Personality and Social Psychology Bulletin
37(6) 731–744

DOI: 10.1177/0146167211400620
http://pspb.sagepub.com
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Individual Differences in Vagal Regulation Moderate Associations Between Daily Affect and Daily Couple Interactions

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Abstract

Previous research suggests that cardiac vagal regulation (indexed by respiratory sinus arrhythmia, or RSA) provides a physiological substrate for affect regulation, which presumably underlies adaptive interpersonal functioning. The authors tested these associations in the context of daily interactions between 68 cohabiting couples. Participants underwent a laboratory assessment of RSA during rest and also during a series of psychological stressors. Subsequently, they kept daily measures of affect and interaction quality for 21 days. Individual differences in baseline and stress levels of RSA moderated within-person associations between daily affect and the quality of couple interactions. The pattern of results differed for women versus men. Men with lower vagal tone or higher vagal reactivity had stronger associations between daily negative affect and daily negative interactions, and men with higher vagal tone had more positive daily interactions overall. Women with higher vagal tone had stronger associations between daily positive affect and daily positive interactions.

Keywords

affect regulation, RSA, vagal regulation, romantic relationships, psychophysiology

Received July 15, 2010; revision accepted January 11, 2011

Affect regulation, defined as internal and transactional processes through which individuals modulate the experience or expression of positive and negative affect (Eisenberg, Fabes, Guthrie, & Reiser, 2000; Gross, 1999), is essential for effective coping, social functioning, and overall mental health (Gross, 2002). Capacities for affect regulation shape individuals' perceptions, appraisals, and reactions to emotionally charged experiences, and hence, relationship researchers have increasingly investigated whether individual differences in affect regulation influence romantic relationship functioning (reviewed in Diamond & Hicks, 2004). *Cardiac vagal regulation* has become one of the most widely researched physiological indices of affect regulation. *Vagal* refers to the functioning of the 10th cranial nerve, which provides inhibitory input to the heart via the parasympathetic nervous system (PNS) and helps to regulate metabolic output in response to environmental events. Vagal regulation (indexed by respiration-related variability in heart rate, also known as *respiratory sinus arrhythmia*, or RSA) is thought to provide a physiological substrate for emotion regulation (Appelhans & Luecken, 2006; Hastings et al., 2008; Lewis, Lamm, Segalowitz, Stieben, & Zelazo, 2006; Ochsner & Gross, 2008; Porges, 2007; Thayer & Lane, 2000). Studies have found that individual differences in vagal regulation are related to children's and adults' emotional experience, expression, and regulation and that they have particular relevance for interpersonal functioning (Gyurak & Ayduk, 2008; Porges, 2003). Yet no prior research has directly investigated whether individual differences in vagal regulation are associated with day-to-day romantic relationship functioning. The present research addresses this question by testing whether tonic vagal control of heart rate (denoted *vagal tone*) and stress-induced changes in vagal control of heart rate (denoted *vagal reactivity*) are associated with the overall quality of couples' daily interactions and with the degree of day-to-day linkage between affect and interaction quality.

Vagal Regulation and Affect Regulation

The specific relevance of vagal regulation for affect regulation, specifically in the service of social behavior, has been

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set forth by Thayer and Lane's (2000) neurovisceral integration model and Porges's polyvagal theory (Porges, 2003). Briefly, both the PNS and the sympathetic nervous system (SNS) are involved in the moment-by-moment physiological changes triggered by environmental demands—changes in heart rate, blood pressure, sweating, and so on. Yet the SNS and the PNS have antagonistic effects on autonomic functioning, and thus, stress responses such as heart rate acceleration can be brought about by activation of the SNS, withdrawal of the PNS, or some combination of the two. Generally, cardiovascular activity is under inhibitory parasympathetic control, such that tonic levels of vagal activity provide a constant "brake" on cardiovascular functioning. This tonic inhibitory control is highly adaptive, as it allows for rapid and efficient modulation of cardiovascular activity in the service of changing environmental demands. Although the SNS influences on heart rate are relatively slow acting, typically taking several seconds, vagal inhibition can be suspended in a matter of milliseconds (Saul, 1990). Hence, individuals with robust vagal regulation of heart rate (i.e., "high vagal tone") are conceptualized as having nervous systems that respond quickly and flexibly to environmental demands, recover more effectively from emotional arousal (Porges, 1991; Thayer & Lane, 2000), and hence show more flexible and adaptive patterns of day-to-day emotional responding and social engagement (Beauchaine, 2001).

Numerous studies have provided empirical support for this overall model. For example, infants with greater vagal tone are more facially expressive, more reactive to novel events, and better able to sustain attention and avoid distraction (Fox, 1989; Porges, 1991) and high behavioral inhibition (Snidman, 1989). Children and adults with low vagal tone show ineffective behavioral coping in response to stress (Fabes & Eisenberg, 1997; Fabes, Eisenberg, & Eisenbud, 1993) as well as higher levels of anger, hostility, mental stress, and generalized anxiety (reviewed in Brosschot & Thayer, 1998; Friedman & Thayer, 1998; Horsten et al., 1999). Complementing these findings, recent research also suggests that vagal tone is associated with tonic positive affectivity (Oveis et al., 2009), which may provide a relational "building block" promoting approach-oriented behavior and fostering social resources (following Fredrickson, 1998).

