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Respiratory sinus arrhythmia, emotion, and emotion regulation during social interaction

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Abstract

Respiratory sinus arrhythmia (RSA) figures prominently in emotional responding, but its exact role remains unclear. The present study tests two hypotheses: (1) Between-person differences in resting RSA are related to emotional reactivity, and (2) within-person changes in RSA are related to regulatory efforts. Pairs of women watched an upsetting film and discussed it. One woman in each of the experimental dyads was asked to either suppress or to reappraise during the conversation. Their partners and both members of the control dyads conversed naturally. Between-person differences in resting RSA were assessed with paced breathing, and within-person changes in RSA were calculated from baseline to the conversation accounting for respiration. Women with higher resting RSA experienced and expressed more negative emotion, and women who attempted to regulate their emotions either by suppressing or reappraising showed larger increases in RSA than controls.

Descriptors: Respiratory sinus arrhythmia, Emotion regulation, Social interaction

Respiratory sinus arrhythmia (RSA) refers to the periodic fluctuations in heart rate that are linked to breathing. RSA is determined largely by vagal influences on the heart, and as such provides a noninvasive index of parasympathetic activity (for other factors influencing RSA and issues regarding its interpretation, see Berntson, Cacioppo, & Quigley, 1993; Grossman & Kollai, 1993; Grossman & Taylor, in press). A growing body of theory and research suggests that RSA figures prominently in emotional responding (Beauchaine, 2001; Demaree, Robinson, Everhart, & Schmeichel, 2004; Diamond & Hicks, 2005; Fabes & Eisenberg, 1997; Frazier, Strauss, & Steinhauer, 2004; Kettunen, Ravaja, Naatanen, & Keltikangas-Jarvinen, 2000; Porges, 1995a, 1995b; Porges, Doussard-Roosevelt, & Maiti, 1994; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996; Thayer & Lane, 2000); however, its exact role remains unclear.

Two major hypotheses regarding the link between RSA and emotional responding have been offered: (1) differences between people in resting RSA are associated with individual differences in emotional reactivity (Beauchaine, 2001; Demaree et al., 2004; Diamond & Hicks, 2005; Frazier et al., 2004; Kettunen et al., 2000; Porges, 1995b, 2003; Porges et al., 1996; Salomon, 2005; Thayer & Lane, 2000), and (2) acute changes within a person in RSA accompany either self-regulatory efforts or shifts in emotional experience (Beauchaine, 2001; Frazier et al., 2004; Kettunen et al., 2000; Porges, 1995b, 2003; Porges et al., 1996; Thayer & Lane, 2000).

Although appealing, the evidence for these hypotheses is limited in several ways. First, the existing literature is complicated by the myriad of ways in which RSA resting levels and state changes can co-occur or overlap. For example, any measure of resting RSA can also be conceptualized as a response to that measurement situation. Similarly, changes in RSA may be linked to situational factors such as experimental manipulations (Bazhenova, Plonskaia, & Porges, 2001; Beauchaine, 2001; Hansen, Johnsen, & Thayer, 2003; Houtveen, Rietveld, & De Geus, 2002; Ingjaldsson, Laberg, & Thayer, 2003), or they may take the form of changes in resting RSA due to factors such as recovery from depression (Chambers & Allen, 2002). Thus, although there is a large literature on RSA and emotion, there are relatively few studies in which between-person differences in resting RSA are clearly distinguished from within-person changes due to task demands, making it difficult to evaluate the evidence for the between- and within-person hypotheses suggested above. To add to this confusion, respiration is rarely taken into account in the existing literature, although it is well documented that RSA is strongly influenced by breathing parameters and that ignoring respiration can introduce both measurement error and potential confounds (Berntson et al., 1993; Grossman, Beek, &

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Wientjes, 1990; Grossman & Kollai, 1993; Houtveen et al., 2002). Finally, although there are large literatures on RSA in children and clinical populations, research on healthy adults is limited, and restricted to solitary settings such as viewing films alone. This makes it unclear whether and how RSA might be related to emotional responding during adult social interactions. This gap in the research is notable given that social interactions can both provoke strong emotions and demand extensive emotion regulatory efforts (Keltner & Kring, 1998).

In the present research we address these limitations by measuring between-person differences in resting RSA during a paced breathing task, as well as acute within-person RSA changes in response to an experimental manipulation of emotion regulation during face-to-face interactions between healthy adults. In addition, we measured respiration throughout, allowing us to account for its influences on RSA. To prepare the ground for our study, we first review prior research related to the between- and within-person hypotheses suggested above.

Between-Persons Differences in Resting RSA

Based on an extensive review of the literature, Beauchaine (2001) suggests that high levels of resting RSA are indicative of physiological flexibility, and that this predisposes the individual to emotional reactivity and engagement with the physical and social environment. For example, high resting RSA in infants has been associated with both negative and positive emotional reactivity, whereas in childhood it is associated with socio-emotional competence (Beauchaine, 2001). Beauchaine suggests that this pattern may emerge due to normative development, whereby the autonomic flexibility associated with high resting RSA facilitates engagement with and reactivity to the environment in infants, as well as the capacity to react flexibly to social situations as the child matures. On the flip side, low levels of resting RSA in adults have been associated with a wide range of psychopathologies that can be characterized by emotional rigidity and poor social functioning, including depression (Carney et al., 2000; Rechlin, Weis, Spitzer, & Kaschka, 1994), anxiety (Friedman & Thayer, 1998a, 1998b; Thayer, Friedman, & Borkovec, 1996; Watkins, Grossman, Krishnan, & Sherwood, 1998), alcoholism (Ingjaldsson et al., 2003), and hostility (Brosschot & Thayer, 1998; Demaree & Everhart, 2004; Sloan et al., 1994).

It is important to note that, although these psychopathologies typically involve intense negative emotions, those emotions are generally inflexible and not responsive to environmental stimuli. This point has caused some confusion in the literature, with low RSA in clinical populations described both as being associated with excessive reactivity (e.g., Demaree et al., 2004) and with excessive rigidity (e.g., Thayer & Lane, 2000). We prefer the latter interpretation, which is in keeping with the theoretical assumption that RSA levels are indicative of degrees of physiological flexibility (Beauchaine, 2001; Porges, 1995b; Porges et al., 1994; Thayer & Lane, 2000). Given this assumption, if we extrapolate to healthy adults we might expect high levels of resting RSA to be associated with greater intensity of emotional responses (within the normal range).

