiratory sinus arrhythmia, Emotion, Heart period, Skin conductance, Valence, Arousal

Autonomic nervous system responses to affective stimuli have been extensively investigated over the last century to elucidate both normal and pathological experience, as well as the relationship between affect and health (for recent examples, see Finney, Stoney, & Engebretson, 2002; Rottenberg, Kasch, Gross, & Gotlib, 2002; Vrana & Rollock, 2002). These studies have typically focused on responses mediated by the sympathetic branch of the autonomic nervous system (e.g., electrodermal activity) or processes innervated by both the sympathetic and parasympathetic nervous systems (e.g., heart rate). Researchers have only recently begun studying the relationship between respiratory sinus arrhythmia (RSA), a response solely innervated by the parasympathetic nervous system, and emotion.

RSA refers to rhythmic fluctuations in heart rate associated with respiration, which results from activity of the tenth cranial nerve, the vagus. During inspiration, vagal activity is attenuated and heart rate accelerates. During expiration vagal activity is reinstated, causing heart rate to slow. Research has demonstrated that RSA is primarily determined by the activity of a branch of vagal fibers originating from the medullary nucleus ambiguus and terminating at the sino-atrial node of the heart (Berntson et al., 1997; Porges, 1997). As interpreted by Porges in his Polyvagal Theory (Porges, 1995, 1997), nucleus ambiguus fibers evolved to facilitate the complex emotion responses and social behavior seen in mammals. Thus, measures of RSA are thought to provide a noninvasive window into the relationship between an evolutionarily recent nucleus ambiguus vagal system and affective experience.

Two sources of structural evidence link RSA to emotion. Efferent fibers from the nucleus ambiguus innervate the larynx, an important structure for communication of emotional state through vocalization (Porges, 1995; Porges, Doussard-Roosevelt, & Maita, 1994). Also, afferent fibers of the nucleus ambiguus are believed to terminate in the source nuclei of the facial and trigeminal nerves, which facilitate the emotion behaviors of facial expression and vocalization. Along with structural evidence, empirical studies relating RSA to emotion in humans have accumulated over the last few decades (e.g., Chambers & Allen, 2002; Cole, Zahn-Waxler, Fox, Usher, & Welsh, 1996; Fox, 1989; Porter, Porges, & Marshall, 1988; Umhau et al., 2002). However, some studies have not distinguished between tonic levels of RSA and changes in RSA, which generally show only modest association. Also, studies have typically not examined whether RSA indexes emotional responding or affect regulation processes.

Gross (1998, 1999) described a model in which emotion response tendencies are influenced by affect regulation processes at several points in the emotion generation cycle to produce observed emotional reactions. In this model, emotion response tendencies are adaptive subjective, behavioral, and physiological responses to significant environmental or internal events, whereas emotion regulation is any process, initiated by the individual to influence the experience or expression of those

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tendencies. Because emotion regulation is a dynamic process, response tendencies are constantly being influenced by previous and current emotion regulatory attempts. It is rare that any observed emotional reaction is ever completely unregulated. However, some situations elicit greater regulation than others. For example, reactions in the context of overt observation or with a co-actor present are likely heavily influenced by regulatory processes, whereas emotional reactions without overt observation or social demands may be more reflective of individuals' response tendencies.

Measures of emotional experience may also be influenced differentially by response tendencies and regulation processes. For example, the magnitude of emotional response may be less affected by regulatory processes than the variability of emotional responses over time. This is because variability measures contain information about the range of emotion responses. Emotionally dysregulated individuals have poor ability to adapt their emotion responses to fit changing situations or expectations (Gross, 1999; Gross & Munoz, 1995), so one might expect poorly regulated individuals to show an abnormal range of responding but not necessarily an altered magnitude of response. Retrospective reports may also be heavily influenced by regulatory processes, because they involve significant cognitive reappraisal of one's experience.

Tonic RSA

Studies examining tonic RSA levels clearly support a connection between RSA and emotional experience (Beauchaine, 2001). However, it remains unclear whether tonic RSA is related to emotion response tendencies, emotion regulation, or both. In infants and young children, increased baseline RSA has been associated with increased physiological and behavioral reactivity to positive and negative stimuli (e.g., Calkins & Fox, 1992; Fox, 1989; Stifter & Fox, 1990; Stifter & Jain, 1996). These data suggest that RSA is a marker of general reactivity to emotional stimuli. However, in studies of older children and adolescents, higher baseline RSA is associated with positive affect, coping, and social competence and inversely related to negative affect (e.g., Eisenberg et al., 1996; Fabes, Eisenberg, & Eisenbud, 1993; Mezzacappa et al., 1996). The latter findings implicate RSA as an index of emotion regulation processes.