Although the majority of research on vagal regulation has focused on tonic levels (typically assessed by measuring RSA at rest), an increasing body of research has focused on *changes* in vagal regulation triggered by stress and other environmental demands. Polyvagal theory (Porges, 2001) suggests that the normative, adaptive pattern is for RSA to *decline* during stress (a pattern typically denoted vagal "withdrawal"), which allows for a rapid and effective increase in heart rate *without* requiring energy-costly SNS mobilization. Vagal withdrawal has been observed in numerous studies of children, adolescents, and adults engaged in stressful or affectively negative tasks (Beauchaine, 2002; Beauchaine, Katkin, Strassberg, & Snarr, 2001; Pieper, Brosschot, van der Leeden, & Thayer, 2007; Sack, Hopper, & Lamprecht, 2004; Thayer, Friedman, & Borkovec, 1996). Yet many individuals show stress-induced *increases* in RSA (Berntson, Cacioppo, & Fieldstone, 1996; Sahar, Shalev, & Porges, 2001), and the implications of this pattern of "vagal engagement" remain a topic of debate. Vagal engagement during stress is thought to index active *regulatory effort* (Beauchaine, 2001; Kettunen, Ravaja, Naeaetaenen, & Keltikangas Jaervinen, 2000; Segerstrom & Nes, 2007; Thayer & Lane, 2000), which facilitates attention and vigilance to environmental demands. Katz (2007) has argued that individuals exposed to *chronically* stressful environments may develop a stable pattern of increased RSA, which may help them to monitor their environment and maintain control over their emotions and behavior. Yet although such a pattern might prove adaptive in the short term, it may prove taxing over the long term. Many researchers have begun to conceptualize regulatory capacity as relatively finite, analogous to a muscle that tires on repeated use (Muraven & Baumeister, 2000). Hence, individuals who show chronic patterns of increased RSA in response to stress might experience chronic regulatory "fatigue," leaving them vulnerable to frequent failures of self-control (Vohs, Baumeister, & Ciarocco, 2005). This may explain why individuals who show heightened RSA during stress show multiple indices of emotion dysregulation, such as depression, anxiety, and hostility (Hessler & Fainsilber Katz, 2007; Neumann, Sollers, Thayer, & Waldstein, 2004; Vella & Friedman, 2007). The implications of such a pattern for day-to-day interpersonal functioning have not been investigated.

The Current Study

The current study uses laboratory assessments of vagal regulation and daily diary assessments of couples' affect and daily interactions to address two overarching questions: First, do individual differences in vagal regulation predict *between-person* differences in the average quality of couples' day-to-day interactions? Second, do individual differences in vagal regulation moderate *within-person* associations between daily affect and daily interaction quality? The first question basically concerns whether individuals with poorer capacities for affect regulation make poorer interaction partners on a day-to-day basis. Theoretically, individuals who have lower vagal tone and higher vagal reactivity to stress may be less able to mobilize positive affect (Gable, Reis, Impett, & Asher, 2004; Langston, 1994) and down-regulate negative affect (Diamond & Hicks, 2005; Fabes & Eisenberg, 1997; Gyurak & Ayduk, 2008) in the service of day-to-day social functioning, rendering them less interpersonally responsive and competent. If this is the case, then these deficits in social functioning should be discernable to these individuals' *partners* in the context of the quality of day-to-day couple interactions.

Hence, we predict that individuals with lower vagal tone (Hypothesis 1a) and greater vagal reactivity (Hypothesis 1b) will be rated by their partners as interacting less positively (i.e., expressing less closeness, connectedness, and understanding) and more negatively (i.e., expressing more conflict and criticism) during their daily couple interactions. Our second overarching research question concerns links between an individual's daily affect and the quality of his or her same-day couple interactions. Theoretically, individuals with effective affect regulation should be particularly adept at maintaining adaptive social behavior even when they are experiencing high levels of negative affect, and previous research suggests that this is the case among individuals with robust vagal regulation (Fabes & Eisenberg, 1997; Gyurak & Ayduk, 2008). Accordingly, we expect that within-person associations between day-to-day negative affect (as reported by the individual) and day-to-day interaction quality (as reported by the individual's partner) should be stronger among individuals with lower vagal tone (Hypothesis 2a) and greater vagal reactivity (Hypothesis 2b). In contrast, we expect that the within-person association between day-to-day *positive* affect and day-to-day interaction quality will be *attenuated* among individuals with lower vagal tone (Hypothesis 3a) or greater vagal reactivity (Hypothesis 3b), based on the expectation that deficits in affect regulation should hamper individuals' ability to mobilize and benefit from positive emotions and experiences (Diamond & Aspinwall, 2003). It bears noting that because there is far more research on the implications of vagal regulation for *negative* affectivity than for *positive* affectivity, our hypotheses regarding positive affectivity are more tentative than our hypotheses regarding negative affectivity. It also bears noting that the aforementioned hypotheses entail no presumptions about the causal direction of links between daily affect and daily interaction quality. Previous research suggests that such links are fundamentally bidirectional: Individuals' affective states shape their interpersonal behavior, *and* the quality of their interpersonal interactions feeds back to influence their ongoing affective states (reviewed in Diamond, Fagundes, & Butterworth, 2010). We expect that both of these pathways are moderated by individual differences in affect regulation (i.e., poorly regulated individuals will behave more negatively toward their partners when they are in a bad mood, *and* they will experience greater negative affect as a consequence of negative couple interactions).

We do not advance specific hypotheses regarding gender differences in the hypothesized effects, given the lack of prior theory and research on gender and vagal regulation. However, we believe that this question has been underinvestigated: Several studies have detected gender differences in overall indices of vagal regulation and in their links to psychological functioning (D'Antono, Moskowitz, Miners, & Archambault, 2005; Ottaviani, Shapiro, Davydov, & Goldstein, 2008), and yet the full extent and range of such gender differences remain unknown, given that many studies of vagal regulation use single-sex samples (e.g., Butler, Wilhelm, & Gross, 2006; Diamond & Hicks, 2005; Horsten et al., 1999). We therefore plan to conduct all of our analyses using parallel process models, which allow for a simultaneous but separate estimation of effects for female versus male partners, controlling for within-couple dependency.

Finally, although there is currently no empirical evidence to suggest that one's *partner's* vagal regulation should moderate associations between one's own daily affect and one's interaction quality, we plan to examine potential partner effects, in line with previous research on the actor-partner interdependence model (Campbell & Kashy, 2002; Kashy & Kenny, 2000).

Method

Participants

Participants were 68 cohabitating heterosexual couples (136 individuals total), all of whom had been together for at least 2 years, who were part of a larger study of day-to-day proximity and day-to-day functioning in cohabiting couples (see Diamond, Hicks, & Otter-Henderson, 2006, 2008). Participants ranged in age from 20 to 53, with a mean of 28 ($SD = 7.0$). Mean relationship length was 6 years ($SD = 4.7$), and 75% of couples were married. Couples were recruited through newspaper advertisements and electronic messages distributed to academic departments at several local universities.