Unfortunately very little research on healthy adult samples exists, and the results that have been reported are mixed. On the one hand, high levels of resting RSA were associated with greater variability and intensity of emotional experience in men responding to a Rorschach test (Kettunen et al., 2000). Similarly, high resting RSA predicted a greater ability to exaggerate expressive behavior in response to a disgusting film (Demaree et al., 2004). On the other hand, it was also associated with less spontaneous disgust expression to the same film, and in another study baseline RSA was unrelated to either emotional experience or expression in response to a range of negative and positive films (Frazier et al., 2004). Likewise, under low to moderate levels of daily stress, baseline RSA was unrelated to emotional responding, and at high levels of stress, it predicted less emotional reactivity (Fabes & Eisenberg, 1997).

There are several reasons to believe that these scant and contradictory findings may have arisen due to methodological issues. First, RSA is strongly influenced by respiration rate and depth, and if these factors are not taken into account, then individual differences in RSA are unlikely to be directly linked to differences in vagal tone (Berntson et al., 1993; Grossman & Kollai, 1993; Grossman et al., 1990; Houtveen et al., 2002). Despite this, in the small research on healthy adults, this confound is not addressed, and this may contribute to the variable results. Second, Porges' Polyvagal Theory (Porges, 1995a, 1995b, 2003; Porges et al., 1994, 1996) suggests that the evolutionary function of the "smart vagus," which is responsible for RSA, is to enable the flexible emotional responding that is required for mammalian social behavior. In addition, social situations can enhance emotional responses and provoke extensive emotion regulatory efforts (Keltner & Kring, 1998). As such, RSA may show more robust associations with emotional processes in social situations, and the lack of results from studies using film-viewing paradigms (e.g., Frazier et al., 2004) may be due to these solitary situations failing to reliably engage the vagal system.

In the present research, we took two steps to address these concerns. First, we used a paced breathing task to limit the variability in respiration across participants when measuring individual differences in RSA. There is growing debate on the issue of whether RSA is ever an accurate index of individual differences in cardiac vagal tone or whether it is at best an indicator of phasic vagal modulation of heart rate (see, e.g., Grossman & Kollai, 1993; Grossman & Taylor, in press; Hayano et al., 1991). However proponents on both sides of the debate agree that if respiratory parameters are not equated across participants, then RSA is not a valid indicator. The use of a paced breathing task also allowed us to consider heart rate, respiration rate, and respiration volume under controlled conditions as independent predictors of subsequent emotional reactivity, thereby evaluating whether RSA is predictive above and beyond these other parameters. This approach is in keeping with the suggestion of Grossman and colleagues (Grossman & Kollai, 1993; Grossman & Taylor, in press) that including heart rate can improve the prediction of vagal tone from RSA. It also enabled us to rule out the possibility that variability in the participants' emotional reactivity to the paced breathing task resulted in differences in breathing parameters that artificially elevated RSA in emotionally reactive individuals.[1]

Second, to study RSA in a social context, we investigated the ability of the physiological measures to predict individual differences in emotional experience and expression during face-to-face conversations between adult women. We focused on women because there is some evidence that they have higher resting levels of RSA than men (Jonsson & Sonnby-Borgstrom, 2003) and are

[1]The authors thank an anonymous reviewer for pointing out this potential confound and for suggesting these additional analyses to help rule it out.

also more emotionally reactive (Kring & Gordon, 1998), which might lead to more pronounced effects. As a topic for conversation we asked the women to watch and then discuss an upsetting documentary war film. Our prior research has shown that discussing this film evokes strong negative emotional responses (Butler et al., 2003). We predicted that higher levels of RSA during the paced breathing task would be associated with greater emotional reactivity during the conversation in the form of increased negative experience and expression.

Within-Person Changes in RSA

Although resting RSA is sometimes found to be correlated with RSA changes within a person (Porges et al., 1994, 1996; Salomon, 2005), the two are not redundant, and various authors have argued that they are differentially related to emotional processes (Beauchaine, 2001; Frazier et al., 2004; Kettunen et al., 2000; Porges, 1995b; Porges et al., 1996; Rottenberg, Wilhelm, Gross, & Gotlib, 2003; Rottenberg, Salomon, Gross, & Gotlib, 2005). Thus, whereas resting RSA is hypothesized to reflect autonomic flexibility, and hence be related to emotional responsivity as discussed above, acute changes in RSA are theorized to relate to self-regulatory efforts and mood state (Beauchaine, 2001; Frazier et al., 2004; Porges, 1995a, 1995b; Porges et al., 1994, 1996). More specifically, vagally mediated heart rate deceleration, with corresponding increases in RSA, is expected to occur when an organism attends to and engages with an environmental stimulus or when it relaxes in a safe environment. In humans, this may often be driven by self-regulatory efforts designed to facilitate such engagement or relaxation and may be accompanied by corresponding positive mood states. In contrast, decreases in RSA are expected when an organism responds to the environment with a fight-or-flight activation pattern, which involves vagal withdrawal and increased sympathetic activation. Thus reductions in RSA in nonclinical populations have been assumed to index physiological responses to stressors and to be accompanied by negative mood states due to the presence of those stressors (Beauchaine, 2001; Porges, 1995b; Thayer & Lane, 2000).

In contrast to the research on resting RSA, the literature on acute changes in RSA is much smaller. In one study, alcoholics with relatively good self-control over their drinking showed increases in RSA in response to an imaginary drinking task, whereas their counterparts with poor self-regulation did not, suggesting that the more self-regulated drinkers' successful efforts to restrain themselves led to the RSA increases (Ingjaldsson et al., 2003). Turning to normative samples, there is some evidence from children that increases in RSA accompany positive mood inductions and social engagement, whereas decreases in RSA are produced by negative mood inductions and laboratory stressors (Bazhenova et al., 2001; Beauchaine, 2001). There is also some evidence from the limited work on healthy adults that RSA increases can be produced through relaxation (Houtveen et al., 2002) and are associated with positive mood (Ingjaldsson et al., 2003), whereas RSA decreases are provoked by laboratory stressors such as cognitive challenges (Hansen et al., 2003; Houtveen et al., 2002) and by negative mood inductions such as worrying (Thayer et al., 1996) or phobic distress (Wilhelm & Roth, 1998). As with the research on resting RSA, however, the findings are not uniform. In one study of children, both a positive and a negative mood induction resulted in RSA decreases (Beauchaine, 2001), and RSA decreased to both positive and negative films in a study of normal adults (Frazier et al., 2004).

