MEDITATING WITH A FRIEND ENHANCES MEDITATION-RELATED IMPROVEMENTS TO VAGAL TONE

A Thesis
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Masters of Arts

by
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ABSTRACT

Social support has been shown to improve both physical and mental health. Previous research suggests social resources provide metabolic relief by dampening vigilance and threat response. However, the extent to which social support influences autonomic nervous system function is unclear. Motivated by Polyvagal Theory and Social Baseline Theory, the current study examines social support and meditation as potential resources to moderate the influence of the vagal nerve over the cardiovascular system. Time domain measures of heart rate variability (RMSSD) and subjective units of distress (SUDS) were examined using a linear mixed-effects model (contemplative practice*social condition) while controlling for nuisance variables. Data analysis revealed no significant main effect between contemplative practice or the presence of social support and changes to vagal tone. However, an interaction was found between social support and meditation such that when meditating, those with social support showed the greatest heart rate variability.

BIOGRAPHICAL SKETCH

In May 2019, Sydney received her B.A. in Cognitive Science from the University of Virginia where she worked as an undergraduate researcher in Dr. Xiaorong Liu's Neurobiology Lab. In December 2021, Sydney will graduate with an M.A. in Developmental Psychology from Cornell University in collaboration with Dr. Marlen Gonzalez's Life History Lab and Dr. Adam Anderson and Dr. Eve De Rosa's Affect and Cognition Lab.

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INTRODUCTION

Strong, reliable social relationships have long been foundational to humans' well-being. Desires of having loving support systems composed of closely knit friends and family can be seen globally and throughout human history. This year, we were able to witness the necessity for social relationships. To top off the added fear of COVID-19, the effects of social isolation for many were devastating and debilitating. A study surveying faculty and students at universities found more than 90% reported having been affected by the shutdown and unable to perform work or studies (Leal Filho et al., 2021). Others have found large increases in depression and anxiety among isolated first-year college students following the lockdown (Fruehwirth et al., 2021, Son et al., 2020).

The presence of social support is considered to be strongly related to physical health outcomes (Cohen, 1997; Uchino, 2009; Compare et al., 2013). Low levels of social support have higher mortality rates, especially cardiovascular disease (Compare et al., 2013). Social isolation itself has been long deemed a high-risk factor for all types of morbidity. Social support can be further understood by parsing the concept of perceived social support from received social support. Perceived social support describes the self-reported access to *potential* social support (Uchino, 2009) and has a strong physiological effect on reducing plaque build-up, cardiovascular reactivity, and blood pressure (Howard et al. 2017).

Social Baseline Theory

How and why perceived social support has such a strong influence over health can be explained by Social Baseline Theory (Beckes & Coan, 2011, Coan & Sbarra, 2015) and the phenomenon of "yielding" (Gonzalez et al., 2021). The Social Baseline Theory (SBT) suggests the presence of others helps lower vigilance and conserve often costly metabolic and neural resources devoted to the brain. In this way, the human brain at baseline assumes a predictable social environment. Emotional regulation, in this instance, is not characterized by the active neural effort, but by an absence of effort altogether returning the brain to a baseline state.

In this context, perceived social support can be thought of as a measure of social predictability. When it is expected that support will not be readily available, the body will take on more costly metabolic and neural functions to prepare for unexpected threats (Coan et al., 2017). When alone, this can manifest through increased stress hormones, an overactive sympathetic nervous system, and heightened anxiety (Reblin & Uchino, 2008).

SBT can be better understood through a 2006 handholding fMRI study (Coan et al., 2006). Sixteen married women were subject to the threat of shock while holding their husband's hand, the hand of an experimenter, or no hand at all. They found that when holding hands, especially that of their husband's, threat response was attenuated by dampening brain activation. Areas involved in emotional regulation like the dorsolateral prefrontal cortex, caudate, and areas involved emotional-related homeostasis like the superiors colliculus also showed less activation when holding hands. In this way, the social regulation of emotions doesn't occur through a process of emotional regulation, but instead through returning the brain to a baseline state that doesn't require additional neural effort for emotional regulation. It is theorized that in the presence of others, we relax our metabolic and neural investments, and conserve resources through a process called yielding (Gonzalez et al. 2021). This recent study by Gonzalez et al. (2021), used the handholding paradigm and found that metabolic resources are conserved during a subsequent stress task when in the presence of a relational partner.