Measures

Means and standard deviations for all study measures, stratified by gender, are provided in Table 1, and correlations among all study measures are provided in Table 2. Each participant completed a paper-and-pencil diary once a day (at bedtime) for 3 weeks.[1] The diaries assessed *positive and negative affect* with the Positive and Negative Affect Schedule (Watson, Clark, & Tellegen, 1988), which contains two 10-item scales, one for positive affect and one for negative affect. *Positivity and negativity of daily of interactions with partner* was assessed with a measure designed by Reis, Sheldon, Gable, Roscoe, and Ryan (2000) to assess associations between everyday experiences of relatedness and daily well-being. Positive interaction quality is indexed by ratings (on a 1 to 5 scale) of the extent to which the interaction elicited feelings of closeness with the other person, involved meaningful conversation, and elicited feelings of being understood and appreciated. Negative qualities are indexed by ratings of the extent to which the interaction involved arguments or conflict and made the individual feel self-conscious or judged by the other person.

Table 1. Descriptive Statistics for Study Variables

	Female		Male	
	M	*SD*	*M*	*SD*
Age	29	7.0	28	7.0
Body mass index	23.6	4.6	25.7	3.6
Average daily positive affect	2.9	0.49	2.8	0.49
Average daily negative affect	1.5	0.37	1.5	0.30
Average daily rating of positivity of daily interactions with partner	3.2	1.0	3.4	1.0
Average daily rating of negativity of daily interactions with partner	1.2	0.62	1.2	0.55
RSA during baseline (vagal tone)	5.1	0.63	5.0	0.55
RSA during stress tasks	3.8	0.58	3.7	0.62

Note: All respiratory sinus arrhythmia (RSA) values are calculated as $\ln(ms^2)$.

Because we used paper-and-pencil diaries (rather than electronic diaries with an automatic timestamp), we cannot confirm that each and every entry was made on time (rather than participants skipping one day and then completing the diary information on the next day). However, we maximized compliance with the diary protocol by carefully explaining to our participants that because we had statistical procedures capable of dealing with "skipped days," there was no reason for them to try to fill in missed entries and that we needed them to leave such days blank. We also emphasized that their financial compensation was not tied to the number of completed entries. In addition, consistent with Green and colleagues' recommendations for maximizing diary compliance (Green, Rafaeli, Bolger, Shrout, & Reis, 2006), we sought to establish a strong rapport with our participants and to increase their sense of investment in the study by personalizing their diaries with large stickers showing their first names and also by giving each couple a personalized calendar that displayed their first names and tracked their study progress. Also, we assigned each couple their own research assistant ([RA] whose name and cell phone number were printed directly on their diary) so that they could direct all of their questions to the same person. The RA periodically contacted them to address any questions or concerns. Green and colleagues (2006) noted that such strategies were highly effective in increasing compliance, and their research found that when using such techniques, data collected using paper-and-pencil methods were basically equivalent to data collected using time-stamped electronic collection procedures.

In all, 96% of the affect and interaction data were complete across all people and all days. We used PAN (Schafer, 2001) to impute within-person data. Following standard procedures for imputation, we repeated each imputation procedure five different times, resulting in five slightly different data sets, to approximate the type of measurement error that is represented in real but not imputed data. We then conducted all of our analyses with each set, and the final coefficients we present are averages of the coefficients that were generated by each of the five runs. This technique has been shown to perform well when data are missing at random and even acceptably under some cases of nonrandom missingness (Schafer & Graham, 2002).

To assess RSA, continuous recordings of ECG and respiration were amplified and filtered through a James Long Company (Caroga Lake, NY) four-channel bioamplifier, Model LMD-04, with the ECG channel high-pass filter set to .1 Hz and a low-pass filter set to 1000 Hz. ECG was recorded with disposable electrodes placed on the participant's chest in a triangular configuration. Respiration depth and frequency were measured by a latex rubber pneumatic bellows girth sensor fitted around the participant's chest. All physiological signals were fed into an A/D interface box and stored on an IBM-compatible computer. The sampling rate was 1000 Hz for all channels. Data analysis was implemented with the James Long Company PHY General Physiology Analysis System software, which permits visual inspection and manual editing of artifacts. Approximately 1% of data were edited for artifacts using interpolation of adjacent points. RSA was assessed on the basis of the ECG and respiration data. Interbeat intervals (IBIs) were calculated as the time in milliseconds between successive R waves in the electrocardiogram, and the "peak-to-valley" method (Grossman & Svebak, 1987) was used to derive RSA on the basis of these IBIs. This method computes the difference (in milliseconds) in the heart period between inspiration onset and expiration onset. For any particular episode of time, the sum of these "peak-to-valley" measurements divided by the total number of breaths is calculated as an estimate of RSA for that episode. Peak-to-valley methods are widely used and show high correlations with other methods of assessing RSA (Grossman, van Beek, & Wientjes, 1990). RSA values were logged before analysis to normalize their distribution. Because respiration frequency is known to be associated with measurement of RSA (Ritz, Thoens, & Dahme, 2001), we residualized all of our RSA values for respiratory frequency before entering them into analyses (see Berntson et al., 1996).

Following the recommendations of Kamarck, Debski, and Manuck (2000; Pruessner et al., 1997), we aggregated reactivity measures across the four experimental tasks to increase reliability. Before doing so, we used repeated measures analyses to test for task effects in RSA reactivity and found none; correlations between RSA reactivity scores were .61 for the anger and math tasks, 80 for the anger and speech tasks, .68 for the anger task and the relationship discussion, .74 for the math and speech tasks, .66 for the math task and the relationship discussion, .80 for the speech and math tasks, and .73 for the speech task and the relationship discussion. Reliability analyses revealed that aggregating these reactivity scores yielded an index with high reliability, Cronbach's $\alpha = .90$.