Again, the variability of these findings may be partially due to unmeasured breathing parameters introducing measurement error and confounding influences. To address this, in addition to measuring RSA during the paced breathing task, we also measured RSA changes from a baseline period, during which pairs of participants watched a mildly positive nature film, to a conversation between them about an upsetting documentary war film that they had also previously both watched. We measured respiration throughout, allowing us to ascertain that changes in respiration rate and volume could not account for changes in RSA, which is important if we are to assume that RSA changes were at all related to vagal levels (Grossman et al., 1990; Houtveen et al., 2002). It also allowed us to statistically remove the influence of respiration on RSA, thereby increasing our power to detect group differences in RSA changes, so long as no group differences in respiration were observed (Miller & Chapman, 2001).[2] These issues are particularly important when changes in respiration are expected, as in the present research involving conversation. Finally, we also measured heart rate throughout, allowing us to consider whether this measure provided convergent evidence with RSA regarding changes in cardiac vagal tone.

In addition to these methodological issues, in most research on within-person changes in RSA, self-regulatory processes are confounded with changes in emotional experience and expression. Thus it remains unclear whether RSA changes are associated primarily with attentional and cognitive processes involved in self-regulation in general or with the emotional changes that result from such regulation or both. To begin to disentangle these factors, we experimentally manipulated emotion regulation efforts during the conversations and compared two forms of regulation both with each other and with an uninstructed control group.

The regulation strategies we focused on are expressive suppression, which involves inhibiting emotion expression, and cognitive reappraisal, which entails thinking about a situation in such a way that desired emotions are generated. Both strategies are prevalent in everyday life for down-regulating negative emotion (Gross & John, 2003; John & Gross, 2004), and prior research suggests that both strategies should reduce negative expressive behavior (Gross, 1998, 2002; Gross & John, 2003). Despite these similarities, the two strategies have also been shown to have differential effects on emotional experience and positive expression (Gross, 1998, 2002; Gross & John, 2003). Expressive suppression, on the one hand, should fail to reduce negative experience and should lead to reduced positive expression. In contrast, cognitive reappraisal should reduce negative experience while increasing positive expression. Thus, if RSA increases are associated with self-regulatory efforts in general, then both expressive suppression and cognitive reappraisal should lead to

[2]Using respiration difference scores as covariates removes the variance in RSA changes within persons accountable for by changes in respiration within persons, but it does so across subjects, not within subjects (Grossman & Taylor, in press). In other words, it reflects the covariation of two difference scores across subjects, not the covariation of two measures within persons over time. To properly remove the variance due to within-person covariation of respiration and RSA, more than two time points of measurement would be required, which were not available in the present research. The authors thank an anonymous reviewer for suggesting the analysis of respiratory change as a second method to rule out the possibility that RSA changes were driven purely by respiratory changes.

RSA increases relative to the uninstructed control group. If, however, RSA increases are associated with enhanced positive experience or expression, then cognitive reappraisal—but not expressive suppression—should produce RSA increases. Given the lack of prior research, we made no predictions regarding which was the more likely outcome.

Methods

Participants

One hundred and ninety female college students between the ages of 18 and 28 ($M_{age} = 20.0$, $SD = 1.9$) participated in the present study, for which they were each paid $30. The distribution of self-reported ethnicity was 43.2% European American, 34.7% Asian American, 3.7% Latin American, 2.6% African American, and 15.8% Other. All participants were fluent English speakers and provided written consent prior to the experimental session.

Design

Participants were randomly assigned to take part in pairs, with the stipulation that they had not met before. Each pair was then randomly assigned to either an uninstructed control group ($n = 36$ pairs), a suppression group ($n = 33$ pairs), or a reappraisal group ($n = 26$ pairs).[3] Within the suppression and reappraisal groups one woman in each pair was randomly assigned to receive emotion regulation instructions (described below), whereas her partner remained uninstructed.

Paced Breathing

Participants in a pair were greeted and briefly introduced to each other. They were then seated 2 m apart, separated by an opaque screen that prevented them from seeing each other. They were told that the purpose of the experiment was to better understand emotional responding during conversations. After attaching physiological sensors, participants were instructed to listen to a soft tone that rose and fell in pitch and were asked to breathe in as they heard the tone rising and to breathe out as the tone fell. They were told that this would provide a physiological baseline for later measurements. Once the participants indicated that they understood the instructions, the experimenter left the room and the tone began. The tonal pattern was designed to induce a respiratory frequency of 9 cycles per minute and was presented for 2 min. This procedure is recommended to keep respiration rate constant between individuals during assessment of individual differences in resting RSA (Grossman, Stemmler, & Meinhardt, 1990; Wilhelm, Grossman, & Coyle, 2004).

Film Stimuli

Following the paced breathing task, participants viewed a 6-min relaxing nature film to provide a baseline measure for the assessment of within-person changes in RSA. After this baseline film, the participants then watched an upsetting 11-min documentary film about the bombing of Hiroshima and Nagasaki during World War II. Everyday emotion-laden conversations often revolve around a shared emotional event, and this film provided such a shared stimulus for the participants to discuss. Our prior research has shown that this film elicits high levels of sadness, anger, and disgust as well as strong religious and political opinions (Butler et al., 2003). The films were presented on a television monitor positioned such that both participants could see it while not being able to see each other.

Conversation and Emotion Regulation Manipulation

Random assignment to the suppression, reappraisal, or control condition took place immediately after a pair viewed the war film. The participants were given headphones and told that they would be listening to some music while additional baseline physiological measures were collected. This provided the opportunity to deliver emotion regulation instructions to one randomly chosen woman in each of the regulation group pairs. Thus, unbeknownst to their uninstructed partners, the suppression regulators received tape-recorded instructions via the headphones asking them "to try to behave in such a way that your partner does not know that you're feeling anything at all," and "to try not to show any emotion in your face or your voice" during the conversation. Similarly, the reappraisal regulators heard instructions asking them "to try to look on the bright side," and "to try to find anything positive you can in the film or the conversation." Their uninstructed partners, plus the individuals in the control condition, were asked "to try to interact normally," followed by a bland musical segment. Following the delivery of the instructions, the experimenter removed the partition and asked participants to discuss their thoughts and feelings during the film, the implications of the film for human nature, and its relevance to their religious and political beliefs. Participants were free to signal the end of the conversation when they so chose. Conversations ranged in length from 3.9 min to 20 min (mean = 9.8 min).