Polyvagal Theory

Porges' Polyvagal Theory (PVT) suggests similar mechanisms for how social support can reduce physiological costs (Porges 2007). According to Porges, increased influence of the vagal nerve over the heart, characterized by increased heart rate variability (HRV), supports spontaneous social engagement. He suggests that as a result of mammalian evolution, the primary vagal regulation of the heart shifted from unmyelinated pathways originating in the dorsal motor nucleus (DMX) of the vagus to myelinated pathways originating from the nucleus ambiguus (NA) of the vagus. The newly developed myelinated pathways function as a fast-acting vagal brake, rapidly inhibiting and disinhibiting vagal tone to the heart. When the vagal brake is released heart rate speeds up, whereas increasing inhibitory vagal control of the heart slows down heart rate. This allows for either rapid mobilization when the brake is removed (fight-flight) or calming, self-soothing, and socially-engaging behaviors when the brake is maintained. Therefore it can help or hinder behaviors depending on its weakness or strength. For instance, strong vagal innervation, which can be thought of by how quickly the driver can switch between the brake and gas, will allow the heart to be more flexible; mobilizing, and relaxing quickly. Weak vagal innervation results in an inflexible heart, unable to move quickly from an elevated state to a relaxed state, resulting in more often than not, sympathetic dominance over the nervous system characterized by heightened anxiety and vigilance (Porges 2007). When vagal innervation is weak the switch between the gas and the break is delayed.

The theory proposes that the myelinated vagus is related to prosocial behaviors via a mechanism called the social-engagement system. In humans, the vagal nerve is anatomically connected to muscles that control eye gaze, create facial expressions, and tune hearing to the frequency of the human voice, all of which are strongly tied to prosocial behavior (Porges, 2007). Engagement with these social indicators fosters calm behavioral states by inhibiting sympathetic influence over the heart. Through a process Porges calls "neuroception" the vagus elicits physiological states that can support social engagement or fight-flight. Neuroception refers to the neural processes that assess risk and vigilance, in mammals specifically.

What Porges describes here is similar to what SBT describes as the predictability of social relationships. The process of neuroception first requires the evaluation of risk, and then, depending on the physical or visceral environment, elects a state to support either social engagement or fight-flight. The brain distinguishes safe from unsafe, responding to safe environments by not engaging in metabolically costly sympathetic activation, allowing for engagement in social behaviors. Similarly, in SBT, being alone requires more costly metabolic activity because of heightened threat vigilance, while being around others dampens threat vigilance and metabolic spending.

Familiarity and predictability go hand-in-hand with conserving metabolic resources in SBT. Being more familiar with the potential outcome of someone else's actions allows for a more accurate evaluation of risk. It's safer to yield metabolic resources to someone who is known to be a reliable source of support, rather than someone who is a reliably poor source of support or a stranger, whose behaviors are unknown. The effectiveness of the social-engagement system should be affected by the predictability of social resources, although how the system differentiates "safe" social stimuli from "unsafe social stimuli" is not yet understood.

Additionally, from the perspective of SBT, activation of the social-engagement system would be the baseline assumption of the brain. This may seem contradictory since SBT emphasizes that overall less activation characterizes the baseline state. However, in PVT it isn't the amount of vagal activation that accounts for vagal tone, but the strength of vagal projections to the heart. Therefore, activation of the social-engagement system doesn’t require more neural effort. Instead, it inhibits sympathetic activation, which results in an overall decreased neural effort.

Effects of Contemplative Practice

Contemplative practices like meditation have also been found to influence vagal tone and increase heart rate variability (HRV); a measure of vagal tone (Peng et al., 2004; Krygier et al., 2013). Although there are hundreds of different types of meditation, they are broadly understood as “a family of complex emotional and attentional regulatory strategies developed for various ends (Lutz et al., 2008).

The amount of meditative practices that have been the subject of scientific studies isn’t quite as vast and can be understood via three categories (Lutz et al., 2008, Kok, Waugh, et al., 2013). The first, focused attention meditation, involves the meditator focusing their attention on a certain sense or stimulus, like breath or other bodily sensations. Eventually, it becomes easier and takes less energy for the meditator to focus and direct attention. Open monitoring meditation builds upon the core of focused attention meditation. In this next practice, there is no longer a singular point of focus. Instead, the meditator observes any thoughts and feelings that arise but does not engage with them. Rather than being pulled into a memory or thought, the meditator observes the memory but does not engage with it, remaining present in the moment. Finally, kindness and compassion meditation alters the focus of meditation from oneself to one’s connection with others. This practice again builds upon skills learned in focused attention meditation and open-monitoring meditation. The meditator can begin by focusing on breath and slowly shift focus towards a person or group with the intention to cultivate feelings of closeness and kindness (Kok, Waugh, et al., 2013).

