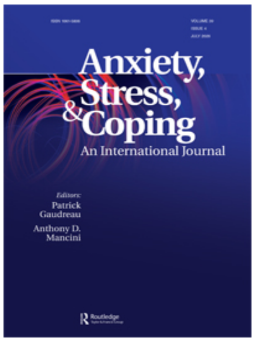

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The effects of transcutaneous vagus nerve stimulation on romantic couples' physiology and behavior during conflict

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ABSTRACT

Background: Conflicts with close others and subsequent affective reactions can have long-term consequences for mental and physical health. Building on recent studies using transcutaneous vagus nerve stimulation (tVNS) highlighting the role of the vagus nerve in social functioning, we examined if tVNS can modulate the emotional, physiological, and behavioral responses to a romantic conflict.

Methods: Romantic couples ($N_{couples} = 67$; $N_{individuals} = 134$) were randomly assigned to tVNS or sham stimulation. Both partners received continuous tVNS or sham stimulation for 15 min before and during a six-minute discussion about a recurring conflict topic. We examined each partner's emotional and respiratory sinus arrhythmia (RSA) reactivity to conflict and the partners' physiological and behavioral attunement to each other.

Results: Our results revealed no condition differences in emotional experiences, but individuals receiving tVNS (vs. sham stimulation) experienced greater decreases in RSA during conflict. Further, while RSA reactivity synchrony did not differ between conditions, couples in the tVNS (vs. sham stimulation) condition showed greater behavioral synchrony.

Conclusions: This work provides experimental evidence supporting the role of the vagus nerve in modulating reactions to stressful social interactions, highlighting the potential of tVNS to subtly influence couple dynamics at physiological and behavioral levels.

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Vagus nerve; vagal flexibility; cardiac vagal reactivity; relationship functioning; relationship well-being

Stressful situations involving close others trigger a wide range of affective reactions that can shape how the situation is handled and impact mental and physical health over time (Robles & Kiecolt-Glaser, 2003). For example, classic research examining conflict conversations with a romantic partner showed that these conversations elicit changes in autonomic cardiac activity, such as increases in sympathetic nervous system arousal (Levenson & Gottman, 1985). Extending this early work, contemporary research implicates the parasympathetic nervous system during these interactions and reveals decreases in respiratory sinus arrhythmia (RSA), a measure of high-frequency heart rate variability occurring over the respiratory cycle (Han et al., 2021). Over decades, researchers have identified how the magnitude of these physiological changes is associated with the immediate dynamics of how a conflict unfolds (Smith et al., 2011) and the long-term quality and stability of relationships (Gottman & Levenson, 2002).

Previous theoretical and empirical work has highlighted the role of the vagus nerve in understanding various affective reactions to stressors and broader social functioning (Balzarotti et al., 2017; Porges, 2001; Thayer & Lane, 2000). For example, higher vagal tone, or tonic levels of

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parasympathetic influence on the heart (as reflected in RSA at rest), has been associated with greater empathic responses to others' distress (Fabes et al., 1993), lower loneliness (Roddick & Chen, 2021), and stronger social integration and acceptance (Geisler et al., 2013). More recently, studies utilizing stimulation of the vagus nerve have provided causal evidence that the vagus nerve plays a role in socio-emotional functioning. For example, transcutaneous vagus nerve stimulation (tVNS) has been found to increase attention to salient social cues such as facial features (Maraver et al., 2020; Zhu et al., 2022) and improve emotion recognition under specific conditions (e.g., recognition for anger but not sadness, Steenbergen et al., 2021; emotions in faces but not bodies, Sellaro et al., 2018; also see Koenig et al., 2021; Zhao et al., 2025).

Nevertheless, with most investigations focusing on rudimentary social processing, if and how tVNS affects complex social interactions like conflicts remain unclear, limiting our understanding of the vagus nerve's role in real-world social dynamics. To the authors' knowledge, only two studies have explored the effects of tVNS on behaviors in social interactions. One study used the prisoner's dilemma paradigm to find that tVNS increases cooperative behaviors in epilepsy patients (Oehrn et al., 2022); another study using a virtual ball-tossing game in which one person was ostensibly ostracized showed that tVNS does not influence helping behaviors (Sellaro et al., 2015). No work has examined the effects of tVNS during interactions within the context of established relationships that mimic real-life exchanges. In the present research, we examined if tVNS can modulate emotional, physiological, and behavioral responses to romantic conflicts.