Only a few studies have directly examined the relationship between tonic RSA levels and emotion in adults. Fabes and Eisenberg (1997) found a significant negative relationship between RSA and daily reports of negative emotional arousal to moderate and high intensity stressors as well as a positive association between tonic RSA and reports of regulatory control. Kettunen, Ravaja, Näätänen, and Keltikangas-Jarvinen (2000) found baseline and task levels of RSA to be positively related to the variability in reports of positive and negative emotion and the co-activation of physiological responses. In the former study, tonic RSA was described as an index of regulatory control, whereas in the latter study, the authors concluded that RSA marks individual differences in emotional responding. Thus, it remains uncertain whether tonic RSA levels are related to emotion response tendencies or affect regulation processes.

The previously described studies relating tonic RSA to emotion in adults have employed situations and/or measures heavily influenced by affect regulation processes. For example, in the Kettunen et al. (2000) study, emotional reactions were elicited using the Rorschach test, with an examiner present, and the measure of interest was the variability of subjective responses. The present research investigated the association between tonic RSA and the magnitude of emotion responses in an experimental context eliciting minimal pull for affect regulation. In the study described below, participants viewed emotionally evocative film segments without the direct presence of an observer or co-actor and were simply asked to report their experience. No instructions were given to alter their emotional experience or expression in any way. This procedure was expected to permit analysis of the relationship of tonic RSA to emotion response tendencies in the absence of strong affect regulation processes.

Changes in RSA

Research with infants, children, and adults has consistently found decreases in RSA during negative emotional experience (Beauchaine, 2001; Friedman & Thayer, 1998; Gottman et al., 1995; Thayer, Friedman, & Borkovec, 1996). However, the relationship between changes in RSA and positive emotion is less clear. In infants, positive affect has been associated with increased RSA (Bazhenova & Porges, 1997), but in young children, with decreases in RSA (Calkins, 1997; Cole et al., 1996; Miller & Wood, 1997). Among adults, Nyklicek, Thayer, and Van Doornen (1997) and Ritz, Alatupa, Thöns, and Dahme (2002) found comparable decreases in RSA during positive and negative affect elicitation, but Kettunen et al. (2000) and McCraty, Atkinson, Tiller, Rein, and Watkins (1995) found slight increases in RSA during tasks eliciting positive affect. These inconsistencies are likely due to several methodological shortcomings. First, the subjective arousal values of emotional stimuli were not measured in these studies. Differences between the arousal values of positive and negative stimuli within and across studies may contribute to discrepancies. Second, studies generally included only one stimulus to elicit positive emotion, limiting generalizability. Last, not all of the studies included a neutral condition, which is essential for determining the magnitude and direction of physiological changes to emotionally charged material.

The present research addresses methodological limitations in the RSA literature by eliciting affect using positive and negative stimuli of comparable arousal value, including a neutral comparison condition, and by including multiple indicators of affective experience. This research adopted a dimensional approach to the measurement of emotional experience. Lang and colleagues (Greenwald, Cook, & Lang, 1989; Lang, Greenwald, Bradley, & Hamm, 1993) have found this approach useful for determining whether physiological measures are related to the hedonic valence or arousal aspects of emotion. Dimensional paradigms confer the advantage of directly assessing the relationship between physiological responses and hedonic valence or arousal values of stimuli. Also, in dimensional approaches, affective experience is typically elicited using multiple pleasant and unpleasant stimuli. The use of multiple stimuli was expected to increase reliability and permits generalization to a larger body of positive and negative affect states.

The Present Study

This study was designed to evaluate the directionality of changes in RSA during positive and negative emotional experience and the relationship of tonic RSA to emotion responses using multiple emotion elicitation periods. The following hypotheses were proposed:

1. Inclusion of multiple positive, neutral, and negative emotion elicitation periods was expected to increase the reliability of subjective, expressive, and autonomic emotion responses.

2. Decreases in RSA were anticipated to both positive and negative emotional stimuli, suggesting a primary relationship with emotional arousal. This was meant to test the notion that vagal withdrawal facilitates quick engagement with the environment (Porges, 1997).
3. Changes in RSA were expected to be less sensitive to the arousal values of emotional stimuli than skin conductance responses (SCRs). Skin conductance measures are generally regarded as the most sensitive indices of emotional arousal (Cacioppo & Tassinary, 1990), whereas interbeat interval (IBI) has been inconsistently related to affective valence and arousal because of its dual innervation by sympathetic and parasympathetic fibers (Greenwald et al., 1989; Vrana, Cuthbert, & Lang, 1989).
4. Tonic RSA was expected to be positively related to the magnitude of subjective, expressive, and other physiological responses during positive and negative affect elicitation. This is inferred from the notion that RSA is associated with both emotion response tendencies and emotion regulation (for a review of studies, see Beauchaine, 2001). If tonic RSA is unrelated to the magnitude of emotion responses, it may suggest that RSA indexes emotion regulatory processes and not response tendencies.