Meditation has been shown to reduce inflammatory immune responses and improve cardiovascular health (Ospina et al., 2007; Anderson et al., 2008; Kok, Coffey, et al., 2008). It is theorized that the driving mechanism behind health improvements of focused attention meditation and open monitoring comes from the ability to more effectively self-regulate negative emotions (Kok, Waugh, et al., 2013). Mechanisms underlying kindness and compassion meditation are thought to occur by increasing the likelihood of positive emotions and feelings of social closeness, both of which are associated with a decreased risk of cardiovascular disease (Kok & Fredrickson, 2010) and increased cardiovascular recovery from stress (Fredrickson & Levenson, 1998).

The connection between meditation and feelings of social closeness and support can be further understood by a study that found through love and kindness meditation (a form of kindness and compassion meditation) positive emotions improve and build positive perceptions of social connectedness which improve vagal tone (Kok et al. 2013). Improved vagal tone, in turn, improves positive emotions, and the cycle continues in an upward spiral, showing that vagal tone can be improved by using meditation techniques to consistently improve positive emotions and perceived social connections. This is consistent with the PVT social-engagement system, as it shows improvement in vagal tone through engagement in social connections. Because it was perceived social connections that were found to be tied to increases in vagal tone and positive emotions, it is also consistent with SBT.

Estimating Vagal Tone

Heart rate variability (HRV), or the variance of length between successive heartbeats, is an indirect measure of autonomic nervous system function and has been commonly used as a metric of general health (Porges, 1995; Cacioppo et al., 2001). A more variable heart rate (high HRV) reflects flexibility to appropriately speed up when in trouble and to slow down when resting. These two responses are controlled by two branches of the autonomic nervous system; the sympathetic and parasympathetic nervous systems (Shaffer et al., 2014).

In psychopathology like PTSD, schizophrenia, and anxiety, we usually see an overactive sympathetic system and a weakened parasympathetic system, characterized by a weakened innervation to the vagus nerve, the primary source of parasympathetic projections to the heart (Young & Benton 2018). Cardiac vagal tone is the strength of these parasympathetic projections to the heart that we can indirectly measure using HRV (Laborde et al., 2017). High HRV and more variability indicate higher vagal tone and parasympathetic presence, while low HRV and less variability indicate lower vagal tone and sympathetic presence.

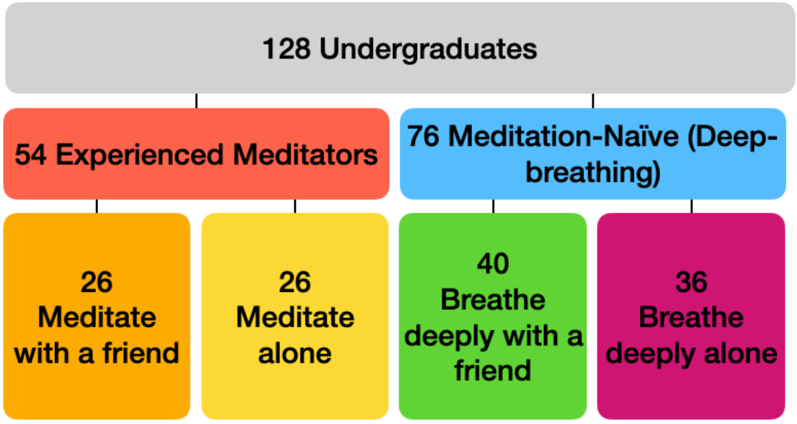
Reduced HRV is associated with poor cognitive function, an increased risk of death, the development of diabetes, and cardiovascular disease (Dekker et al., 2000; Young & Benton 2018). Additionally, psychopathology including bipolar disorder, anxiety disorders (Scott & Weems, 2014), and PTSD (Gentzler et al., 2009) are associated with low HRV. Improving general health through exercise, nutrition, and sleep has been shown to increase short-term HRV and cognitive functioning, and therapeutic solutions like meditation, mindfulness (Krygier et al., 2013), and expressive writing (Bourassa et al. 2017) have shown similar results.

The Present Study

This current study looks to further understand how social support and meditation could have potentially additive improvements to cardiovascular health and resilience to stress. We analyzed respiratory data, ECG data, and subjective units of distress (SUDS) of participants either practicing meditation or breathing deeply with either a source of social support alone. This allows us to see the separate and additive effects of meditation and social support. We expected increased HRV for all groups after contemplative practice and greater increases in HRV for participants that meditated and had access to social support. To test the resilience provided by our conditions, we followed this with a task where participants were inundated with CO2 enriched air to elicit a stress response. As the sympathetic system took over, we expected decreased HRV for all groups, but less of a decrease in HRV for participants that had the buffer of meditation and social support prior to the CO2. Subjective distress was expected to increase for all groups during the CO2 stress task, while a smaller increase was expected for participants that meditated and had access to social support.