Video Prompted Recall of Emotional Experience

Immediately after the participants completed their conversation, the videotape of it was replayed for them to watch. While they watched themselves they were asked to try to recall how they had felt at the time and to use a rating dial (described in more detail in the Measures section) to indicate their remembered experience. They were explicitly told to indicate their remembered experience, not their current experience. Participants were given a chance to try moving the dial without looking down at their hand, and then were left alone to watch the video of themselves and provide the ratings. This procedure, developed by Levenson and Gottman (Gottman & Levenson, 1988; Levenson & Gottman, 1983), has been shown to be a valid and sensitive measure of emotional experience (Fredrickson & Levenson, 1998; Gottman & Levenson, 1988; Tsai & Levenson, 1997).

Measures

Physiological measures. EKG was recorded using Beckman miniature electrodes in a standard Lead II configuration. The signal was conditioned with an SA Instruments 12-channel bioamplifier and sampled at 400 Hz using a Data Translation 3001 PCI 12-bit 16-channel analog-to-digital converter. Heart period (HP) was calculated as the interval in milliseconds between successive R-waves after outliers due to artifact or ectopic activity had been corrected or interpolated. For ease of interpretation, HP was converted to heart rate (HR) for analyses with the formula HR = 60,000/HP. RSA was calculated using customized computer software written in MATLAB (Wilhelm, Grossman, & Roth, 1999). The beat-by-beat HP values were converted into instantaneous time series with a resolution of 4 Hz. HP time series were then linearly detrended and the power spectral

[3] Although power analyses become quite complicated with nested data, the worst-case scenario is that power is determined by the highest grouping level, which in the present case was the dyad (Snijders & Bosker, 1999). With 95 dyads, the present study had adequate power to detect moderately small effects in the range of Cohen's $d = .30$.

densities were derived for each period using the Welch algorithm, which ensemble averages successive periodograms (overlapping 256-point segments were Hanning windowed and subjected to fast Fourier transform, and estimates of power were adjusted to account for attenuation produced by the Hanning window). RSA was computed by summing power spectral density values over the frequency band associated with respiration (0.15–0.50 Hz). The resulting values were normalized using the natural logarithm. Period averages for HR and RSA were computed for the paced breathing task, the baseline film, and the conversation. Within-person changes in HR and RSA were calculated by subtracting a person's average during the baseline film from her average during the conversation, and so positive values reflect HR or RSA increases to the conversation.

Two channels of respiration were measured using inductive plethysmography bands (Ambulatory Monitoring, Ardsley, NY) placed around the chest and abdomen. Measurements were calibrated against fixed volume bags using the least-squares method, and respiratory rate and tidal volume were calculated breath by breath using the same customized software as for RSA (Wilhelm et al., 1999). Tidal volume values were normalized using the natural logarithm (respiratory rate was normally distributed in its original scale). Period averages were computed for the baseline film and conversation. Within-person changes in respiratory rate and tidal volume were calculated by subtracting the baseline film average from the conversation average.

Emotion experience. Emotional experience was measured using a bipolar (positive, negative) rating dial developed by Levenson and Gottman (1983; Gottman & Levenson, 1988). Participants manipulated the dial while watching the videotape of their own conversation, using it to continuously report on the positivity–negativity of their remembered experience. The dial turned through 180°, with one end anchored by "positive," the other by "negative," and with "neutral" in the middle. Participants were instructed to move it more or less continuously to indicate how they felt during the conversation. They were explicitly told to report how they remembered feeling during the conversation, not how they felt at the time of the rating. The dial was attached to a potentiometer in a voltage dividing circuit that fed into the same computer that collected the physiological measures.

Emotion expression. Participants were videotaped during the conversation using two cameras hidden behind darkened glass and positioned so that one camera focused on each participant's face and upper torso. The two camera images were then combined into a single split-screen image using a special effects generator. The videos were scored for each participants' emotion-expressive behavior using custom designed computer software (CodeBlue, R. Levenson) that allows real-time coding of behaviors with 1-s resolution.

We used a "cultural informant" approach to coding in which the gestalt of all simultaneously occurring communicative signals, both verbal and nonverbal, is taken into account when assigning a behavioral segment to one of the coding categories. Emotion expression was distinguished as being either positive or negative. Positive expression included explicit statements of positive affect such as, "That was pretty funny," positive evaluations such as, "Well, at least the bomb ended the war and probably prevented a lot of other people from dying," and nonverbal signals such as smiling and laughing. Negative expression also came both in the form of explicit statements, such as "The film was really upsetting," as well as in nonverbal grimaces, frowns, and looks of disgust, annoyance, and frustration. Because conversations differed in length, we used proportions for all analyses.

Coders were blind to the participants' experimental condition. One person coded all videotapes, and four others provided reliability ratings on 15 tapes each. Thus 60 of the 95 tapes were coded by two raters. Reliabilities were excellent (positive expression: average $r = .90$; negative expression: average $r = .95$). For tapes that were coded by two raters, the mean of the ratings was used for final analyses.

Data Analysis

Data arising from face-to-face interactions are likely to violate the assumption of independence that is required for standard ANOVA and regression approaches. For example, emotionally expressive individuals may elicit more emotional responses from a partner, resulting in correlated error terms. This lack of independence can result in inaccurate significance tests and erroneous conclusions (Campbell & Kashy, 2002; Kashy & Kenny, 1997; Kenny, 1996a, 1996b; Kenny, Mannetti, Pierro, Livi, & Kashy, 2002). To test our hypotheses, therefore, we treated the dyad as the unit of analysis and used the REPEATED statement in SAS PROC MIXED, along with a Satterthwaite estimation for the degrees of freedom, to allow for a correlated error structure within dyads (Campbell & Kashy, 2002; Laurenceau & Bolger, 2005). This approach is similar to regression but allowed us to test the effects of individual level predictors, such as RSA during paced breathing, while accounting for potentially correlated emotional outcomes within dyads. As such, this approach provides conservative estimates. Within-person changes in respiratory rate and tidal volume were included as covariates in the analyses of within-person changes in RSA, after we first established that there were no group differences in baseline or change scores for the respiratory parameters. All predictors were treated as fixed factors. The emotion regulation manipulation was dummy-coded to reflect three groups: (1) the suppressors, (2) the reappraisers, and (3) the uninstructed participants (this group included the uninstructed control dyads and the uninstructed partners of the suppressors and reappraisers).

Finally, the behavioral measures were nonnormally distributed, but graphical exploration suggested they could be well approximated by a Poisson distribution. To address this, for analyses in which the dependent variable was behavioral, we used a SAS macro (GLIMMIX) to implement a generalized model using a log link function and a Poisson error distribution (Littell, Milliken, Stroup, & Wolfinger, 1996). This approach provides accurate significance tests in the transformed space. Descriptive measures, however, are presented in the original units.