Methods

Participants

Fifty-six undergraduate students (28 women) between the ages of 18 and 26 ($M_{\text{age}} = 19.1$, $SD = 1.53$) participated for course credit. The racial distribution was 61% Caucasian, 27% Asian American, 5% African American, 4% Hispanic, and 3% biracial or other. Men and women did not differ in age, $t(54) = 0.26$, $p > .75$, or ethnicity, $\chi^2(4) = 7.48$, $p = .11$. None of the participants reported cardiovascular problems or use of substances or medications affecting psychophysiological measures. All participants were asked to refrain from using products with caffeine or nicotine for at least 4 h prior to participation.

Emotional Stimuli

Film clips are an effective method for eliciting emotion (Gross & Levenson, 1993; Kring & Gordon, 1998). Nine film segments (three positive, three neutral, and three negative), each 120 s in length, were used to elicit affect. The positive segments consisted of a situation-comedy sketch, an Olympic-moments highlight tape, and a game-winning basketball play. The neutral films consisted of three nature scenes: a beach sunset, a canoe trip, and a sunrise. The negative segments involved a young boy calling for his mother while approaching a door that was not expected to be open, a person breaking into a house and following the inhabitant upstairs, and a young child being taken to the emergency room after hitting his head. A separate group of 42 undergraduates rated the film segments using the Semantic Differential Scale (Mehrabian & Russell, 1974). The positive segments were rated as pleasant and arousing (range 1–7; 1 = *unpleasant/relaxed*, 7 = *pleasant/aroused*; valence $M = 5.15$, $SD = 0.78$, arousal $M = 4.89$, $SD = 0.73$), the negative segments as unpleasant and arousing (valence $M = 3.54$, $SD = 0.49$, arousal $M = 4.92$, $SD = 0.75$), and the neutral segments as neutral and relaxing (valence $M = 4.21$, $SD = 1.05$, arousal $M = 2.57$, $SD = 0.58$). The positive and negative films were rated as considerably more arousing than the neutral film, $F(1, 40) = 352.94$, $p < .001$, and they did not differ in reported arousal, $F(1, 40) = 0.11$, $p > .70$.

Films were shown in blocks of three with a 2-min baseline period immediately before and after each block. One positive, one neutral, and one negative film were randomly assigned to each block, and films were separated by a brief period during which subjective reports were acquired. Also, a 1-min stabilization period followed each film segment to allow physiological measures to return to baseline levels. Baseline periods were employed to examine tonic RSA and to determine changes in RSA from baseline to film periods. Two counterbalanced orders of film segment presentation were used to control for order effects. Film orders were chosen so that all a priori film valence types occurred in the same average position. The film segments were presented via a VCR connected to a television monitor placed approximately 44 in. from each participant's face.

Dependent Measures

ECG and electrodermal activity (EDA) were recorded using electrodes applied to the surface of the skin. ECG and EDA were acquired using Biopac amplifiers (ECG bandpass 1–35 Hz; EDA bandpass DC-1 Hz), sampled at 1000 Hz, and stored on a computer running Acqknowledge 5.2 physiological data acquisition software. For ECG, Biopack EL 501 small disposable electrodes were placed in a lead II configuration. Deviant IBIs were identified and edited by visual inspection. RSA was quantified via spectral analysis of the IBI data, yielding total variance (ms^2) within the respiratory range (0.15–0.40 Hz; Berntson et al., 1997). Baseline and film-period measures of RSA were transformed via natural logarithm to normalize the distribution (Riniolo & Porges, 2000). EDA was acquired using a Biopack TSD103A EDA transducer filled with Unibase paste (0.05 M NaCl) and positioned on the volar surface of the first two fingers of the left hand. The number of SCRs, defined as fluctuations exceeding 0.05 μS, were determined for each recording period. Physiological data were imported into SPSS 11.0 (SPSS, 2002) for analysis. Changes in physiological measures were computed by subtracting the average of the values for the baselines preceding and following each film from the value for each film. Then, for each participant, physiological change scores and other emotion response measures were averaged within a priori valence categories.[1]

Participants' facial expressions were videotaped using a video recorder positioned unobtrusively inside a speaker box enclosure above the TV monitor. The number and intensity of positive, neutral, and negative expressions was judged by two independent coders for each film segment using the FACES coding system (Kring & Sloan, 1991). Intraclass Correlation Coefficients (ICC) model (2, 2) was used to determine the reliability of these judgments (Shrout & Fleiss, 1979). This statistic takes into account mean differences between raters and can be considered a measure of agreement. Interrater reliability was adequate for the number and intensity of affect-congruent expressions to positive and negative films (positive number $r_2 = .72$, intensity $r_2 = .81$;