Figure 1

2x2 Design



METHOD

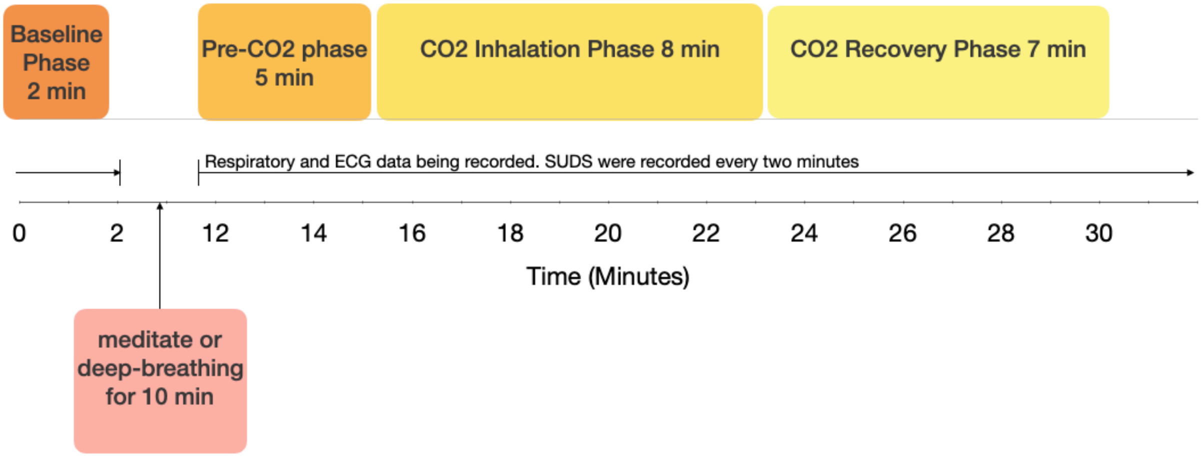
Participants and Data Collection

Participants included both meditation-naive and meditation-experienced students. Undergraduate students experienced in meditation were recruited from the *Buddhism in the Modern World* class offered through the Religious Studies Department at the University of Virginia. While enrolled in the Buddhism class, students practiced one hour of meditation a week with a group. Undergraduates inexperienced in meditation were recruited from the School of Arts and Sciences. Students were excluded from the meditation-naive group if they practiced meditation for an hour or more a week. All participants came in pairs. In total 128 undergraduates were recruited to the study; 26 experienced meditators who completed the contemplative+social phase alone, 26 experienced meditators who completed the contemplative+social phase with a friend, 40 mediation-naïve participants who completed the contemplative+social phase without a friend, and 36 meditation-naïve participants who completed the contemplative+social phase with a friend.

All participants were accompanied to the lab with a partner to complete a series of questionnaires accounting for known moderators before psychophysical data collection. Meditators and non-meditators were randomly assigned to either an alone or with partner condition. At baseline recording, all participants were separated from their partners. Following baseline readings, meditation naïve participants were instructed to breathe deeply for 10 minutes while experienced meditators were asked to meditate for 10 minutes. During this phase, participants in the friend condition had their partners rejoin them for a contemplative practice; either meditation or deep-breathing. Following the contemplative practice, partners were separated and all participants completed a respiratory stress task in which they breathed in carbon dioxide enriched air (7%). They were not alerted as to when the CO2 task would start. Both subjective distress and psychophysiology data were recorded during the CO2 administration. After a set amount of time, normal levels of oxygen returned to the air for the CO2 recovery phase. Psychophysiology was collected using the BIOPAC data acquisition system.

Figure 2

Experimental Structure



Notes: Experimental Phase: **a) Baseline Phase**: participants' respiratory and ECG data and subjective units of distress (SUDS) are recorded before any manipulations. **Contemplative+Social Phase:** participants meditated or deep-breathed either with or without a friend in the room. **b) Pre-CO2 Phase:** participants with partners are separated. Respiratory, ECG and SUDS data recording resumes. **c) CO2 Inhalation Phase**: without being alerted, the participant begins to breath in C02 enriched air. **d) CO2 Recovery Phase**: without being alerted, CO2 enrichment stops and air returns to normal levels of oxygenation

Measures

ECG Data Cleaning. Raw ECG data was cleaned using the ARTiiFACT HRV processing tool. IBI's were extracted using the ecgExtract tool using a sampling rate of 1000 Hz. R-peak detection threshold was set to 200µV with a global threshold. The ibiArtifactProcessing tool was then used to correct and detect artifacts in IBI data using the Berntson detection method and the cubic spline interpolation processing method. Undetected R-peaks were manually corrected. Frequency and time domains were calculated using the hrvAnalysis tool with an interpolation rate of 4 Hz, window width of 120 s during the baseline period, 240 s during the contemplative practice period, 480s during the CO2 enrichment period, and 480s during the post-CO2 recovery period. Window overlap was set to 50% with frequency bands 0.04,0.15,0.40. Fifteen participants of the 128 were excluded due to missing or corrupted data. Because certain participants were not able to complete the CO2 enrichment stage of the experiment, 8 participants were included with HRV measures from only the baseline phase and the contemplative-practice/social phase. In total, data from 113 participants were collected from the baseline and contemplative practice conditions, and data from 105 participants were collected from the CO2 enrichment condition and the recovery condition.