Table 2. Correlations Among Study Variables

	1	2	3	4	5	6	7	8	9	10	11
1. Female's vagal tone											
2. Female's vagal reactivity	–.34**										
3. Female's average daily positive affect	.30*	–.19									
4. Female's average daily negative affect	.12	.13	–.21								
5. Female's average daily positivity of interactions (rated by male partner)	–.01	–.01	.18	.05							
6. Female's average daily negativity of interactions (rated by male partner)	.06	.13	.02	.21	–.01						
7. Male's vagal tone	.04	.13	–.06	.07	–.20	–.06					
8. Male's vagal reactivity	.03	.10	–.12	.13	–.01	–.07	–.04				
9. Male's average daily positive affect	.18	–.07	.40**	–.09	.65***	–.06	–.20	.13			
10. Male's average daily negative affect	.03	.11	–.11	.25*	–.01	.35*	.16	.07	–.19		
11. Male's average daily positivity of interactions (rated by female partner)	.05	–.14	.31*	.05	.57**	–.10	.05	–.03	.39**	.12	
12. Male's average daily negativity of interactions (rated by female partner)	.18	–.01	–.23	.59**	.00	.34**	–.06	.01	–.17	.22	.06

Note: Vagal reactivity calculated as change from baseline, residualized for respiratory frequency.
*$p < .05$. **$p < .01$. ***$p < .001$.

Procedures

All participants were instructed to refrain from eating, smoking cigarettes, and consuming caffeinated beverages within 2 hours of the experiment (verified at the laboratory). After the couple provided informed consent, one of the partners was escorted to a waiting room down the hall. The other partner was fitted with the physiological equipment (described below) and seated on a small couch. Participants were instructed to sit quietly and relax for 5 minutes to get adjusted to the physiological equipment, after which they spent 3 minutes rating their liking of landscape photographs (to engage their attention in a restful, pleasant task, following Jennings, Kamarck, Stewart, & Eddy, 1992). They spent the last 3 minutes of the baseline period breathing slowly (4 seconds for inhalation and 4 seconds for exhalation) in time with a prerecorded tape. This 3 minutes served as the formal measure of resting RSA (indexing vagal tone). Having participants pace their breathing during the baseline assessment is recommended to standardize respiratory parameters and yield more accurate assessments of between-person differences in tonic RSA (Grossman, Stemmler, & Meinhardt, 1990).

Next, the "relationship description task" was initiated. Participants were instructed to provide a description of their current relationship with their partner (for 2 minutes), including specific illustrative examples of their partner's character and behavior. Next, for 1 minute, they described their thoughts and feelings regarding either an anticipated or hypothetical physical separation from the partner, such as a work-related trip. This task was selected to prompt the participant to actively reflect on concerns about relationship quality, security, and partner availability. The next three tasks were standard psychological stressors. The first task (denoted the "math task") involved performance of serial subtraction (Earle, Linden, & Weinberg, 1999; Lai & Linden, 1992). Participants began with the number 9,000 and repeatedly subtracted 13. They were instructed to perform these subtractions mentally, without speaking, but every 20 seconds they were signaled to report the last number they reached. They were told that their performance was being scored for speed and accuracy, and approximately every 90 seconds, the experimenter interrupted the participant and reminded him or her that both speed and accuracy were important. At three different points, the participant was asked to go back to a previous number (implying poor performance). This task lasted approximately 7 minutes.

Next, the "speech task" was initiated. This performance task was modeled on similar evaluative tasks that have been found to reliably elicit negative affect and anxiety (Dickerson & Kemeny, 2004; Kirschbaum, Pirke, & Hellhammer, 1993). Participants were instructed to imagine that they were applying for a job and that they had to prepare a speech convincing the personnel committee of their qualifications. They were instructed to deliver the speech into a camera that was placed directly in front of them (and which was conspicuously adjusted and focused by the experimenter to heighten evaluation apprehension) and were told that their performance would be evaluated using a scale widely used by human resource managers to screen potential job candidates. Several minutes after the participants began speaking, the experimenter interrupted them and asked them to explain apparent falsehoods on their resume. This task lasted approximately 5 minutes.

Last, participants completed an "anger recall" task (Anderson & Lawler, 1995; Siegman & Snow, 1997) for 2 minutes. They were instructed to describe in detail a recent experience that had made them extremely angry, frustrated, or stressed. Afterward, participants were debriefed and unhooked. They were then escorted to a waiting room where they completed questionnaire measures while the same procedure was completed with their partners (couples had no opportunity to discuss the tasks during the experimental session). Before leaving the laboratory, a research participant gave both partners their 3-week daily diary, familiarized them with the format and questions, and answered any questions that they had. Couples were paid $100 for their study participation after returning their completed diaries.

Results

Model Definition

The multivariate module of HLM, known as HMLM (Bryk & Raudenbush, 1992), was used to permit simultaneous estimation of multilevel random coefficient models for the female and male partner of each couple, thereby permitting simultaneous estimation of effects for each member of the couple, while controlling for within-couple dependency. This technique is designed for multilevel data structures in which observations at one level of analysis (in this case, daily ratings of affect and interaction quality) are nested within higher levels of analysis (individuals, which are then nested within dyads). Within-person and between-person effects are estimated simultaneously. To analyze both members of the couple while controlling for the within-dyad dependency between them, we used a parallel process model (Raudenbush, Brennan, & Barnett, 1995). This model treats the dyad as the unit of analysis, beginning with a Level 1 equation that predicts the outcome variable (ratings of interaction quality) from two dummy codes, one for the female partner and one for the male partner, and excludes the intercept:

$$\text{Interaction Quality}_{day\ i,\ dyad\ j} = \pi_{1ij}\ (\text{Female}) + \pi_{2ij}\ (\text{Male}) + e_{ij}$$

Note that the dependent variable (DV) is always the partner's rating of interaction quality (i.e., the female's interaction quality *as rated by her male partner* and the male's interaction quality *as rated by his female partner*). For the purpose of explaining the model, we are using the general term *interaction quality*, although we model positive and negative interaction quality in separate models.