[1]Physiological changes were examined in two additional ways. Both raw film values uncorrected for baseline values and the difference between each film and the most proximal baseline were computed. For the latter measure, the middle film in each block did not have a baseline period immediately preceding or following it, so the average of the two most proximal baselines was subtracted from this film. In both cases, analyses produced a similar pattern of findings to those reported and therefore were not included.

negative number $r_2 = .64$, intensity $r_2 = .73$). To calculate interrater reliability to the neutral film segments, the maximum number and intensity of expressions (positive or negative) was computed for each rater. In spite of the few expressions given to the neutral films, interrater reliability was adequate (number $r_2 = .62$; intensity $r_2 = .63$). Ratings of the number and intensity of expressions were averaged across coders for the positive and negative film segments. The maximum number and intensity of expressions coded by any rater was used for neutral films. This approach yields a conservative estimate of the true differentiation between film segments.

For analyses examining the relationship between facial expression measures and the valence values of stimuli, the number of negative expressions was subtracted from the number of positive expressions to each film, so that higher numbers indicate a greater number of positive expressions. For analyses examining the relationship between facial expressions and the arousal values of stimuli, the intensity of affect-congruent expressions was taken as the value for the positive and negative films. Because there were no expected expressions to the neutral film, the maximum intensity of positive or negative expressions was used. Due to the lower reliability and infrequency of expressions to the neutral film, correlation and regression analyses examining the relationship between tonic RSA and the number and intensity of expressions were performed only for the positive and negative film segments.

Subjective reports of valence and arousal to the films were obtained using the average of seven ratings. Five ratings (two valence, three arousal) were obtained from a five-point version of the Semantic Differential Scale (Mehrabian & Russell, 1974) and two items (one valence, one arousal) from the Self-Assessment Manikin (Bradley & Lang, 1994). This procedure was used because pilot data indicated that the number of items could be reduced without significantly reducing reliability. The valence scale consisted of ratings from the "Unsatisfied/Satisfied" and "Annoyed/Pleased" items from the Semantic Differential Scale and the valence manikin series from the Self-Assessment Manikin. The arousal scale consisted of ratings from the "Relaxed/Stimulated," "Calm/Excited," and "Sluggish/Frenzied" items from the Semantic Differential Scale and the arousal manikin series from the Self-Assessment Manikin. Internal consistency analyses of pilot data indicated that one more item was needed for the arousal scale in order to have comparable reliability. For each item, the scale ranged from 1 to 5, with Self-Assessment Manikin items being reverse scored. Coefficient alphas for the valence and arousal scales were moderate to high across film categories (valence $\alpha = .70$–$.89$; arousal $\alpha = .70$–$.90$).

Procedure

After providing initial written informed consent, participants were told that the purpose of the present study was to determine how young adults perceive and attend to films. Following a brief explanation of study procedures, participants were seated in a comfortable chair facing a television screen inside a small sound-attenuated room. Once sensors were applied, participants read the instructions for completing the subjective report scales and were told to complete the ratings after viewing the entire film segment. They viewed a 30-s nature scene and rated it, after which they had a chance to ask any questions about the procedure. Participants were then left alone in the sound-attenuated room for a 5-min period of accommodation, while the experimenter was seated in an adjacent control room. At the beginning of each prefilm baseline, participants were given the following instructions adapted from Fredrickson and Levenson (1998): "Relax and try to empty your mind of all thoughts, feelings, and memories." This instruction was given to reduce the possibility of participants ruminating about emotion-laden experiences during baseline recording.

Several procedures were incorporated to minimize participants engaging in conscious affect regulation strategies. In the consent processes, participants were informed that their behavior would be recorded, but no other mention of the camera was made and participants were not aware of the exact location of the camera; a procedure approved by the Case Western Reserve University Institutional Review Board. Second, participants were told to rate the films according to how it made them feel. They were instructed that the experimenters are only interested in their impressions and it was emphasized that people experience the films in many different ways. Last, participants viewed and rated all of the films alone, in a separate room from the experimenter. The success of these procedures at minimizing the pull for conscious affect regulation was supported by the fact that the majority of participants spontaneously reported during debriefing that they did not remember they were being videotaped and a review of videotaped recordings indicated that participants were engaging in off-task behaviors implying the perception of being alone (e.g., grooming behaviors, yawning, talking to oneself).