Results

Between-Persons Analyses

Correlations between RSA, respiration, and heart rate during the paced breathing task are provided in Table 1. As expected, RSA was negatively correlated with heart rate, but was unrelated to respiration rate or volume, likely due to the small variability in these measures resulting from the constraints on breathing imposed by the paced breathing task (respiration rate: $M = 9.11$, $SE = 0.23$; tidal volume: $M = 6.67$, $SE = 0.36$).

Table 1. *Correlations among Physiological Measures during the Paced Breathing Task (PBT) and Changes in Physiological Measures Calculated as Conversation minus Baseline Film (Change)*

		RSA		Respiration rate		Tidal volume		Heart rate	
		PBT	Change	PBT	Change	PBT	Change	PBT	Change
RSA	PBT	—							
	Change	– .17*	—						
Respiration rate	PBT	– .04	.06	—					
	Change	– .05	– .27*	– .10	—				
Tidal volume	PBT	.03	– .05	.05	.25*	—			
	Change	.05	.16*	– .02	– .49*	– .13	—		
Heart rate	PBT	– .42*	– .12	.00	.11	.21	– .01	—	
	Change	.12	– .41*	– .07	.02	.05	.22*	.02	—

Notes. All degrees of freedom between 184 and 187.
*$p < .05$.

We predicted that women with higher RSA during the paced breathing task would be more emotionally reactive to the conversation, and that this would be demonstrated by their increased levels of negative emotion experience and expression, as well as by reduced positive expression. This hypothesis was supported. RSA during the paced breathing task predicted more negative self-reported emotional experience, $b = 0.06$, $t(168) = 2.10$, $p < .05$, $r^2 = .025$, more negative expressive behavior, $b = 0.11$, $t(183) = 2.29$, $p < .05$, $r^2 = .028$, and less positive expressive behavior, $b = -0.15$, $t(160) = -3.35$, $p. < .01$, $r^2 = .065$. To ensure that these effects were not mediated by emotion-based differences in breathing, we repeated these analyses, forcing both respiratory measures as predictors before entering RSA. In all cases, RSA remained a significant predictor of emotional responding whereas neither respiratory parameter was. Furthermore, none of these effects interacted with the regulation manipulation and they remained significant when both RSA and the manipulation were included as predictors.

Finally, some evidence suggests that including heart rate along with RSA can improve prediction of vagal tone and, furthermore, that individual differences in RSA in the absence of heart rate differences have unknown value as indicators of vagal tone (Grossman & Kollai, 1993; Grossman & Taylor, in press). To address this we reran all analyses using just HR as a predictor or HR and RSA as predictors or HR, RSA, and respiration as predictors. In none of these models did heart rate predict emotional outcomes, although RSA continued to do so. Thus women with higher RSA during paced breathing had greater negative emotional reactivity during the conversations, regardless of their emotion regulation status and even when accounting for residual variability in respiration during the paced breathing task. These effects were small, however, and not accompanied by parallel effects of heart rate, which raises some doubt as to whether they were mediated by individual differences in vagal tone. We address this issue further in the Discussion section.

Within-Person Analyses

Regulation-group differences in emotion experience and expression. Our goal in comparing the impact of both suppression and reappraisal on RSA was to disambiguate the effects of regulation per se from its accompanying changes in emotion experience or expression. For this goal to be met it was important that suppression and reappraisal differed in their impact on emotional responding. Manipulation checks showed that this was the case. Relevant group means and standard errors are provided in Table 2. As has been shown previously (Butler et al., 2003; Gross, 1998, 2002), women who suppressed their emotion expression did not differ from the uninstructed participants in their experience of emotion, $b = -0.01$, $t(161) = -0.12$, n.s., whereas women who reappraised reported less negative emotion experience, $b = -0.18$, $t(165) = -2.19$, $p < .05$, Cohen's $d = -.32$. Also as predicted, both suppressors and reappraisers expressed less negative emotion than the uninstructed participants (suppressors: $b = -10.84$, $t[176] = -5.46$, $p < .01$, Cohen's $d = -.95$; reappraisers: $b = -10.30$, $t[180] = -5.46$, $p < .01$, Cohen's $d = -.82$); however, the reappraisers expressed more positive emotion than the uninstructed participants, $b = 11.03$, $t(151) = 10.14$, $p < .01$, Cohen's $d = 1.43$, whereas the suppressors expressed less, $b = -3.58$, $t(146) = -3.65$, $p < .01$, Cohen's $d = -.51$.

Taken together, these results show that (a) the uninstructed participants were characterized by high levels of both positive and negative expression, combined with fairly negative experience, whereas (b) the suppressors were generally inexpressive, but experienced the same levels of negative experience as the uninstructed participants, and (c) the reappraisers experienced and expressed more positive emotion than the other groups. These group differences provide the basis for examining whether (a) RSA increases result from emotion regulatory efforts in general, in which case both the suppressors and the reappraisers should show increases relative to the uninstructed participants, or whether (b) RSA increases result from more positive emotional experience, in which case the largest increases should be in the reappraisers.

Table 2. *Regulation Group Means and Standard Errors for Emotion Experience and Expression*

	Uninstructed participants	Suppressors	Reappraisers
Emotion experience (– 1 to+1)	– 0.17 (0.03)	– 0.18 (.07)	0.01 (0.07)*
Negative expression (0–100)	18.52 (0.75)	7.79 (1.51)*	8.27 (1.70)*
Positive expression (0–100)	8.34 (0.51)	3.97 (0.91)*	19.50 (1.03)*

Notes. Negative values for emotion experience reflect negative experience, whereas positive values reflect positive experience. Values for negative and positive expression are the percentage of total conversation time spent engaged in that expressive behavior.
*Group differs from the uninstructed participants with $p < .05$.