Mechanisms of tVNS and implications for stressful interactions

Considering that one of the purported working mechanisms of tVNS concerns increased vagal activity, much work has explored vagally mediated heart rate variability (HRV) measures as a potential "biomarker" of tVNS (Burger et al., 2020). Drawing on findings that tVNS can increase HRV (e.g., Forte et al., 2022; Geng et al., 2022), one might speculate that tVNS delivered during conflict could mitigate the typical reductions in HRV observed during stressful situations. However, evidence for tNVS-induced modulation of HRV has largely been inconsistent (Soltani et al., 2023; Wolf et al., 2021), perhaps reflecting the fact that any effects of tVNS, which stimulates the afferent branch of the vagus nerve, on HRV are likely indirect (also see Jigo et al., 2024). Critically, most existing investigations have administered tVNS while participants were at rest (e.g., Borges et al., 2019; Sclocco et al., 2020; Villani et al., 2019). The context in which the stimulation takes place is important because tVNS effects on vagal activity may be more apparent when examining modulation of reactivity, rather than resting levels. In situations where vagal withdrawal is expected, such as in stressful conflict interactions, tVNS, which stimulates afferent vagal fibers projecting to the nucleus tractus solitarius (NTS), can promote more flexible responding of the parasympathetic system, manifesting as increased reactivity. The NTS projects to several brain regions including the locus coeruleus (LC) which can also modulate parasympathetic activity through its inhibitory control over brainstem autonomic centers (Wood et al., 2017).

To the extent that tVNS increases vagal reactivity, it is conceivable that the impact spills over to influence the overall dynamics of the stressful interaction. Conceptualizing vagal flexibility – variability in RSA across tasks – as a trait-like individual difference, Muhtadie et al. (2015) suggested that greater vagal reactivity reflects social sensitivity. Their studies showed that high vagal flexibility was linked to outcomes such as better detection of social cues and more pronounced affective responses to social feedback. Relatedly, greater vagal flexibility has also been linked to improved person perception – accurately detecting observable personality traits (e.g., extraversion) of target individuals (Human & Mendes, 2018). Although limited work has explored the implications of RSA reactivity in romantic conflicts specifically, such reactivity is likely related to partner interaction dynamics. Here, we focus on the extent to which partners' physiology and behaviors are in sync as broad indicators of their general attention to and engagement with each other during this stressful interaction.

The possibility that tVNS affects partners' attunement to each other aligns with its known effects on the LC, a primary source of norepinephrine (NE; also see Colzato & Beste, 2020). The LC-NE system plays a critical role in modulating attention and vigilance, enhancing responsiveness to contextual information (Maness et al., 2022; Unsworth & Robison, 2017). Although evidence for tVNS effects on LC-NE activity (inferred using indirect markers like pupil dilation; D'Agostini et al., 2023; Keute et al., 2019; Sharon et al., 2021) has been mixed, the LC-NE account nonetheless supports the idea that tVNS may facilitate interpersonal attunement by increasing sensitivity to subtle social cues such as partner's gestures during conflict. In short, there may be multiple (e.g., parasympathetic, noradrenergic) pathways through which tVNS could affect physiological or behavioral synchrony.

Overview

To examine the effects of tVNS on responses to stressful interactions, we randomly assigned romantic couples to active tVNS or sham stimulation. Both partners received continuous stimulation for 15 min before and during a conflict conversation. We examined various outcomes reflecting different affective experiences: (1) self-reported emotions, (2) RSA reactivity, (3) synchrony in RSA reactivity, and (4) synchrony in movements. Because this study, to our knowledge, is the first to apply tVNS during live social interactions, we approached it as exploratory and did not formulate a priori hypotheses. For example, while we considered the possibility that tVNS enhances parasympathetic flexibility, leading to increased RSA reactivity (i.e., greater withdrawal) in response to conflict, it is also possible that, by increasing tonic vagal activity or enhancing central autonomic control (e.g., via NTS-mediated modulation of basal autonomic gain rather than reactivity per se), tVNS could instead reduce the magnitude of vagal withdrawal required to meet sympathetic demand, thereby buffering RSA decreases during conflict. Likewise, to the extent that the conflict elicits negative social cues, the enhanced social sensitivity or attentional tuning account would predict stronger negative emotional responses among those receiving tVNS; yet, considering that conflict interactions also involve subtle positive cues (e.g., cooperation), this same mechanism could instead yield a null overall effect on negative emotion. Regardless, examining self-reported emotions was important for determining whether any observed effects in physiological or behavioral domains were accompanied by differences in consciously experienced emotion.

RSA reactivity was operationalized as changes in RSA during conflict compared to baseline. To capture synchrony, we examined non-directional concurrent synchrony in RSA reactivity (Helm et al., 2018). Directional hypotheses which assume asymmetrical influence (one partner influencing the other) were not the focus of our study in which dyads engaged in a joint conversation, without role distinctions (e.g., speaker and listener); our sample also included same-gender couples, making dyads indistinguishable by gender as well as other within-dyad roles (e.g., parent and child). For movement or behavioral synchrony, we used the Motion Energy Analysis (MEA; Ramseyer, 2020) which uses a frame-differentiating method to quantify changes in movement and allows for examining two or more people's temporal coordination. Of note, while the primary focus of this paper is on the effects of tVNS during conflict, the study also included a positive interaction task (i.e., gratitude exchanges). See the Supplemental Online Material (SOM) for full analyses of this positive interaction and for results showing that experiences during this task did not significantly influence our primary findings.