Data Analytic Strategy

For each dependent measure, 2 (film order) $\times$ 3 (film valence) repeated-measures ANOVAs were used to examine differences in emotional responses between films. Specific hypotheses were made regarding emotion responses to a priori valence categories based on previous work from our laboratory (Frazier, 2000); therefore only linear and quadratic contrast analyses are reported (Rosenthal & Rosnow, 1991). For contrast analyses, film segments were ordered positive, neutral, and negative so that linear contrasts compared positive to negative films, and quadratic contrasts compared the average of positive and negative films to the neutral film. Contrast order was chosen so that significant linear contrasts suggested a primary relationship with affective valence of the stimuli, whereas significant quadratic contrasts indicated a primary relationship with arousal. To determine the sensitivity of each measure to the valence and arousal properties of stimuli, one degree of freedom F values were converted to the effect size r for each linear and quadratic contrast. Pearson's r is an alternative to d for 1 degree of freedom linear and quadratic comparisons (Rosenthal & Rosnow, 1991).

To examine the relative sensitivity of changes in SCRs and RSA to emotional arousal, effect sizes were compared using the t test for the significance of the difference of dependent correlations. This test required computing a third correlation between RSA and SCRs for each film segment, converting these correlations to Fisher's z, averaging them, and then converting back to r. The resulting average correlation was taken as the third correlation for this analysis.

The hypothesis that tonic levels of RSA are positively related to the magnitude of emotion responses to positive and negative films was examined using linear regression analyses with baseline or film RSA, film order, and gender as independent variables. The frequency and intensity of expressions, valence and arousal ratings, and changes in SCL, RSA, and IBI to the positive and negative film segments were dependent variables in separate analyses. Baseline and film values of RSA were averaged across the four baselines or three films per valence category in order to produce the most reliable indices of tonic RSA (baseline RSA $r_4 = .95$; positive film RSA $r_3 = .95$; neutral film RSA $r_3 = .93$; negative film RSA $r_3 = .96$).

Results

Reliability of Emotion Responses

To determine the improvement in reliability when three rather than one indicator of emotional responding is employed for each valence category, ICC (model 3; Shrout & Fleiss, 1979) were computed for each response within each valence category. ICCs (3, 3) gives the reliability of the average of three indicators and only takes into account the rank ordering of individuals, ignoring mean differences. This measure was used because generalization was only desired to this set of films and not to the larger population of affective film segments. Thus ICC (3, 3) represents the reliability of the assessment of emotional responding when three indicators are used to compute a composite score. It is equivalent to Cronbach's alpha for a three-item test (Streiner & Norman, 1995). ICC (3, 1) gives the reliability of any one of the films and thus yields the approximate reliability if only one film segment were available. Comparison of these two indices was used to estimate the increase in reliability of the assessment of emotional experience by having multiple films.

Reliabilities for one film ranged from $r_1 = .14$–.62, whereas reliabilities for the average of three films ranged from $r_3 = .33$–.83. Differences between the reliability coefficients derived using ICC (3, 1) and ICC (3, 3) were computed using Fisher's r to z conversion. On average, the reliability of responses was improved by $\Delta r = .26$ (subjective report $\Delta r = .26$, facial expressions $\Delta r = .27$, physiological responses $\Delta r = .26$). This increase was significant, $t(20) = 26.64$, $p < .001$, and indicated that averaging measures within a priori valence categories produced more reliable estimates of affective experience.

Subjective and Expressive Responses

To determine whether film segments elicited the expected affect states, analyses were performed for subjective and expressive response measures. Table 1 presents means and standard deviations of response measures to the film segments. As expected, the positive films elicited greater pleasantness, $F(1, 52) = 39.20$, $p < .001$, than the neutral films, and the neutral films evoked greater pleasantness than the negative film, $F(1, 52) = 39.80$, $p < .001$. The positive and negative films also elicited substantially greater arousal than the neutral films, $F(1, 52) = 316.42$, $p < .001$. Although positive and negative films were equated for arousal in the pilot study, positive films were rated as less arousing than the negative films in the present study, $F(1, 52) = 20.50$, $p < .001$. Examination of Table 1 indicates that this difference, although highly significant, was modest in terms of the magnitude.

The positive films elicited more positive than negative expressions in comparison with the neutral film, $F(1, 52) = 103.53$, $p < .001$; however, the neutral and negative films did not significantly differ in the number of positive versus negative expressions, $F(1, 52) = 1.58$, $p = .21$. The positive and negative films elicited more intense expressions than the neutral film, $F(1, 52) = 96.61$, $p < .001$, and the positive film elicited more intense expressions than the negative film, $F(1, 52) = 21.35$, $p < .001$. In spite of slight differences in the observed pattern of valence and arousal/intensity elicited by the a priori valence categories, these data strongly indicated that the film segments elicited the intended affective states. Based upon the pattern of subjective and expressive responses, physiological measures displaying a primary relationship with valence were expected to show a predominant linear effect (positive different from negative), whereas measures associated with arousal should display a predominant quadratic effect (positive+negative different from neutral) across film valence categories.