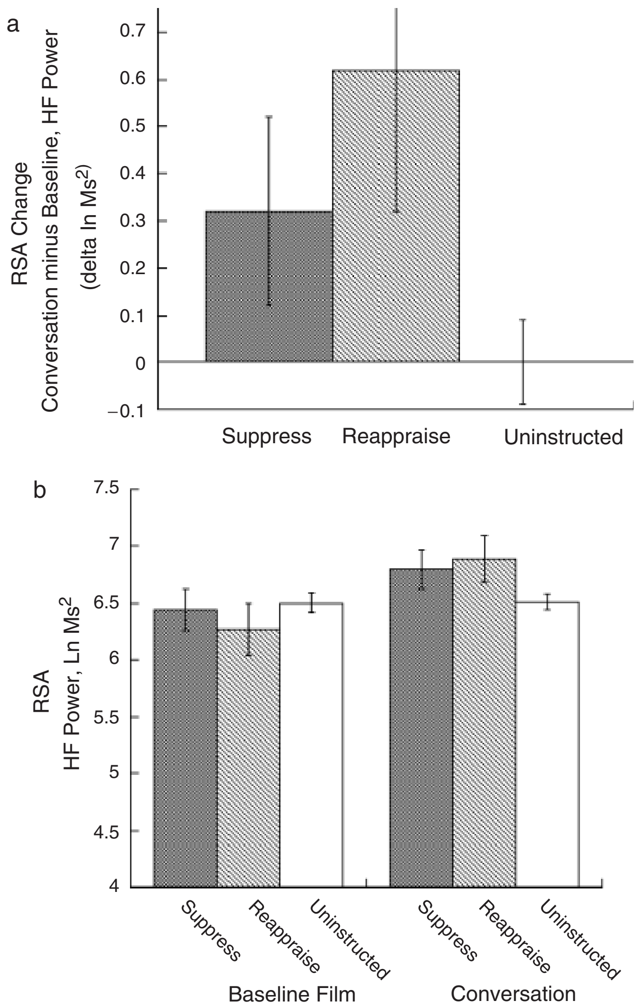

Figure 1. a: Emotion regulation group means and standard errors for RSA changes from baseline film to conversation. b: Emotion regulation group means and standard errors for RSA during the baseline film and the conversation.

Regulation-group differences in physiological responding. Correlations among RSA, respiration, and heart rate changes from baseline to conversation are presented in Table 1. As would be expected, RSA changes were negatively associated with heart rate and respiration rate changes, but positively associated with tidal volume changes. A comparison of RSA changes among the regulation groups, after accounting for changes in respiration as covariates, supports the hypothesis that emotion regulation in general, rather than positive emotional responding, produces RSA increases. The upper panel of Figure 1 shows that RSA did not change from the baseline film to the conversation for the uninstructed women. In contrast, both the suppressors and the reappraisers showed significant increases in RSA (suppressors: *M RSA* change = 0.32, $t[179] = 2.92$, $p < .01$, *C.I.* .11 to .57; reappraisers: *M RSA* change = 0.63, $t[179] = 2.67$, $p < .01$ *C.I.* .20 to .85). The lower panel of Figure 1 presents the group means and standard errors across conditions. Although changes in tidal volume were unrelated to RSA changes, $F(1,177) = 0.56$, $p > .45$, respiration rate changes did significantly contribute to RSA changes, $b = 0.12$, $t(177) = -3.14$, $p < .01$, $r^2 = .052$. In summary, RSA clearly increased from the baseline film to the conversation for women who increased their efforts to regulate their emotions, whereas it did not change for women who conversed at their usual levels of self-regulation.

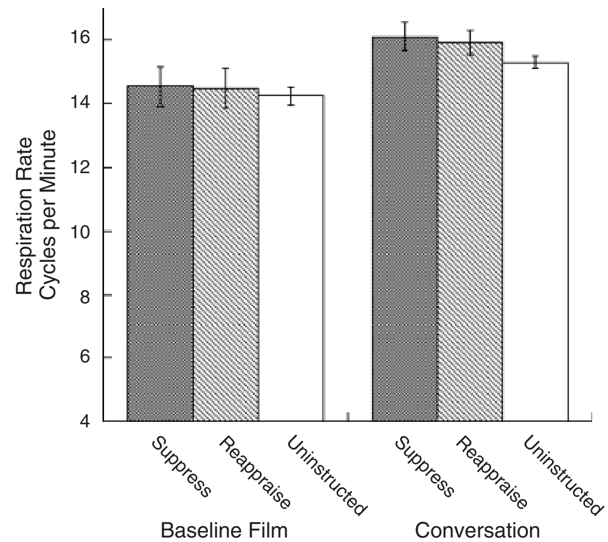

Figure 2. Emotion regulation group means and standard errors for respiration rate during the baseline film and the conversation.

Respiration changes. To interpret the RSA changes that arose due to the emotion regulation manipulation as being vagally mediated, it is important to establish that respiratory parameters were not differentially affected by the manipulation. If suppressors and reappraisers showed increased tidal volume or decreased respiration rate relative to the uninstructed participants, then this might account for their increased RSA. The results suggest this was not the case. As shown in Figures 2 and 3, there were no differences among the regulation groups in either respiration rate change, $F(2,156) = 0.55$, $p > .57$, or tidal volume change, $F(2,155) = 1.14$, $p > .32$. Rather, all groups showed increased respiration rates and tidal volume during the conversation as

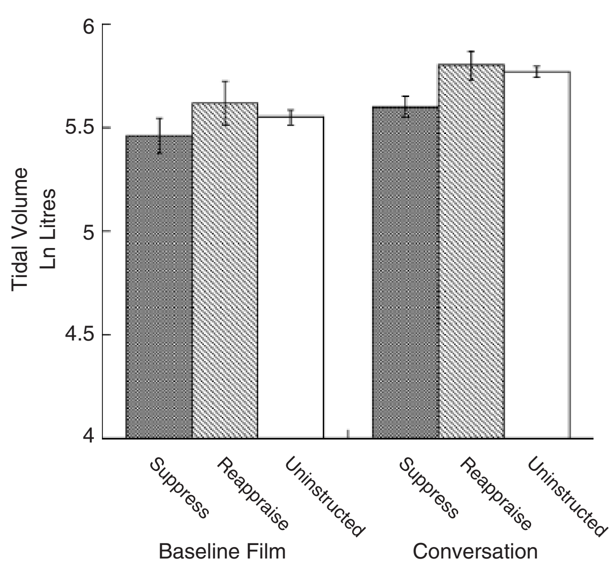

Figure 3. Emotion regulation group means and standard errors for tidal volume during the baseline film and the conversation.