Methods

Participants

Deidentified data and R codes used in the current study are available at https://osf.io/pru7f/?view_only=2ed48aeea44244aa8a84614a64d4aaa9. This study was approved by the Institutional Review Board at University of California, San Francisco. The study was registered on Clinicaltrials.gov on June 2, 2023 (NCT05899413). Participants were recruited in the San Francisco Bay Area through various community and university newsletters and listservs, flyers around the city, Reddit, and word of mouth.

Participants were eligible for the study if they and their partner were 18–35 years old, fluent in English, had no major chronic diseases or untreated psychiatric diagnoses, were not taking any confounding medications, and did not have unremovable piercings on the tragus. Participants were also required to have been in a relationship with their partner for at least one year and be able to complete the in-person laboratory visit together. With the target size of 70 couples, we recruited 80 couples, accounting for potential data loss. We excluded ten couples who experienced session failures (e.g., the tVNS device turned off during the session). The ten couples to be excluded were determined prior to any data analysis.

After excluding five individuals whose physiological data during the conflict were unavailable and one whose baseline RSA was unavailable, our final analytic sample consisted of 134 individuals. Table 1 presents participants' sociodemographic and relationship characteristics, separated by condition. For physiological synchrony analyses, we examined 130 individuals (65 couples) with both partners' data available. For analyses on behavioral synchrony, we excluded three more couples in which at least one partner disapproved use of their recorded videos.

Tasks and measures

Pre-visit survey

Prior to the lab visit, participants completed surveys assessing sociodemographic and relationship characteristics, and provided height and weight, which we used to calculate Body Mass Index (BMI), a covariate. Participants also responded to a 5-item measure of relationship satisfaction

Table 1. Participant and relationship characteristics ($N = 134$).

Variables	*N* (%)
Gender	
Male	66 (49%)
Female	64 (48%)
Non-binary	2 (1%)
Unidentified	2(1%)
Age *M* (*SD*)	27.90 (4.29)
Ethnicity	
Asian	62 (46%)
White/European American	56 (42%)
Middle Eastern/North African	3 (2%)
African American/Black	3 (2%)
American Indian or Alaska Native	3 (2%)
Multiracial	5 (4%)
Unidentified	2 (1%)
Education	
≤ high school diploma/GED	9 (7%)
Associate/Bachelor's degree	75 (56%)
Graduate and professional degree	48 (36%)
Unidentified	2 (1%)
Relationship status	
Dating seriously	77 (58%)
Engaged	23 (17%)
Domestic partnership	6 (4%)
Married	28 (21%)
Relationship type	
Opposite-sex	112 (84%)
Male-male	8 (6%)
Female-female	6 (4%)
Others	8 (6%)
Relationship duration in years *M* (*SD*)	4.33 (2.73)

Notes: *M* = Mean, *SD* = Standard deviation. tVNS = Transcutaneous vagus nerve stimulation. See SOM for a detailed breakdown by condition.

($\alpha = .81$) and a 7-item measure of commitment ($\alpha = .79$; Rusbult et al., 1988), which we used to test pre-existing differences across conditions. Additionally, they rated 24 relationship issues (adapted from Geiss & O'Leary, 1981) on a scale ranging from 0 (*issues that rarely if ever raise conflict*) to 10 (*issues that raise frequent or intense conflict*). Responses to this scale were used in the conflict interaction described below.

Conflict interaction and post-interaction survey

The procedures were based on Levenson and Gottman (1983) and previous studies that examined physiological reactivity during conflicts (e.g., Godfrey & Babcock, 2020; Raby et al., 2015). Couples were told that they would discuss a conflict topic relevant to their relationship and try to resolve it. The interaction would involve the following steps: (1) couples selecting a topic to discuss together, (2) reflecting on the topic independently for three minutes, (3) each partner taking turns expressing their thoughts and feelings about the topic for one minute (the speaking order was predetermined based on the alphabetical order of their first names), and (4) couples engaging in free discussion for six minutes, with the goal of resolving the issue. We analyze the 6-minute joint discussion.