Changes in Physiological Measures

Figure 1 presents changes in physiological measures to the film segments. To examine the hypothesis that RSA is sensitive to the arousal values of stimuli, independent of valence, linear and quadratic contrasts were computed as previously described. RSA decreased to positive and negative but not neutral film segments, linear $F(1, 52) = 1.38$, $p = .24$, $r = .16$; quadratic $F(1, 52) = 4.10$, $p = .05$, $r = .27$, indicating a relationship with arousal independent of valence. SCRs were also significantly related to arousal independent of affective valence, linear $F(1, 52) = 0.22$, $p = .64$, $r = .06$; quadratic $F(1, 52) = 94.37$, $p < .001$, $r = .80$, but IBI displayed a significant relationship with valence not arousal, linear $F(1, 52) = 6.17$, $p = .02$, $r = .33$; quadratic $F(1, 52) = 0.38$, $p = .54$, $r = .09$. None of the contrasts involving gender or film order were significant, largest $F(1, 52) = 0.94$, $p > .33$, indicating the pattern of changes in physiological responses was highly similar for genders and film orders.

Table 1. *Means and Standard Deviations of Subjective, Expressive, and Physiological Responses to Positive, Neutral, and Negative Film Segments*

	Valence category					
	Positive		Neutral		Negative	
	M	*SD*	*M*	*SD*	*M*	*SD*
Valence ratings	4.08	0.63	3.39	0.69	2.64	0.61
Arousal ratings	3.33	0.53	1.65	0.53	3.61	0.56
Expression number (positive–negative)	1.97	1.78	– 0.16	0.72	– 0.35	1.22
Expression intensity	1.19	0.56	0.44	.043	0.75	0.60
ΔIBI (ms)	9.42	32.44	10.45	23.21	16.61	32.22
ΔRSA (ln ms^2)	– 0.12	0.26	– 0.07	0.23	– 0.14	0.29
ΔSCRs	3.94	4.25	– 1.55	2.36	3.70	5.18

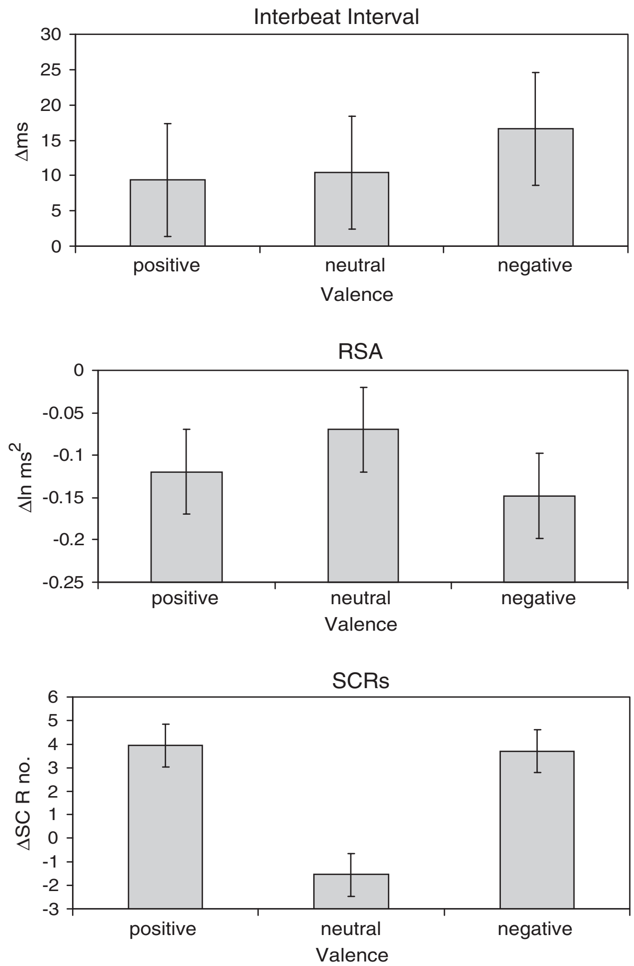

Figure 1. Mean and 95% confidence intervals of changes in IBI (Δms), RSA (Δ ln ms^2), and SCRs (Δ number of SCRs) to the film segments.

Table 2 presents the sensitivity of each response measure to the a priori valence and arousal values of emotional stimuli. Changes in SCRs were significantly more sensitive to emotional arousal than changes in RSA, $t(53) = 4.27$, $p < .001$. RSA was only modestly related with other physiological responses across the film segments (IBI $r(54) = .29$–.36, SCRs $r(54) = -.19$–.30). Changes in RSA also were minimally related to subjective and expressive responses (subjective $r(54) = -.15$–.23; expressive $r(54) = -.18$–.14). There were no significant gender differences for any of the analyses, largest $z = 1.77$, $p = .08$.