Heart Rate Variability. HRV was calculated from raw ECG data as RMSSD. HRV can be measured in many ways and one of them is through calculating a root mean square of successive deviations (RMSSD) between adjacent heartbeats. RMSSD is a time-domain measure which is resilient to changes in respiration rate (Shaffer & Ginsberg, 2017). To compare experimental phases, time-domain measures were chosen as they are resilient respiratory changes. Frequency domain measures, specifically high-frequency HRV (HF), were not used for this reason.

Subjective Units of Distress Scale (SUDS). Participants were asked, “Imagine this is a distress thermometer to measure your feelings. Using a 0 to 100 scale where 0 is totally relaxed and 100 is the highest distress/anxiety/discomfort that you have felt, how anxious/distressed are you right now?” SUDS were collected from participants every 2 minutes over the course of a 24 minutes period. Participants with at least 6 of 12 SUDS reports were included in the analysis. Out of 128 participants, 10 participants were disqualified for under 6 SUDS reports, and 12 participants were disqualified for having missing or unlabelled SUDS reports. The data from a total of 106 participants were used in this analysis. In total, there was 1 SUDS report taken at baseline, 2 during the contemplative/social condition, 4 during the CO2 challenge, 4 during post-CO2 recovery, and 1 after the task. Due to the missing data in both the ECG files (15 from baseline and contemplative+social phase, 23 from CO2 and recovery phase) and the SUDS files (22), there were participants used in the SUDS analysis that weren’t used in the HRV analysis due to missing ECG files or attrition. Likewise, there were participants included in the HRV analysis whose SUDS data was lost.

Nuisance Variables.

ASI-3: Anxiety Sensitivity Index (Taylor et al. 2007): A 16-item scale measuring the degree to which a person is concerned about the physical symptoms of their anxiety.

ECR_S: Experience in Close Relationship Scale (Wei, Russel, et al. 2007): A 12 item scale measuring attachment style of close relationships.

IOS: Inclusion of Other in the Self Scale (Aron, Aron, et al. 1992): A single-item scale to measure how close the respondent feels with another person.

Analysis

A linear mixed-effects model was run on the HRV and SUDS data where the social and contemplative conditions were independent variables and the experimental phase and gender were categorical predictors along with additional continuous covariates (ASI, ECR_S, IOS). HRV and SUDS scores varied randomly by participant.

A pairwise analysis of the social conditions and contemplative conditions was used to explore interaction effects. To explore potential confounding variables, the differences in friendship length were compared between the meditation and deep-breathing groups with a linear effects model. The baseline differences in HRV between groups were also explored using a linear effects model. Pairwise comparisons were done to further explore the source of any differences.

Analyses were done using RStudio. The package *lme4* was used to run the linear mixed-effects model and the package *emmeans* was used to view pairwise differences and interactions within the model. The package *ggplot2* was used to visualize the data. The linear mixed-effects model was fitted by restricted maximum likelihood (REML). T-tests used Satterthwaite's method with an alpha level of 0.95.

RESULTS

HRV analyses were conducted among 113 participants, and the SUDS analyses were conducted among 106 participants. The average age for the sample was 19.08, ranging from 18 to 22. The racial distribution of the sample was approximately 67% white, 24% Asian, 5% biracial, 4% black, and 1% unreported.