After receiving the instructions, couples were given a list of three topics to choose from. Unknown to the couples, this list was generated using participants' responses regarding the frequent topics of arguments that they provided in the pre-visit survey. The three topics were chosen based on the highest average ratings of the two partners. If no topics averaged higher than 3, the list included an option of "any topic that recently triggered a conflict or disagreement in the relationship." Following the interaction, participants completed a short questionnaire that asked them about their **positive affect** ("During the conversation, overall, I felt … "; 1: not at all positive, 7: extremely positive), **negative affect** ("During the conversation, overall, I felt … "; 1: not at all negative, 7: extremely negative), and **productivity** ("Overall, the conversation was productive"; 1: strongly disagree, 7: strongly agree). To keep the interim surveys brief, single-item measures were used; internal consistency reliability estimates were not applicable.

tVNS device and stimulation

We used a research edition of an auricular vagus nerve stimulator (tVNS RE, Vagus.net™, UK) that sends current-controlled stimulation in symmetric biphasic waveforms. The tVNS RE conforms to EU directive 93/42/EEC medical device standards and ISO/IEC 17050-1. This device consists of a handheld stimulator and an electrode clip. Following previous research (Kraus et al., 2007), electrodes were placed on the left earlobe (free of cutaneous vagal innervation; Peuker & Filler, 2002) for the sham stimulation condition and on the tragus for the tVNS condition.

The experimenter first cleaned the stimulation loci with alcohol cotton swabs to reduce skin resistance. To identify the lowest stimulation intensity that participants could perceive, we adopted the staircase procedures used in previous research (e.g., Schuerman et al., 2021). Specifically, the experimenter placed the electrode clip on the participant's left ear (tragus or earlobe) and increased the stimulation levels by 0.1 mA, starting from zero, until the participant reported feeling a tingling sensation. Experimenters confirmed the threshold twice, and the stimulation level was set at 0.2 mA below each participant's perceptual threshold to minimize discomfort and allow couples to converse as naturally as possible. We delivered stimulation at the individually calibrated intensity continuously during the interaction, and the default device settings we adopted were as follows: frequency = 30 Hz, phase duration = 250μs, interphase interval = 50μs, and max voltage = 65 V.

The average intensity was 0.71 mA ($SD = 0.46$, ranging from 0.1 to 2.8) in the sham stimulation condition and 0.58 mA ($SD = 0.33$, ranging from 0.1 to 1.4) in the tVNS condition (not significantly different, $t(127) = 1.87$, $p = .06$). Of note, there were nine individuals (five in the sham and four in the tVNS condition) who reported feeling the sensation even at 0.1 mA for whom stimulation at 0.1 mA was used. An experimenter in another room remotely controlled the intensity of the stimulation during couples' interactions.

Physiological data acquisition

Participants' physiological responses were continuously recorded during the baseline and all interactions. We collected electrocardiography (ECG) and impedance cardiography, which were integrated using an MP150 system (Biopac Systems Inc., Goleta, CA). Spot sensors were placed in a modified lead II configuration on the torso (near the right clavicle and below the left rib cage) to measure ECG (Mendes, 2009). Data were acquired using Acqknowledge software at a sampling rate of 1000 Hz. RSA was calculated using the HRV module (Version 3.2.13) from Mindware Technologies (Gahanna, OH), which computes the natural logarithm of the power within the high-frequency band (0.15–0.40 Hz) of the HRV spectrum. RSA was scored in 30-second intervals. Although 60-second epochs are generally recommended, 30-second epochs have been reliably used in previous dyadic studies (Caldwell et al., 2019; Oshri et al., 2023; Qaiser et al., 2023) and may sufficiently capture high-frequency activity especially when the heart rate is elevated (i.e., shorter heart period; Quigley et al., 2024), as in conflict settings.[1] After data collection, trained research assistants blind to the condition visually inspected all data for artifacts and edited them as needed (e.g., removal of misplaced R-peaks).

Post-study survey

Before debriefing and being informed of the condition they were assigned to, participants answered a few questions about their experience of the stimulation and the tVNS device. Among others, we asked them how uncomfortable the tVNS device was (full items available in SOM).

Study procedure

Interested individuals first completed a screening questionnaire to confirm eligibility. Eligible participants were contacted to schedule a lab visit and received a link to the consent form and pre-visit survey two days before the visit. Couples were assigned to the tVNS or sham stimulation condition once both partners completed the survey.

Upon arrival, partners were escorted to separate rooms to receive a study overview and undergo threshold testing for stimulation. They then reunited, were connected to physiological sensors, and rested for five minutes (baseline) while seated at an angle partially facing each other and a wall-mounted camera (Figure 1). Full study procedure, including the timing of the stimulation is illustrated in Figure 2. Following a cool-down period, participants completed a brief questionnaire about their experience with the stimulation and were debriefed.

Data analysis

All analyses were conducted in R. Multilevel model analyses were conducted using the package *lmer*. All tests were two-tailed, with a significance threshold of $\alpha = .05$, and corresponding p-values are reported.