Table 2. *Effect Sizes for Linear and Quadratic Contrasts*

		Effect sizes (r)	
		Valence (linear)	Arousal (quadratic)
Subjective report	Valence	**.84****	.04
	Arousal	.53**	**.95****
Facial expressions	Number	**.80****	.70**
	Intensity	.56**	**.76****
Physiological measures	ΔIBI	**.33***	.09
	ΔRSA	.16	**.27***
	ΔSCRs	.06	**.80****

Note: Predominant relationship with valence or arousal is in bold face. *$p < .05$, **$p < .001$.

Tonic RSA and Emotional Reactivity

Baseline RSA was unrelated to subjective, expressive, or physiological measures, largest $t(52) = 1.81$, $p = .08$, $r = .24$. Nonsignificant results were also obtained for film RSA, largest $t(52) = 1.07$, $p = .29$, $r = .14$. The exception was the prediction of changes in SCRs to the neutral film, $t(52) = 2.34$, $p = .02$, $r = .30$. This finding was unexpected and likely due to inflated Type I error for these comparisons. Gender was a significant predictor of arousal ratings to the neutral film, $t(52) = 2.91$, $p < .01$, $r = .37$, in both sets of analyses, with women reporting greater relaxation than men. However, film order and gender were not significant predictors in any other analysis, largest $t(52) = 1.61$, $p = .11$, $r = .21$. The lack of significant findings relating tonic RSA to subjective, expressive, and other physiological measures was not likely due to a lack of power. This study had adequate power for detecting a medium effect size, $r = .30$; power = .81, $\alpha = .05$. Also, the average correlations between tonic RSA levels and response measures were small (baseline RSA $r(54) = .06$, film RSA $r(54) = .06$), and several of the relationships were opposite of the predicted direction.

Discussion

Several important findings emerged in the present research. RSA decreased during both positive and negative emotions, indicating a relationship with emotional arousal, independent of valence. The quadratic relationship for RSA was moderate in magnitude and was significantly smaller than the large quadratic effect for skin conductance measures. Also, RSA displayed different relationships with emotion dimensions than IBI, indicating significant directional fractionation. Finally, tonic RSA levels were unrelated to subjective, expressive, and other physiological response measures. Each of these findings has important practical and theoretical implications for understanding emotion processing and for informing future psychophysiological research.

Decreases in RSA to both positive and negative arousing affect states is consistent with the notion that vagal activity at the sino-atrial node provides for a rapid engagement of either approach or withdrawal tendencies (Porges, 1995). The discrepancy between the present findings and research indicating increases in RSA during positive experience (Bazhenova & Porges, 1997; DiPietro, Porges, & Uhly, 1992) may be due to age differences in study samples. If true, a developmental shift in RSA responding may parallel the increased differentiation and expression of arousing and relaxing positive affect states during development. Alternatively, the discrepancy may be due to the fact that most studies in infants and children have not measured the arousal values of emotional stimuli. In this case, positive affective states elicited in previous studies may be substantially less arousing than negative affect states, falsely implying a valence effect. The latter explanation highlights the need to measure the valence and arousal properties of stimuli and include neutral stimulus conditions when making inferences regarding the directionality of physiological changes to emotion.

The moderate magnitude of RSA changes relative to skin conductance changes indicates that skin conductance is preferred in studies employing a single physiological measure of emotional arousal. However, RSA and skin conductance were only modestly correlated, suggesting that RSA and skin conductance measures differentially classify some individuals as aroused and others as not aroused. This was not a surprising finding given the directional fractionation of many autonomic responses (Stern, Ray, & Quigley, 2001). In future studies, RSA may provide an adjunct or alternative to skin conductance for quantifying arousal. Measurement of RSA may be particularly useful for examining affect in individuals with dementia who can no longer reliably report their experience (Kramer, Gibson, & Teri, 1992), individuals who show diminished or absent skin conductance responses (Catania, Thompson, Michalewski, & Bowman, 1980), or in participants who are taking medications influencing electrodermal but not cardiac responses (Hveem, Svebak, Hausken, & Berstad, 1998). Studies of emotion and aging are particularly likely to encounter these situations, because older adults are more likely than younger adults to be taking medications affecting psychophysiological response (Schmader et al., 1998) and skin conductance responses are attenuated with age (Fowles, 1986).