Because this Level 1 equation does not contain an intercept, the coefficients for the male and female dummy codes, π_1 and π_2, end up representing the true scores for the DV for the female and male partners of couple j on day *i*, which become the DVs for subsequent levels of analysis. This particular type of multivariate multilevel model, in which the Level 1 equation creates population true scores for each member of the couple, uses an unrestricted Level 1 variance structure, which allows for a unique error variance for the males and females and a covariance between them. This structure is analogous to computing two multilevel models and allowing the DVs to be correlated at a constant amount over time. The model fit is parallel to a standard HLM model in which the error variance is fixed over time.

Level 2 of the model focuses on within-person associations between daily interaction quality and individuals' daily positive and negative affect. At this level, a regression equation is calculated for each separate individual, predicting the DV (interaction positivity or negativity on day *i*, as rated by one's partner) from the individual's positive affect and negative affect on day *i*. Hence, the Level 2 models take the following forms:

$$\pi_1\ \text{Female's Rating of Interaction Quality with Male}_{day\ i,\ dyad\ j} = \beta_{10ij} + \beta_{11}\ \text{Male's Positive Affect}_{ij} + \beta_{12}\ \text{Male's Negative Affect}_{ij}$$

$$\pi_2\ \text{Male's Rating of Interaction Quality with Female}_{day\ i,\ dyad\ j} = \beta_{20ij} + \beta_{21}\ \text{Female's Positive Affect}_{ij} + \beta_{22}\ \text{Female's Negative Affect}_{ij}$$

The β_{10} and β_{20} coefficients are the intercepts of the model, representing the predicted value of the DV when all of the independent variables are zero. Because the independent variables (positive and negative affect) are both centered around the individual's own within-person mean, this means that β_{10} and β_{20} represent predicted values of the DV (interaction quality) at the individual's average level of positive and negative affect. The slope terms β_{11} and β_{12} (for the male's model) and β_{21} and β_{22} (for the female's model) represent the degree to which day-to-day variation in the individual's affect is associated with corresponding day-to-day variation in his or her partner's rating of the quality of their interactions. Because both positive and negative affect are included in the model, the slope for positive affect represents variation that is independent of corresponding variation in negative affect, and vice versa.

Level 3 tests for moderation of the within-person effects by between-person characteristics (specifically, vagal tone and vagal reactivity, both of which were centered at the sample mean; centering was conducted separately for males versus females). So, for example, when the DV is positive interaction quality, the Level 3 moderating effect of vagal tone on β_{10} (the Level 2 intercept) tests whether this intercept (i.e., men's average positive interaction quality, as rated by their female partners) was significantly higher among men with higher vagal tone. Level 3 moderating effects on Level 2 *slopes* (e.g., β_{11} and β_{12}) test whether the within-day *associations* between daily affect and daily interaction quality are stronger or weaker among men with high versus low vagal tone. Note that Level 3 parameters are denoted *G*, to distinguish them from Level 2 (β) and Level 1 (π) parameters, yet all of these parameters are regression slopes. All analyses checked for interactions among vagal tone and vagal reactivity, and none were found. We also tested models that included, as a Level 2 covariate, the value of the DV on the *previous* day, to control for dependency across days. None of the results were changed, and so we did not include this covariate (or other nonsignificant effects) in final models. All reported *p* values are calculated with two-tailed tests, with the exception of directional hypotheses, which were tested with one-tailed *t* tests on model coefficients and noted as such in the text. All models controlled for age and body mass index, as these variables are known to be associated with individual differences in vagal regulation. In the current sample, women's age was correlated with vagal tone and vagal reactivity ($r = -.60$ and $r = .25$), and women's body mass index was correlated with vagal tone ($r = -.26$). Men's age and body mass index were correlated with vagal tone ($r = -.27$ and $r = -.17$).

Overall Interaction Quality

Coefficients for all HLM models are presented in Table 3. The prediction that one's overall interaction negativity and positivity (as rated daily by one's partner) would be associated with vagal tone (H1a) and vagal reactivity (H1b) received partial support, and only among men. As predicted, men with higher levels of vagal tone were rated by their partners as interacting more positively (but not less negatively) on average across the study, $G = .24$, one-tailed $p < .05$. There were no significant effects for men's vagal reactivity. Among women, we detected no associations between overall interaction quality and either vagal tone or vagal reactivity.

Moderating Effects on Within-Person Associations Between Affect and Interaction Quality

We predicted that individuals with lower vagal tone (H2a) or higher vagal reactivity (H2b) would show stronger associations between their negative affect and the quality of their daily couple interactions. This prediction was confirmed, although the pattern of results was different for men than for women. Among men, the association between daily negative affect and the negativity of daily couple interactions (as rated by their female partners) was more pronounced among men with lower vagal tone, $G = -.14$, one-tailed $p < .05$. In parallel fashion, the association between men's daily negative affect and the *positive* quality of their daily interactions was more pronounced among men with lower vagal tone, $G = .27$, one-tailed $p < .05$. Also as predicted, the association between daily negative affect and the negativity of couples' interactions was more pronounced among men with greater vagal reactivity, $G = .53$, one-tailed $p < .001$. Figure 1 displays the estimated slopes relating daily negative affect to the positivity and negativity of daily couple interactions among men with high and low vagal tone (defined as 1 *SD* above and below the mean). As depicted, among men with low vagal tone, a

Table 3. Associations of Vagal Tone and Vagal Reactivity With Overall Interaction Quality and With Within-Person Associations Between Daily Interaction Quality and Daily Affect

Model term	Coefficient
DV: Negativity of men's daily couple interactions	
Intercept (i.e., average rating across all days)	1.1***
Male's same-day positive affect	–0.002
Male's same-day negative affect	0.14**
Male's vagal tone	–0.14*
Male's vagal reactivity	0.53***
Male's age	–0.004
Male's body mass index	–0.02
DV: Positivity of men's daily couple interactions	
Intercept (i.e., average rating across all days)	3.28***
Moderators: Male's vagal tone	0.24*
Male's body mass index	–0.004
Male's age	–0.01
Male's same-day positive affect	0.02
Male's same-day negative affect	–0.22**
Moderators: Male's vagal tone	0.27†
Male's body mass index	0.03*
Male's age	–0.03*
DV: Negativity of women's daily couple interactions	
Intercept (i.e., average rating across all days)	1.2**
Female's same-day positive affect	–0.03
Female's same-day negative affect	0.15**
DV: Positivity of women's daily couple interactions	
Intercept (i.e., average rating across all days)	3.2***
Female's same-day positive affect	0.05
Female's vagal tone	0.20*
Female's body mass index	0.02
Female's age	0.02*
Female's same-day negative affect	–0.002

†$p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$.