Randomization check

We examined condition differences in personal and relational characteristics at baseline, including age, relationship duration, relationship satisfaction, and commitment. To account for the interdependence of the dyadic data, we fitted a series of multilevel models with a random intercept included for participants nested within couples and condition included as a fixed effect. Restricted Maximum Likelihood was used to fit the model parameters. For relationship duration, a couple-level variable, Welch's t-test was conducted.

Subjective experience of the conflict

We examined condition differences in couples' self-reported experience of the conflict interaction, specifically in terms of emotions during the conversation and its productivity. We ran a parallel set of multilevel models as described above.

Figure 1. Example positioning of the couple during the study.

Physiological reactivity

We first examined if the conflict interaction elicited significant changes in RSA compared to baseline by comparing RSA levels across the two task periods. The multilevel model nested participants within couples, included a fixed effect of task, and allowed for a random slope of task. We then calculated reactivity scores by subtracting the raw RSA score during the last 30 s of baseline from every segment of the interaction. We fit a two-level crossed model with random intercepts for individuals and couples.[2] The model estimated the effect of condition (coded as – 0.5 for sham and 0.5 for tVNS) on RSA reactivity. Time was included as a fixed effect to account for RSA reactivity trajectories; a random slope for time by individual led to singular model fits, suggesting negligible variance, and was dropped. We also tested but dropped an interaction between time and condition, which was not significant. In our follow-up models, we controlled for sex (male/female/other), age, BMI, and relationship duration, which can influence reactivity to conflicts. To rule out the possibility that any condition effects are reducible to differences in the stimulation experience, the next model additionally controlled for stimulation intensity and general discomfort.

Physiological synchrony

Following previous recommendations (Helm et al., 2018), we first removed linear time trends from each partner's data by regressing RSA reactivity on time (each segment coded as 1–12) and saving the residuals. Given our interest in the *non-directional* synchrony, we further standardized the residuals, which removes the variability due to individual differences and allows us to interpret the regression coefficient as a correlation-like measure. As preliminary analyses, we examined if RSA

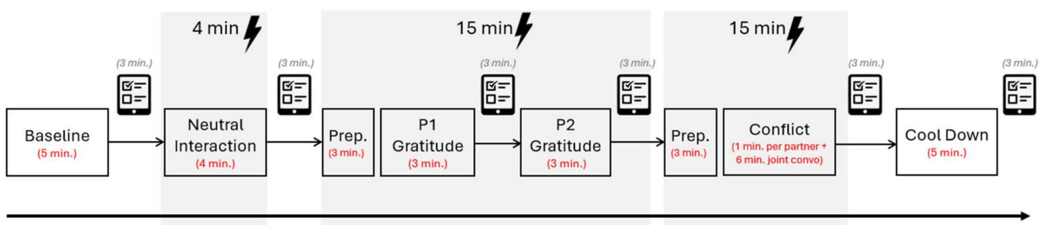

Figure 2. Overview of study procedure. Notes: Gray shaded areas indicate periods during which active or sham stimulation was delivered. The duration of stimulation is denoted with a lightning icon at the top. Fixed durations of each study segment are shown in red within each box. Survey icons indicate interim questionnaires, which took approximately 3 min to complete (duration varied across participants).

synchrony is associated with the degree of RSA reactivity by averaging individual reactivity scores across each couple and correlating this with their synchrony. In short, this tested whether more physiologically reactive couples were also more in sync physiologically. We then ran a multilevel model predicting Partner 2's standardized residuals from Partner 1's, with no intercept due to prior standardization. A random slope was included to model between-couple variability in synchrony,[3] and an interaction term between condition and Partner 1's standardized residuals tested condition differences in synchrony.

Behavioral synchrony

To estimate behavioral synchrony, we used the MEA program (version 4.01, www.psync.ch; Ramseyer, 2020). MEA employs frame-differentiating algorithms to generate two time-series by quantifying pixel changes in predefined regions of interest (ROIs). For MEA, videos were standardized to a resolution of 1280 × 720 pixels with a frame rate of 30 frames per second. We set one ROI per partner that covered their entire body and used a default threshold of 20 for minimal movement, which ensured sufficient detection. We calculated behavioral synchrony using the rMEA package in R (Kleinbub & Ramseyer, 2021).