Heart Rate Variability

Figure 3

Line plot visualization of RMSSD changes across phases

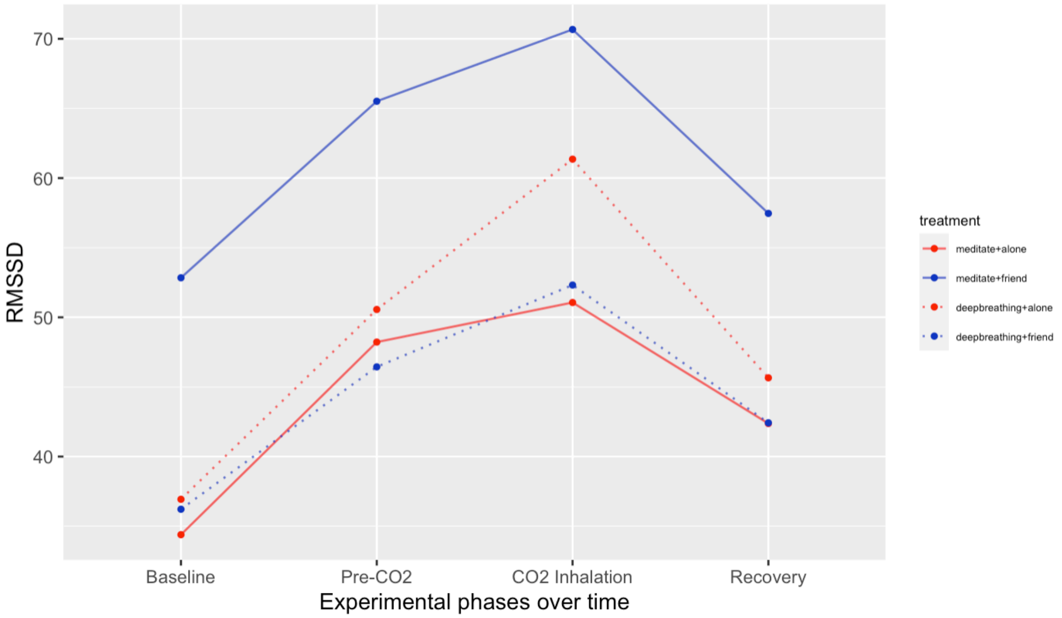


Figure 4

Bar-plot visualization of RMSSD changes across phases with standard error

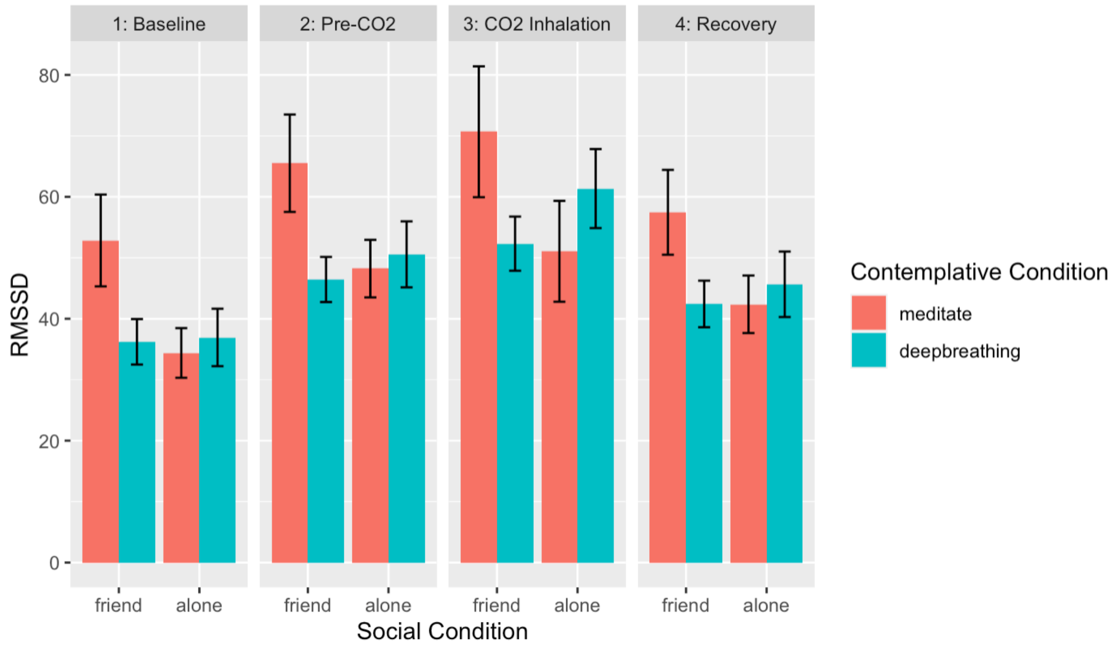


Table 1

Means and standard deviations of RMSSD across phases

Contemplative Condition	**Social Context**	**Baseline**		**Pre-CO2**		**CO2**		**Recovery**	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Meditation	Alone	34.39	19.54	48.22	22.64	51.06	38.81	42.37	21.63
	With Friend	52.84	36.88	65.52	39.14	70.67	50.34	57.46	32.65
DB	Alone	36.93	28.28	50.56	32.48	61.36	36.66	45.65	30.38
	With Friend	36.22	20.44	46.44	20.26	52.32	23.92	42.43	20.57