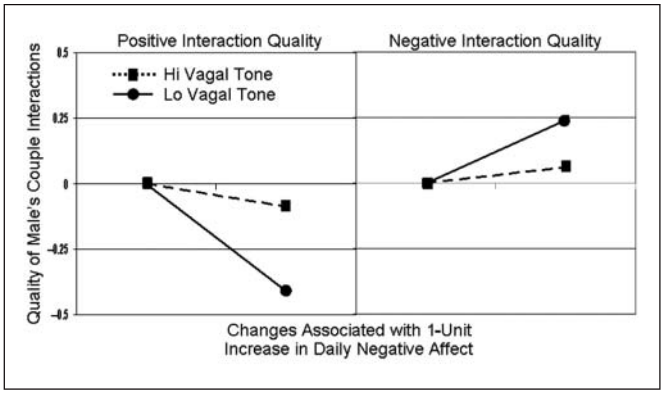

Figure 1. Moderating effects of men's vagal tone on within-person slopes relating men's daily negative affect to their positive and negative interaction quality

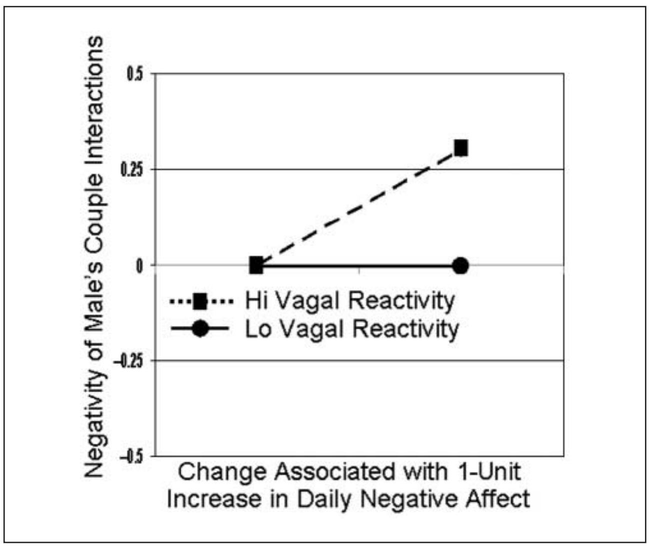

Figure 2. Moderating effects of men's vagal reactivity on within-person slopes relating men's daily negative affect to their negative interaction quality

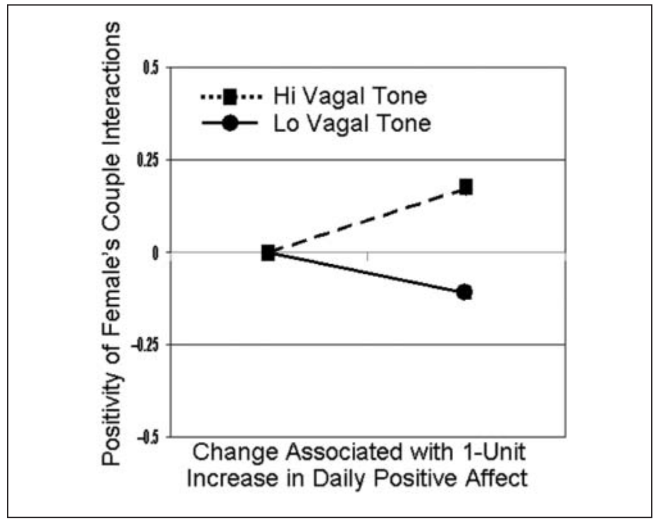

Figure 3. Moderating effects of women's vagal tone on within-person slopes relating daily positive affect to positive interaction quality

one-unit change in daily negative affect was associated with significantly lower interaction positivity (b = –.41, one-tailed $p < .01$) and significantly greater interaction negativity (b = .24, one-tailed $p < .01$). Yet among men with high vagal tone, a one-unit change in daily negative affect was not associated with a change in interaction positivity or negativity ($b_{positivity} = -.09$, $b_{negativity} = .06$, both one-tailed p values = *ns*). Figure 2 displays the estimated slopes relating daily negative affect to the negativity of daily couple interactions among men with high and low vagal reactivity (defined as 1 *SD* above and below the mean). As depicted, among men with high vagal reactivity, a one-unit change in daily negative affect was associated with significantly greater interaction negativity (b = .30, one-tailed $p < .001$), whereas this was not the case among men with low vagal reactivity (b = –.01, one-tailed p = *ns*). There were no significant moderating effects of vagal regulation for links between men's *positive* affect and interaction quality.

Among women, consistent with Hypothesis 3a, women with higher vagal tone showed stronger links between daily positive affect and positive interaction quality, G = .19, one-tailed $p < .05$. This effect is displayed in Figure 3, which displays the estimated slopes relating daily positive affect to the positivity of daily couple interactions among women with high and low vagal tone (defined as 1 *SD* above and below the mean). As shown in Figure 3, among women with high vagal tone, a one-unit change in daily positive affect was associated with significantly greater interaction positivity (b = .16, one-tailed $p < .05$), whereas this was not the case among women with low vagal tone (b = –.11, one-tailed p = *ns*).

As noted earlier, we tested for significant effects of the *partner's* vagal tone and vagal reactivity and found none. Also, given the strong correlations (shown in Table 2) between partner's judgments of the positive and negative quality of their daily interactions (r = .57 and r = .34, respectively), we conducted ancillary analyses using the individuals' *own* rating of the positivity or negativity of their daily interactions as the outcome variable. The only significant effect concerned the association between daily negative affect and daily negativity: Among both men and women, this association was significantly stronger among those with higher vagal tone, $G_{men} = .21$ and $G_{women} = .20$, both two-tailed p values < .05.