RSA decreased to positive and negative stimuli in spite of the fact that IBI increased to negative and deceased to positive stimuli. One interpretation of the differential response patterns for RSA and IBI is that both positive and negative emotional states result in parasympathetic reductions early in the emotion-generation process, but that positive states result in increased, and negative states decreased, sympathetically mediated cardiac responding. This interpretation is supported by previous research demonstrating an association between heart rate and valence using pictures to elicit emotion (Greenwald et al., 1989; Lang et al., 1993). Alternatively, differences in RSA and IBI responding during positive affect may be due to the differential influence of respiration on these measures. Ritz and colleagues (2002) found similar results to those in the present study for uncorrected measures of RSA. However, when RSA was corrected for changes in tidal volume, their results became nonsignificant. This suggests that the observed decreases in RSA may be due to changes in respiration, a possibility that could not be examined in the present study. We suggest that the high correlation between different measures of RSA in previous studies (Grossman, Van Beek, & Wientjes, 1990) makes it unlikely that the present findings would have changed substantially. Although future studies measuring both RSA and respiration are needed to test this assertion.

Tonic RSA was poorly related to subjective, expressive, and other autonomic responses. This finding replicated previous results in our laboratory using a smaller set of film stimuli (Frazier, 2000). Furthermore, the lack of a significant relationship was not likely due to methodological problems because this study had good power for detecting a relationship, observed relationships were small in magnitude and often opposite of the predicted direction, and emotion responses to positive, neutral, and negative affective stimuli had adequate reliability. This finding stands in stark contrast to studies reporting significant relationships between tonic RSA and emotional reactions in adults (Fabes & Eisenberg, 1997; Kettunen et al., 2000). However, the latter studies employed situations where participants were likely engaging in substantial regulation of their response tendencies or measures that included information about the range, but not the magnitude, of emotional responses. In sum, it seems plausible that previous significant findings actually reflect a positive relationship between RSA and affect regulation, not emotion response tendencies. It should be noted, however, that the present study did not exclusively measure response tendencies, particularly because individuals were initially informed of the presence of behavioral recordings. The latter instruction may have increased affect regulation tendencies in some participants.

Another finding from the present research concerned the improvement in the reliability of response measures, particularly autonomic indices, when multiple stimuli were used to elicit emotion. In general, the reliability of emotion responses to individual films was generally poor, but estimates of reliability improved substantially when additional measurement periods were employed. Although this finding is an expected consequence of lengthening a test (Streiner & Norman, 1995), it suggests that future psychophysiological studies of emotion should include at least three and likely more indicators of each affect state to adequately measure responding.

Limitations and Future Directions

Although the present study used multiple indicators of positive, neutral, and negative emotion, findings are still limited by the particular stimuli used and the method of emotion elicitation. Future studies eliciting affect in other ways (e.g., music, relived emotions, directed facial action) will determine whether the present findings generalize to other situations. Also, because the present research employed a dimensional approach to the measurement of emotion, the primary emotion tapped by each film was not quantified. Consequently, differences in RSA responding to discrete emotions could not be directly examined. However, participants were asked informally during debriefing about what emotions they felt most during the movies. Their responses indicated that the negative stimuli primarily elicited fear and that two of the positive stimuli elicited excitement whereas the other stimulus elicited amusement. Post hoc analyses of differences between individual films suggested no differences in changes in RSA to the positive, $F(2, 51) = 0.05$, $p > .90$, or negative, $F(2, 51) = 1.42$, $p > .25$, films. This says little about differences between negative affective states, because only fear was represented; however, it may suggest that decreases in RSA occur to both amusement and excitement/enjoyment. Future studies should directly examine changes in RSA to other types of discrete affect while equating, if possible, the arousal values of these affective states. It is possible that a different pattern of findings will emerge for happiness/joy, anger, or sadness.

We are grateful to an anonymous reviewer for pointing out the possibility that the strong arousal effects observed for RSA and SCRs could be partially due to difficulty inducing strong negative affect states. Specifically, the valence values for negative film segments tended to be closer to the neutral point of the scale than values for positive film segments. This highlights the difficulty with selecting positive and negative stimuli of comparable arousal value while simultaneously achieving valences values that show similar distances from neutral (Lang, 1995). However, it is our opinion that the overall pattern of findings indicated the manipulation was adequate for determining the primary relationship of response measures to emotion dimensions. This perspective is based upon several observations. First, the negative films in the present study elicited valence values that were highly significantly different from the neutral point of the scale, $t(55) = 4.35$, $p < .001$. Second, negative films showed greater intensity of expression than neutral films. Finally, IBI was sensitive to the valence, but not arousal, properties of stimuli, suggesting that the present study was not only successful at manipulating arousal.

The present study was not able to directly test the notion that tonic RSA is reflective of affect regulation and not emotion response tendencies. To test this hypothesis, designs that alter the level of emotion regulation are required, such as having individuals respond to emotional stimuli alone and then in groups or partners. Alternatively, the relationship could be explored under situations where participants simply view emotional stimuli versus having them attempt to change their emotional state (i.e., suppressing or enhancing their expressions or experience). In either case, findings from the present study suggest that significant associations between RSA and emotional reactions will only emerge when individuals are actively regulating their response tendencies.

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