Note: Means are listed as *M*, and standard deviations are listed as *SD*

Table 2

Linear mixed effects model: RMSSD

	SSE	*MSE*	*NumDF*	*DenDF*	*F-ratio*	*p*
Social Context	354.1	354.1	1	101.75	1.9720	0.16328
Contemplative Practice	385.3	385.3	1	101.92	2.1458	0.14604
Phase	21678.5	7226.2	3	313.57	40.2458	**<0.0001*** **
IOS	5.5	5.5	1	102.02	0.0305	0.86161
ASI	60.7	60.7	1	101.67	0.3378	0.56237
ECRR_avoid	272.1	272.1	1	101.34	1.5154	0.22117
Gender	108.4	54.2	2	101.25	0.3019	0.74005
Social:Contemplative	767.1	767.1	1	101.78	4.2722	**0.04138***

Note: Linear mixed effects model (Type III Analysis of Variance) fit by restricted maximum likelihood (REML). t-tests use Satterthwaite's method. *SSE* = sum squared error, *MSE* = mean squared error, *NumDF* = degrees of freedom of the numerator, *DenDF* = degrees of freedom of the denominator. In this model RMSSD is the dependent variable and social context and contemplative practice are independent variables, with time and gender as categorical predictors. IOS (Inclusion of other in self index), ASI (Anxiety sensitivity index), and ECRR_avoid (Experience in close relationships scale) were continuous covariates. Participants were identified as random variables.

Table 3

Pairwise comparison of phase-related RMSSD change

Contrasts			*estimate*	*SE*	*df*	*t-ratio*	*p*
Contemplative Condition	**Social Condition**	**Phase**					
Meditate	Alone	Baseline - Pre-CO2	-13.83	4.03	310	-3.43	0.0534
		Baseline - CO2	-16.14	4.09	311	-3.94	**0.0096****
	Friend	Baseline - Pre-CO2	-12.68	3.94	310	-3.21	0.1007
		Baseline - CO2	-21.03	4.07	311	-5.16	**<.0001*****
Deep-breathing	Alone	Baseline - Pre-CO2	-13.63	3.22	310	-4.23	**0.0031****
		Baseline - CO2	-24.62	3.36	312	-7.32	**<.0001*****
	Friend	Baseline - Pre-CO2	-10.23	3.53	310	-2.90	0.2220
		Baseline - CO2	-15.61	3.57	311	-4.37	**0.0018****

Note: This pairwise comparison of means is from a post-hoc ANOVA that sets RMSSD as the dependent variable and treatment, or “group assignment”, and phase as the independent variables with four levels.

We calculated the root mean square of successive deviations (RMSSD) in milliseconds (ms) for each participant at each of the four stages of the experiment and performed a linear mixed-effects analysis. As expected there was a phase related effect on RMSSD (F(3,313) = 40.24, p<.0001) (Table 2). No main effects were found as a result of the social context variable or the contemplative practice variable. However an interaction was found between social context and contemplative practice (F(1,102) = 4.27,p=.04138.

The effect of phase was further explored in Table 3. RMSSD improved from baseline to the pre-CO2 phase for the deep breathing+alone condition (t(310)=-4.23, p=.0031). Unexpectedly, during the CO2 inhalation phase, RMSSD improved for all groups when compared to baseline; meditate+alone (t(311)=-3.94, p =.0096), meditate+friend (t(311)=-5.16, p<.0001), deep-breathing+alone (t(312)=-7.32, p<.0001), and deep-breathing+friend (t(311)=-4.37, p=.0018).

Table 4

Marginal means of the contemplative practice x social context interaction

Contemplative Practice	Social Context	*M*	*SD*	*MM*	*SE*	*df*	*Lower CL*	*Upper CL*
Meditate	Alone	43.97	27.04	43.0	11.4	101	20.3	65.6
	Friend	61.52	40.13	62.3	11.4	101	39.7	84.9
Deep-breathing	Alone	46.62	31.42	45.8	10.9	102	24.2	67.3
	Friend	44.33	22.23	42.1	10.9	101	22.0	62.3

Note: *M* is the actual mean of RMSSD across all phases, while *MM* is the marginal means of RMSSD across all phases. *SD* = Standard deviation, *SE* = Standard Error, *df* = degrees of freedom, *Lower CL* = lower confidence limit, *Upper CL* = upper confidence limit