Discussion

The current study provides the first evidence for associations between cardiac vagal regulation and the day-to-day interpersonal functioning in cohabiting couples. A strength of the present study is its integration of laboratory-based assessments of vagal tone and vagal reactivity with daily diary data on naturally occurring couple interactions over a 3-week period, shedding new light on how individuals with different patterns of vagal regulation manage the interplay between affect and couple functioning on a day-to-day level. Another important strength of the present study is that we assessed individuals' interpersonal functioning from the perspective of their *partners*. Hence, the effects we detected cannot be attributed to individuals' own perceptual biases regarding the quality of their day-to-day couple interactions. Rather, our findings capture the fact that individuals with different capacities for affect regulation "come across" differently to their romantic partners, especially on days when their affect is particularly positive or negative.

Notably, all of the effects that we detected differed for women versus men, raising important questions about gender differences in vagal regulation and their implications for couple functioning. Most notably, individual differences in vagal regulation showed more pervasive associations with *men's* affect and interactions than with women's, and specifically moderated links between men's daily interactions and their daily *negative* affect. These findings make novel contributions to understanding the interbraided physiological and psychological processes underlying romantic relationship functioning, how these processes differ for women versus men, and their potential implications for men's and women's romantic relationship functioning over the life course (Impett & Peplau, 2006).

Effects for Men

We predicted that individual differences in vagal regulation would be associated with overall interaction quality across the diary assessment period, and we also predicted that vagal regulation would moderate *within-person* associations between daily affect and daily interaction quality. The latter prediction received substantially more support than the former, and more so among men than women. Men with higher vagal tone (indexed by higher baseline RSA) were rated by their female partners as interacting more positively (i.e., expressing more connectedness and understanding) on average than were men with lower vagal tone. This finding is consistent with the notion that vagal tone is specifically related to a positive and flexible dispositionality that promotes affectively positive, approach-oriented social behavior (Oveis et al., 2009). However, the fact that we did not find corresponding associations between vagal tone and men's *negative* interaction quality, and the fact that no such associations were detected among women, suggests that individual differences in vagal regulation are relatively poor predictors of between-person differences in average interaction quality.

Rather, vagal regulation plays a more important role in moderating links between daily affect and daily interaction quality. As discussed earlier, daily affect and daily interaction quality are related to one another in a bidirectional fashion (Reis et al., 2000). These links are relatively adaptive when it comes to positive affect and interactions, allowing for a "broadening and building" of salubrious emotions and interpersonal resources (Fredrickson, 2001). Yet they can prove maladaptive when it comes to negative affect and interactions, often promoting detrimental escalation of negative affect and hostile interpersonal behavior (e.g., Gottman, 1998). Accordingly, we expected that individuals with lower vagal tone would show stronger links between daily negative affect and daily interpersonal behavior but weaker links between their daily positive affect and daily interpersonal behavior.

This prediction was confirmed for men, but only with respect to negative affect. Notably, we found independent effects of *both* vagal tone and vagal reactivity: On days when men with either low vagal tone or high vagal reactivity reported high negative affect, their female partners described them as more critical and argumentative. Yet this was not the case for men with high vagal tone or low vagal reactivity. Men's vagal tone also moderated the association between daily negative affect and *positive* interaction quality. As shown in Figure 1, there was a steep inverse association between negative affect and positive interaction quality among men with low vagal tone, such that these men were described by their female partners as less understanding and less connected on days when the men reported high negative affect. Yet this was not the case for men with high vagal tone. Hence, this pattern of results suggests that robust vagal regulation may allow men to maintain an adaptive degree of dissociation between their negative affect and the quality of their daily couple interactions.

Of course, because links between affect and interaction quality are bidirectional, the moderating effects we detected for vagal regulation might operate through two different pathways: (a) poorly regulated men may be more likely to behave more negatively and less positively toward their romantic partners when they are in a bad mood and (b) poorly regulated men may be more likely to experience heightened negative affect *as a result of* having a low-quality interaction with their partner. Both pathways are consistent with the notion that individuals with higher vagal tone are better able to manage the day-to-day interplay between affect and social interaction (Beauchaine, 2001; Porges, 2003), yet previous research provides more evidence for Pathway 1. For example, Gyurak and Ayduk (2008) found that rejection-sensitive individuals adopted maladaptive strategies for resolving romantic conflict only if they also had low vagal tone. Furthermore, this effect was found to operate through the mechanism of emotional control, suggesting that vagal tone may prove particularly important when individuals are attempting to maintain adaptive interpersonal behavior in the face of strong emotions, consistent with the findings of Fabes and Eisenberg (1997).

Yet perhaps the best evidence for Pathway 1 over Pathway 2 is the fact that when we repeated our analyses using men's ratings of interaction negativity as the outcome (i.e., indicating how critical and argumentative they thought their *partners* were, as opposed to how critical and argumentative *they* were judged as being), we found that high vagal tone *accentuated* (rather than attenuated) the association between men's negative affect and their judgments of their partner's negativity (a moderating effect that we also detected among women). Given research demonstrating that individuals with high vagal tone are less inhibited (Fox, 1989; Snidman, 1989), are more emotionally expressive (Kettunen et al., 2000), are more empathic (Eisenberg et al., 1996; Fabes & Eisenberg, 1997; Fabes et al., 1993), and show more effective recovery from distress (Eisenberg et al., 1996; Fabes & Eisenberg, 1997; Fabes et al., 1993), one possible explanation is that individuals with high vagal tone are more likely to experience and express negative affectivity when confronting negative behavior by their partner, *but* that their effective emotion regulation prevents them from "behaving badly" in return. Specific *sequences* of positive and negative behavior in couples and whether individuals with high vagal tone are better able to interrupt negative sequences and prevent the escalation of negative affect are promising directions for future research.