Following standard practice, we removed outliers (i.e., values higher than 10**SD*) and standardized the values relative to the size of the ROI. Given the high-frequency sampling of MEA data (30 frames per second), the resulting time series are much more fine-grained than those used for RSA, for which there is one value per 30-second interval. To reduce noise and extract meaningful synchrony patterns from MEA data, it is a common practice to compute synchrony scores (i.e., cross-correlations) over shorter time windows, then aggregate those to yield a grand average synchrony score per dyad. Our parameters were determined to enhance comparability with the RSA synchrony analysis: we examined raw (i.e., non-absolute) cross-correlations within 30-second, non-overlapping windows with zero time lag. We then examined how the grand average scores differed among couples receiving tVNS or sham stimulation, and from pseudosynchrony. Comparisons against pseudosynchrony is a useful test to determine if the degree of synchrony between couples is above that expected by chance. This was done by calculating synchrony for 100 randomly paired dyads created by shuffling the time-series within each condition. We conducted a series of Welch's t-tests to compare pseudosynchrony and synchrony within each condition and between conditions. We also examined if condition differences were significant in a regression model controlling for relationship duration and relationship type (opposite-sex vs. not).

Additionally, to improve comparability with the RSA synchrony analysis, we conducted alternative analyses where, rather than creating grand average scores, we retained all per-window raw cross-correlation values for each couple and fitted multilevel models that predict synchrony as a function of condition. This approach allows us to account for couple-level variability in synchrony and yields a closer parallel (though not identical) to the RSA synchrony analysis. Finally, to examine if behavioral synchrony is associated with physiological activities, we correlated both indicators of behavioral synchrony (grand average score and random intercept) with RSA reactivity (averaged across partners).

Results

Randomization check

There was no condition difference in relationship duration, satisfaction or commitment (Table 2). Unexpectedly, participants assigned to the tVNS condition were slightly older.

Subjective experience of the conflict

No condition difference was observed in subjective experience (Table 2). Couples felt similarly positive and negative across conditions and did not differ in perceived productivity.

Table 2. Condition differences: descriptive statistics and comparisons results.

Variables	tVNS ($N = 63$) M (SD)	Sham ($N = 71$) M (SD)	t	p
Background characteristics				
Age	28.17 (4.33)	27.65 (4.26)	2.01	.05
Relationship duration	4.23 (3.06)	4.41 (2.41)	0.41	.68
Satisfaction	6.17 (0.78)	6.21 (0.71)	−0.59	.56
Commitment	6.55 (0.64)	6.62 (0.65)	−0.63	.53
Post-conflict self-report				
Positive affect	5.25 (1.12)	4.87 (1.44)	1.45	.15
Negative affect	2.16 (1.32)	2.38 (1.46)	−0.72	.48
Productivity	5.89 (0.92)	5.69 (1.15)	0.66	.51

Notes: $N = 134$. Statistics reflect the fixed effects of condition (tVNS vs. sham stimulation) in a random intercept model with participants nested within couples, except for relationship duration for which results from Welch's t-test are reported.

Physiological reactivity

Table 3 shows that conflict interaction elicited significant decreases in RSA only among couples in the tVNS condition. Indeed, when examining RSA reactivity, there were significant condition differences, $b = -0.42$, $t = -2.71$, $p = .009$, suggesting that participants in the tVNS condition experienced greater vagal withdrawal. This effect remained significant in a model controlling for gender, age, BMI, and relationship duration, $b = -0.44$, $t = -2.97$, $p = .004$, and additionally, stimulation intensity and discomfort, $b = -0.36$, $t = -2.20$, $p = .03$.

Physiological synchrony

We did not find evidence for significant synchrony in partners' RSA reactivity, $b = -0.01$, $t = -0.22$, $p = .83$, and this did not vary by the condition, $b = -0.04$, $t = -0.40$, $p = .69$. In other words, moment-to-moment changes in one partner's RSA during the conflict did not tend to align with fluctuations in the other partner's RSA.

Behavioral synchrony

We found that behavioral synchrony of couples in both the tVNS, $t(32) = 9.09$, $p < .001$, Cohen's d = 2.97, and sham stimulation condition, $t(33) = 7.89$, $p < .001$, Cohen's d = 2.39, was significantly greater than pseudosynchrony. Put simply, real couples' movements were more in sync with each other than those of randomly-paired two individuals. More importantly, couples receiving tVNS showed greater synchrony compared to those receiving sham stimulation, $t(53) = 2.71$, $p = .009$, Cohen's d = 0.69. This effect remained significant in a regression model controlling for relationship duration and type, $b = 0.05$, $t = 2.60$, $p = .01$. The left panel of Figure 3 illustrates that behavioral synchrony of couples receiving tVNS (blue solid line) was greater than pseudosynchrony (grey dotted line), showing a peak at 0. The right panel shows that it was also significantly greater than behavioral synchrony among couples receiving sham stimulation (grey dotted line). In short, couples receiving

Table 3. Respiratory sinus arrhythmia (RSA) activity during baseline and conflict.