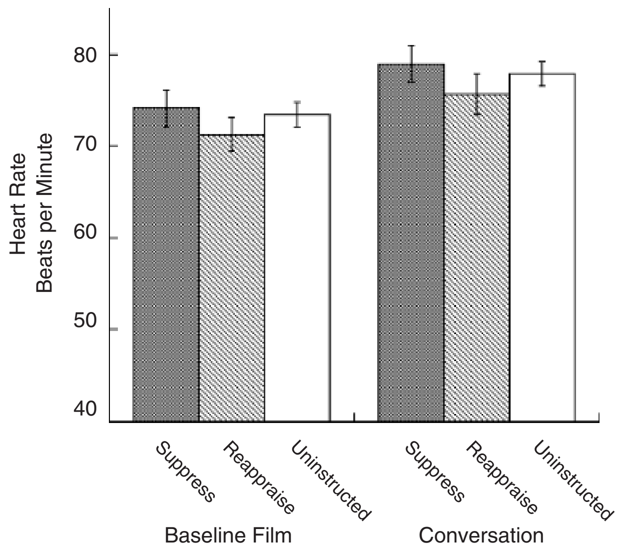

Figure 4. Emotion regulation group means and standard errors for heart rate during the baseline film and the conversation.

compared to the baseline film. Finally, we checked whether group differences in RSA might be accounted for by differences in the percentage of time spent speaking. Again, this did not appear to be the case because there were no group differences in the percentage of the conversation time spent speaking ($F[2,157] = 1.45$, $p > .23$; suppressors: $M = 41\%$, $SE = 1.6\%$; reappraisers: $M = 45\%$, $SE = 1.8\%$; uninstructed: $M = 46\%$, $SE = 1.5\%$).

Heart rate changes. Assuming the RSA increases observed in the suppressors and reappraisers were driven by increased cardiac vagal tone and that there was no simultaneous and proportional increase in cardiac sympathetic activity, then we would expect to see smaller heart rate increases (or perhaps decreases) in the regulation groups. Although RSA and heart rate changes were negatively correlated across the groups (see Table 1), we did not find any group differences in heart rate change, $F(2,160) = 0.51$, $p > .60$. Instead, as shown in Figure 4, all groups showed increased heart rate during the conversation. Thus, although the emotion regulation manipulation reliably increased RSA in both the suppressors and the reappraisers relative to the controls, the fact that it did not differentially influence heart rate weakens the assumption that RSA changes were mediated by alterations in vagal tone.

Discussion

RSA is thought to be related to emotional responding and regulation, but the precise nature of this relationship is not yet clear. In the present study, we investigated the role of RSA in both emotional reactivity and self-regulation during face-to-face interactions between adult women. We found that individual differences in resting RSA, as assessed during paced breathing, predicted increased negative reactivity during the conversation. We also found that within-person increases in RSA, accounting for respiration parameters, occurred when women either suppressed or reappraised their emotions. These results lend strong support to the notion that parasympathetic function is a critical physiological component of emotional processes.

Porges' Polyvagal Theory (Porges, 1995b; Porges et al., 1994, 1996) and Thayer's related Model of Neurovisceral Integration (Thayer & Lane, 2000) provide a theoretical context for the present results. Both models suggest that bidirectional connections between the vagus nerve and the heart evolved to support highly flexible, environmentally contingent mammalian behavior. In safe, relaxing situations, the "vagal brake" functions to increase parasympathetic influences to the heart, thereby slowing heart rate and facilitating attending to, and engaging with, the environment. This braking process is reflected in RSA increases. In contrast, in challenging or threatening situations, the vagal brake is rapidly withdrawn, leading to sympathetic dominance in support of increased metabolic output to energetically respond to the situation. Such vagal withdrawal is reflected in RSA decreases. Given this model, Thayer and Lane (2000) has suggested that resting RSA provides an index of the efficiency of central-peripheral feedback. In keeping with this idea, both Thayer and Porges hypothesize that high levels of resting RSA allow for maximal flexibilty of the vagal brake, and that this should be reflected in a positive association between resting RSA and emotional reactivity. The results from the present study lend some conditional support for this hypothesis; women with higher RSA during the paced breathing task experienced and expressed more negative emotion during the conversations.

At first glance, our finding that higher resting RSA also predicted *decreased* positive expressivity may appear to contradict the hypothesis that higher RSA is associated with increased reactivity. In the present context, however, lower levels of positive expression were in accord with a stronger negative reaction to the generally distressing topic of conversation. This contextual specificity of what constitutes a strong emotional reaction may account for some of the discrepancies found in the existing literature. For example, in some cases, higher resting RSA has predicted increased positive expression (Beauchaine, 2001), and in other cases, it has been unrelated (Frazier et al., 2004). Our present finding that higher RSA predicted reduced positive expression demonstrates that all associations are possible and emphasizes the importance of specifying what would constitute a strong emotional reaction within the specific context of a given study.

Another important distinction is that in the context of the present study, negative emotional reactivity was within the bounds of normal, everyday responding in a nonclinical population. As such, our observation of a positive association between resting RSA and negative emotions is specific to midlevel, socially appropriate emotions in healthy adults. In contrast, we would predict that at pathologically high levels of emotional responding, such as panic attacks or overt hostility, the opposite relation would hold. If resting RSA is indeed an index of optimal flexibility of the vagal brake, then in the pathological case, we would expect higher RSA to be associated with less extreme emotional responses or, in other words, with more effective deployment of the vagal brake. Indeed, there is some support for this in the literature (Friedman & Thayer, 1998a, 1998b; Thayer et al., 1996; Watkins et al., 1998). This potential moderating effect may partially account for the inconsistent relationships reported in the literature, but future research is clearly required to validate this assumption.

Despite the findings in support of our hypotheses, several caveats are important. First, the paced breathing task was only

2 min long and only occurred once. As such, its reliability as an indicator of stable individual differences is unknown. Second, these effects were modest in absolute size, with RSA accounting for approximately 2.5%–6% of the variance in the emotion measures, but this is perhaps not surprising given the multidetermined nature of emotional responding, especially during face-to-face social interactions. Third, if RSA was indeed indexing vagal tone, then we would expect heart rate to also predict emotional responding (Grossman & Kollai, 1993), but this was not the case. This raises interpretative problems and suggests that Polyvagal theory may be inadequate to fully account for our results. Given this lack of corroborative heart rate effects, we must question whether the individual differences in RSA were actually indexing vagal tone. If they were not, then this opens the question of their biological and psychological significance. Future research that carefully clarifies the roles of RSA, heart rate, and respiration under varying psychological and physiological demands will be required to better explicate the exact nature of individual differences in RSA.

Although existing theories are fairly consistent in suggesting that high resting RSA should be associated with optimal emotional flexibility in healthy adults (Beauchaine, 2001; Porges, 1995b; Porges et al., 1994, 1996; Thayer & Lane, 2000), they are less clear with respect to the correlates of within-person changes in RSA. Although they agree that RSA changes accompany engagement and disengagement of the vagal brake (Porges, 1995b; Thayer & Lane, 2000), the internal and external conditions leading to this are poorly specified. Some hypotheses that have been suggested are that differences in emotional experience or differences in purposeful self-regulation may drive RSA changes (Bazhenova et al., 2001; Beauchaine, 2001; Ingjaldsson et al., 2003; Porges, 1995b). In the present research, we tested these competing hypotheses by comparing two forms of emotion regulation that differed in their accompanying emotional state.