Effects for Women

Although the moderating effects of men's vagal regulation were particularly pronounced for *negative* affect, the moderating effects of women's vagal tone were specific to *positive* affect. As shown in Figure 3, women with higher vagal tone interacted more positively with their partners (according to their partners) on days when the women reported greater positive affect. This effect was not observed among women with lower vagal tone. As with the effects detected for men, there are two different pathways through which this moderating effect might operate: Women with higher vagal tone might be better able to mobilize positive affect in the service of sensitive and responsive interactions with their romantic partners, and/or women with higher vagal tone might experience stronger positive emotions *in response* to positive interactions with their romantic partners. As with the findings for men, there appears to be more evidence for Pathway 1 than for Pathway 2, given that previous research on vagal tone and positive emotionality (Oveis et al., 2009) did not find that individuals with higher vagal tone had greater positive reactivity to emotion-eliciting stimuli. However, greater research is clearly necessary on this question, given that there is much less research on the implications of vagal tone for positive than for negative affect. Along these lines, it is notable that we found no associations between vagal regulation (in men or women) and individuals' *own* rating of the positivity of their partner's interaction quality.

The unexpected gender differences we detected regarding vagal regulation also warrant future investigation. Overall, vagal tone played a more pervasive moderating role for men's affect and interactions than for women, and the only vagal reactivity effect that we detected concerned men. It is difficult to interpret these gender differences, given that previous research has devoted relatively little attention to gender differences in the implications of vagal regulation for social and psychological functioning. In particular, it is unknown whether they stem from biological differences between men and women or from culturally based differences in men's and women's relationship roles and behaviors. For example, given that women typically take greater responsibility for relational maintenance than men (Canary & Stafford, 1992; Dainton & Stafford, 1993), women may focus their regulatory "effort" on channeling their *positive* emotions toward positive interpersonal interactions with their partners (i.e., displays of responsiveness and connectedness); men, in contrast, might instead focus their regulatory effort on preventing *negative* emotions from spilling over into criticism and argumentativeness. Another important factor to consider is the fact that interaction quality was judged by individuals' *partners*. Given women's greater accuracy in decoding male partners' moods and signals and their greater sensitivity to aversive couple interactions (Noller & Fitzpatrick, 1990; Notarius, Benson, Sloane, & Vanzetti, 1989), it is possible that men are less adept than their female partners at *detecting* the types of variation in interaction quality that are related to individual differences in vagal regulation. Future research would therefore benefit by triangulating partner reports of couple functioning with objective observational coding to provide a more comprehensive portrait of the role of vagal tone in moderating links between daily affect and daily interactions among men versus women.

Limitations and Future Directions

Perhaps the most important limitation of this research is the fact that—as noted earlier—our data cannot reveal the underlying mechanisms through which individual differences in vagal regulation moderate links between daily affect and daily interaction quality. As noted earlier, future research that relates individual differences in vagal tone and vagal reactivity to specific sequences of behavior is necessary to illuminate these mechanisms. For example, one recent study assessed spouses' RSA *during* a series of marital interactions (Smith et al., 2010). They found that wives who had just undergone a negative interaction with their husband showed greater vagal reactivity during a subsequent argument, whereas wives who had just undergone a positive or neutral interaction with their husband did not show this pattern. The authors suggested that the previous negative interaction "triggered" wives to mobilize self-regulatory resources to manage negative affect during the subsequent argument. This finding is particularly intriguing given that we found that men who were characterized by high vagal reactivity *more generally* (i.e., in response to a laboratory stressor as opposed to a specific interpersonal exchange) showed a heightened association between their daily negative affect and the negativity of their partner behavior. Given that some researchers have suggested that a chronic pattern of heightened vagal reactivity may develop *in response* to chronic environmental demands (Katz, 2007), one possibility is that individuals who experience negative couple interactions *regularly* in their romantic relationships may develop a "habit" of vigilant regulatory effort and emotional control, manifested in chronically heightened vagal reactivity to stress. In other words, perhaps men's vagal reactivity does not, in fact, predispose them to heightened "spillover" from negative affect to negative behavior; perhaps instead, their high vagal reactivity to stress is an indicator that on a day-to-day level, they must actively struggle to control their emotions and behavior. Of course, our correlational data cannot speak to which causal pathway is more likely (and of course, both may be operative). Future longitudinal research is critical for testing how individual differences in vagal tone and reactivity (which show links to both genetic and environmental influences; Cheng, Carmelli, Hunt, & Williams, 1997; Healy, 1992; Matthews, Manuck, Stoney, & Rakaczky, 1988; Tuvblad et al., 2010) develop in early childhood, their degree of stability over the life course, the processes by which they moderate responses to chronic interpersonal stressors and supports, and the degree to which they themselves might undergo continued modification as a result of sustained exposure to such stressors and supports (Diamond, 2001).

Conclusion

A growing body of research suggests that individual differences in vagal regulation represent a physiological substrate for flexible and efficient management of affect, particularly in the context of social interaction. The present study contributes to this research by demonstrating that individual differences in vagal tone and vagal reactivity to stress make unique contributions to romantic couples' patterns of day-to-day positive and negative couple interactions, particularly by moderating within-person links between daily affect and daily interaction quality. A particularly novel contribution of the present research is the detection of gender differences in the patterns of association among vagal regulation, daily affect, and daily interaction quality. These gender differences may prove to be related to some of the pervasive gender differences that have been observed in romantic relationship functioning more generally (Impett & Peplau, 2006) and to gender differences in the health implications of longstanding romantic ties (Kiecolt-Glaser & Newton, 2001). Overall, the findings make novel contributions to understanding the interpersonal implications of individual differences in vagal regulation and to understanding the biobehavioral underpinnings of romantic relationship functioning more generally.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interests with respect to the authorship and/or publication of this article.

Financial Disclosure/Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by Grant 1R03MH64813-01 from the National Institutes of Mental Health, awarded to the first author.

Note

1. For some couples, there were a number of days (no more than 7) during which one partner was out of town. Because we were interested in emotional and interpersonal functioning while couples were together, we excluded these "separated" days from analyses.

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