	Baseline: $M(SD)$	Conflict: $M(SD)$	Change
All	6.62 (0.93)	6.50 (0.82)	$b = -0.11$, $t(68) = -1.89$, $p = .08$
tVNS	6.68 (0.96)	6.47 (0.74)	$b = -0.20$, $t(32) = -2.04$, $p = .05$
Sham[a]	6.56 (0.91)	6.54 (0.89)	$b = -0.02$, $t(70) = -0.29$, $p = .77$

Notes: $N = 134$. Means (M) and standard deviations (SD) of average RSA during baseline and conflict are presented. The change column presents fixed effects of task (baseline = 0, conflict = 1) from multilevel models. [a]Couple-level variance was negligible and nesting participants within couples produced a singular fit warning; participants were not nested. Note that in an equivalent non-nested model for the tVNS sample, the task effect remained significant.

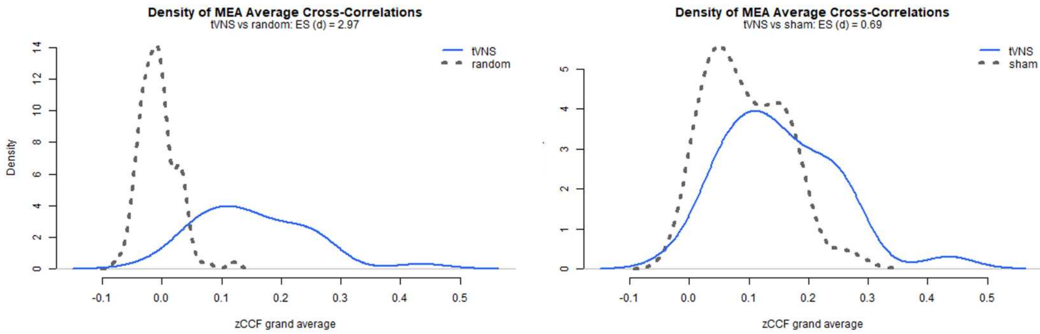

Figure 3. Behavioral synchrony analysis results. Notes: The blue solid lines illustrate the grand average of non-absolute cross-correlation values among couples in the tVNS condition (note the difference is due to the y-axis range). The grey dotted line in the left plot illustrates pseudosynchrony; the one in the right plot illustrates synchrony among couples receiving sham stimulation. Effect sizes (ES; Cohen's d) report the mean difference between the blue and grey distributions (tVNS vs. pseudosynchrony on the left; tVNS vs. sham on the right).

tVNS moved more in sync, not only relative to randomly paired dyads, but also compared to couples receiving sham stimulation. Finally, our multilevel modeling approach led to the same conclusion. Condition had a significant effect on couple's synchrony, $b = 0.06$, $t = 2.72$, $p = .008$. This effect remained consistent in a model controlling for relationship duration and relationship type, $b = 0.06$, $t = 2.62$, $p = .01$.

Discussion

This research examined the effects of tVNS during couples' live conflict interactions. Although this conversation did not yield intensely negative emotion across conditions (see Table 2), perhaps reflecting the artificial settings, participants receiving tVNS showed significant decreases in RSA, suggesting that tVNS promoted vagal withdrawal during the conflict interaction. Further, while there was no condition difference in the extent to which couples' RSA reactivity covaried with one another, couples receiving tVNS showed a greater degree of behavioral synchrony, compared to those receiving sham stimulation or pseudosynchrony.

Our findings on tVNS effects on RSA reactivity is noteworthy considering the mixed evidence for physiological effects of tVNS in the literature, including a meta-analysis finding no significant influence on RSA (Wolf et al., 2021). Several explanations have been proposed, such as the inherently indirect influence of tVNS which targets *afferent* fibers of the auricular branch of the vagus nerve on HRV (Burger et al., 2020; Butt et al., 2020), or systematic heterogeneity, with HRV modulation by tVNS more evident in specific populations (e.g., individuals with low baseline HRV; Geng et al., 2022). Our work introduces yet another explanation pertaining to the importance of context. That is, tVNS may play a more impactful role in situations where vagal withdrawal is expected, with the effects more observable when focusing on changes in RSA rather than stable levels. From this perspective, the field might benefit from moving beyond the question of if or for whom tVNS affects HRV to exploring the contexts in which the effect manifests. As our work centered on a specific type of stressor, further studies are needed to examine whether tVNS modulation of RSA reactivity is generalizable across different tasks engendering vagal withdrawal.

One potential implication of increased RSA reactivity, based on vagal flexibility research, is enhanced sensitivity to social information (Muhtadie et al., 2015), which may be consistent with our observation of increased behavioral synchrony among couples receiving tVNS. From a dynamic systems perspective, interpersonal coordination emerges spontaneously in a self-organized manner, with its strength affected by perceptual processing (Oullier et al., 2008; Schmidt & Richardson, 2008). For example, stronger (unintentional) movement coordination occurs when partners are directly looking at each other's movement rather than looking elsewhere that provides only peripheral access (Richardson et al., 2007). Thus, it is conceivable that enhanced attention to relevant social information, possibly facilitated by RSA decreases, contributed to the observed behavioral synchrony. That said, we found no direct association between RSA reactivity and behavioral synchrony (see SOM), suggesting any link between the two may be indirect, non-linear, or even contingent on other factors.