The regulatory strategies that we compared were suppression, which involves inhibiting emotional expressions, and reappraisal, which entails thinking positively about the situation. Both strategies share general self-regulatory processes such as attending to, and attempting to modify, one's own emotional responding. They also both reduce negative expressivity. Nevertheless, the two strategies differ in a multitude of ways (Butler et al., 2003; Gross, 1998, 2002; Gross & John, 2003; John & Gross, 2004; Richards, Butler, & Gross, 2003). One observed difference in the present study, and one that is particularly relevant to the current analysis, is that suppression did not reduce negative experience whereas reappraisal did. Thus, if RSA increases result from any attempt to increase emotional self-regulation, then they should accompany both suppression and reappraisal. Alternately, if RSA increases result from enhanced positive emotion experience then they should accompany reappraisal, but not suppression.

Our results clearly support the former hypothesis. Both women who suppressed their emotions and those who reappraised them showed significant increases in RSA from a neutral baseline film to the conversation. The uninstructed controls, on the other hand, did not show any systematic changes in RSA. It appears then, that some shared feature of suppression and reappraisal accounted for the RSA increases. One possible candidate for this shared mechanism is that they both require enhanced attention in order to monitor and modify emotional responses. Such attention-demanding tasks have been shown to lead to RSA increases if the task at hand does not require accompanying increases in physical activity (Jonsson & Sonnby-Borgstrom, 2003). For example, silently solving arithmetic problems led to RSA increases (Sahar, Shalev, & Porges, 2001), but similar tasks that required pressing a computer key or verbalizing the answer led to RSA decreases (Beauchaine, 2001; Suess, Porges, & Plude, 1994). A less interesting but plausible possibility is that the RSA increases were driven by nonspecific effects such as trying to follow any sort of instruction during a conversation, and actually had nothing to do with emotion regulation. Either way, one potentially fruitful direction for future research will be to examine whether other forms of conversational tasks, both emotional and nonemotional, lead to similar RSA increases, and if so, whether attentional processes can account for the effects.

The present results fit well with a handful of other studies that have suggested that RSA increases accompany emotion regulatory efforts. For example, Ingjaldsson and colleagues (2003) found that alcoholics with good self-control over their drinking showed RSA increases during an alcohol imagery task. They suggest that these increases reflected the activation of purposeful cognitive processes in the service of inhibiting alcohol-related temptation. A related finding is that individuals who were particularly distressed about a recent marital breakup showed RSA increases when actively thinking about the divorce, suggesting they may have engaged in emotion regulatory efforts to down-regulate the distress induced by this task (Sbarra & Law, 2006). Finally, individuals with the highest RSA during a written disclosure session benefited most from that disclosure in terms of physical health complaints and depression symptoms, possibly because these individuals most effectively engaged in emotion regulatory efforts during the disclosure task (Sloan & Epstein, 2005).

Although the observed group differences in RSA were in accord with our hypotheses, the lack of heart rate effects undermines the interpretation suggested by Polyvagal theory. If the RSA changes we observed were indicative of genuine increases in cardiac vagal tone, and there was no simultaneous increase in cardiac sympathetic activity, then we would expect to see heart rate deceleration in conjunction with the RSA increases in the suppressors and reappraisers. This is not what we found. Instead, heart rate increased from baseline to conversation equally in all groups. As with the lack of an effect for individual differences in heart rate, this raises a concern regarding RSA as an index of vagal tone. Given this lack of corroborative heart rate findings, it is possible that the observed RSA group differences may have been driven by subtle respiratory influences, postural or metabolic changes, sympathetic-parasympathetic interactions, or a host of other possible factors (Grossman & Taylor, in press). Despite the vast literature on psychosocial implications of RSA, there is a dearth of research including heart rate in conjunction with RSA, and essentially none in the context of social interaction. Our finding that RSA and heart rate did not converge in their predictions demonstrates the importance of including both and suggests that extensive research is still required to better elucidate autonomic activity during emotional conversations.

Along similar lines, although the present research incorporated the important methodological feature of taking into account respiratory confounds that are well known to obscure the relationship between RSA and central vagal activity (Berntson et al., 1993; Grossman et al., 1990; Grossman & Kollai, 1993; Houtveen et al., 2002), we cannot completely rule out subtle respiratory effects as the mechanism behind the group differences in RSA. For example, the manipulation may have caused the instructed versus uninstructed participants to phrase their verbalizations slightly differently with concomitant alterations in respiration, while at the same time altering the cognitive demands when not speaking with opposite effects on respiration. Such a pattern could largely cancel out group differences in respiration while still allowing a small RSA effect to appear.[4] Indeed a recent theoretical challenge to Polyvagal theory suggests that the biological function of RSA is linked to the coupling of heart rate and respiratory phase in the service of optimal energy exchange (Grossman & Taylor, in press). If this were the case, the RSA increases observed in the present study may have arisen in response to slight, but reliable, group differences in behavioral and metabolic demands.

As with any research, there are several notable boundary conditions on the results of the current study. To reduce variability in the sample, we focused on women, but future research with men and mixed-sex samples is clearly required to generalize the results. Indeed, given known sex differences in both resting RSA (Jonsson & Sonnby-Borgstrom, 2003) and emotional responding (Kring & Gordon, 1998), it seems possible that sex might moderate the present results. In addition, because this is the first study we are aware of to consider the impact of suppression or reappraisal on RSA and to investigate RSA during adult conversation, there may be numerous factors affecting our results that are specific to our particular study procedures. As an example, the fact that participants took part in pairs for the entire procedure, although for the paced breathing and film viewing they were separated by a screen, may have produced physiological responses during the conversations that were specific to moving from individual tasks to a dyadic task. Similarly, there is likely a host of metabolic demands occurring during conversation that we have not accounted for. Nevertheless, any such factors would have to have been differentially affected by the emotion regulation manipulation in order to represent confounds in the interpretation of the observed RSA increases. Finally, the present study was designed to distinguish between the effects of self-regulation in general as opposed to the effects of changes in emotional experience that may accompany self-regulation. Although this goal was accomplished, it opens the door to the question of mechanism, and sets the stage for future research that can distinguish between the various shared features of suppression and reappraisal that might account for their similar impact on RSA.

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[4]The authors thank an anonymous reviewer for suggesting this alternate interpretation.

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