Alternatively, the increased behavioral synchrony may reflect the influence of LC-NE activity. Considering findings on tVNS effects on attentional processes supposedly modulated by LC-NE activation, including enhanced alertness, faster behavioral responses, and selective auditory attention (Chen et al., 2023; Rufener et al., 2018), our findings may also reflect such mechanisms at work. Future research may benefit from incorporating more proximal indicators of attentional engagement (e.g., using eye tracking) to better identify correlates (or consequences) of either enhanced physiological reactivity or LC-NE processes, and ultimately, the mechanisms driving increased behavioral synchrony.

The physiological and behavioral effects of tVNS should also be interpreted in light of the null findings for subjective emotions. On the one hand, it remains possible that the conversation was too short or too mild for tVNS-induced changes in physiological or behavioral responses to translate into emotional experiences, and such effects may only emerge over time. On the other hand, heightened attention and vigilance to social cues, what we believe underlie increased behavioral synchrony, might have mixed effects on emotional experiences, resulting in an overall null effect. Specifically, increased sensitivity may enhance detection of not only negative but also positive cues the partner displays during conflict, masking clear directional changes in emotion or perceived productivity of the conversation. Relatedly, we also emphasize that greater vagal withdrawal or increased behavioral synchrony itself may not necessarily be more or less adaptive, at least in the moment. Rather, the ability to flexibly adjust to environmental demands, including social stressors, and to stay engaged with the partner, even if it ends up intensifying the conflict momentarily, could confer long-term benefits. Indeed, this aligns with the broad concept of hormesis (Hill et al., 2024), whereby compensatory adaptations to small, manageable doses of stress, such as those arising from daily conflicts, can ultimately strengthen a relationship's resilience over time. Such momentary stress exposures may also provide opportunities for partners' regulatory responses to recalibrate, fostering more effective coping in future challenges.

We also did not find tVNS effects on RSA synchrony. In fact, reflecting the active context of a conflict conversation, which is more likely to activate sympathetic rather than parasympathetic nervous system, we observed some evidence for RSA synchrony during gratitude (see SOM) but not conflict interaction. This aligns with previous work suggesting that RSA covariation is more often observed during relaxing states, such as interactions characterized by low arousal positive emotions (Waters et al., 2017). At the same time, given the significant variability in RSA synchrony among couples, it is possible that other factors (e.g., intensity of conflicts) can moderate the degree of synchrony and even susceptibility to tVNS effects.

Despite the novel contribution this research makes to the literature, several limitations must be noted. First, couples in the tVNS condition experienced more discomfort, likely due to the location of the stimulation clip. Thus, we cannot rule out how this discomfort may have affected the interaction, which may not be captured simply by controlling for the variable in the analyses. Indeed, minor discomfort from the pinching appears to be common in tVNS studies (Kim et al., 2022), highlighting the need for design improvements. Additionally, our participants' atypical settings (e.g., having sensors applied to torso) limited movements and postures. Although this is unlikely to have affected our findings, as all participants across conditions were in the same position, it will be important to replicate the behavioral synchrony finding in a context where no such restrictions are imposed. Further, our work was not adequately powered to examine various moderations, including the possibility that tVNS effects are larger for individuals with low baseline HRV. We explored this moderation and found no significant effects (see SOM) but acknowledge that this null finding may reflect insufficient power.

To conclude, we found that romantic couples receiving tVNS during conflict showed greater RSA reactivity and synchronous movements compared to those receiving sham stimulation. These differences emerged in the absence of differences in subjective experiences. Our findings suggest that tVNS can subtly modulate the dynamics of distressing social interactions and highlight the need for more research given the impact of these interactions on long-term relationship functioning and personal well-being.

Notes

1. Note that all the effects remained in the same direction when using the 60s epochs: RSA reactivity was higher among couples receiving tVNS (b = -0.26, t = -2.00, p = .049) and RSA synchrony did not differ, b = 0.12, t = 1.02, p = .31.
2. Our models, estimated using the *lmer* package, could not incorporate autoregressive residual structures, often recommended for modeling physiological signals like RSA. However, a parallel model estimated using the *nlme* package, where an AR residual structure was specified but the crossed random effects structure were not implemented, yielded equivalent results.
3. When comparing this model to one with fixed effects only, we found that the model with the random slope provided a better fit, $\chi^2(1) = 8.20$, p = .004, indicating significant between-couple variability in RSA synchrony.

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