Table 5

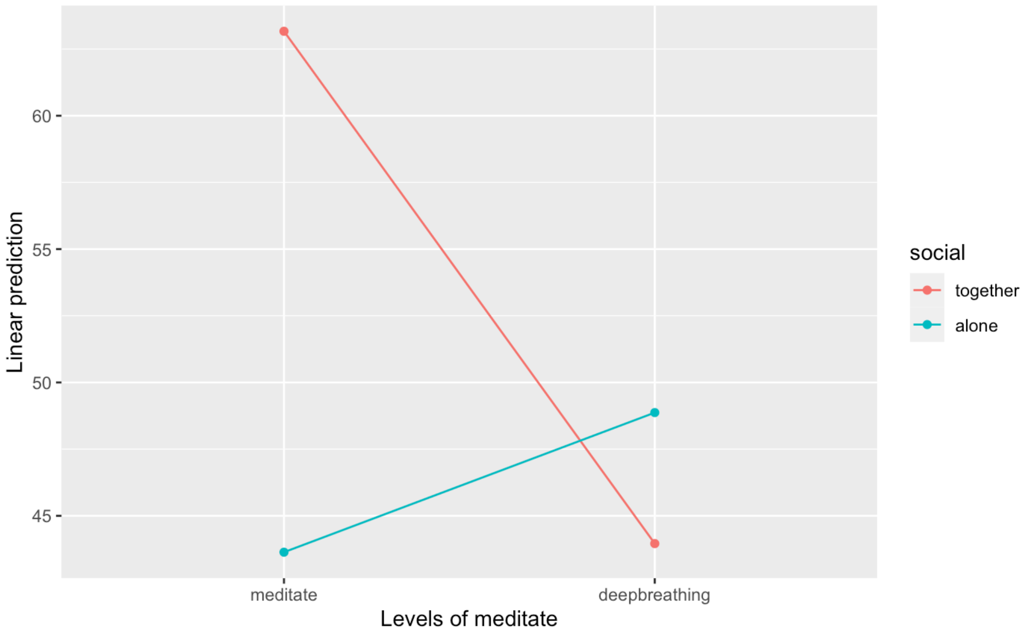
Pairwise comparison of completive practice x social context interaction

Contemplative Practice	Social Context	*estimate*	*SE*	*df*	*t-ratio*	*p*
Meditate	(Friend - Alone)	19.33	8.32	102	2.324	**0.0221***
Deep-breathing		-3.65	7.41	102	-0.492	0.6237
(Meditate - DB)	Friend	20.20	8.32	102	2.425	**0.0170***
	Alone	-2.80	7.93	102	-0.354	0.7244

An analysis of the interaction revealed that when the contemplative condition was meditation (Table 5), having a friend present predicted higher HRV levels than being alone (t(102)=2.324, p=0.0221), and when a friend was present, a contemplative practice of meditation predicted higher HRV than deep-breathing (t(102)=2.425, p=0.0170).

Figure 5

Visualization of the interaction effects between the contemplative practice and the social context



Note: Linear prediction is the model's prediction of RMSSD given the conditions of social context and contemplative practice

Table 6

ANOVA Table for RMSSD at Baseline

	DF	*SSE*	*MSE*	*F-value*	*p*
treatment	3	5430	1810.1	2.4728	0.06551
residuals	109	79788	732.0		

Note: This post-hoc ANOVA sets RMSSD as the dependent variable and treatment, or "group assignment", as the independent variable with four levels. The test only examines differences in RMSSD values at Baseline.

To further explore potential confound factors, a linear effects model (Table 6) was run to determine if there were any significant differences in RMSSD between the groups at baseline. Upon investigation, no significant differences were found.

Table 7

Mean and standard deviation of friendship length (months)

Contemplative Practice	Social Context	M	SD	*MM*	*SE*	*df*	*Lower CL*	*Upper CL*
Meditate	Alone	4.54	4.33	4.54	10.24	108	-15.75	24.80
	Friend	9.77	16.06	9.77	10.02	108	-10.10	29.6
Deep-breathing	Alone	40.17	70.73	42.39	8.18	108	26.17	58.6
	Friend	25.02	52.71	25.02	9.12	108	6.94	43.1

Table 8

ANOVA: friendship length (months)

	DF	*SSE*	*MSE*	*F-ratio*	*p*
Social Context	1	1741	1741.5	0.7330	0.3939
Contemplative Practice	1	17897	17867.3	7.5202	**0.0072****
Social C: Cont P	1	2803	2803.0	1.1798	0.2798
Residuals	107	254223	1375.9		

Note: This analysis of variance set friendship length as the dependent variable, and social context and contemplative practice as independent variables.

Table 9

Pairwise comparison of differences in friendship length (months)

Contemplative Practice	Social Context	*estimate*	*SE*	*DF*	*t-ratio*	*p*
Meditate	Friend - Alone	5.23	14.2	107	0.368	0.7140
Deep-breathing		-15.15	12.2	107	-1.238	0.2184
Meditate - DB	Friend	-15.2	13.5	107	-1.33	0.2595
	Alone	-35.6	13.6	107	-2.723	**0.0076****

Post-hoc ANOVA was run to determine differences between the length of time participants had known their friends (Table 8). The linear effects model showed an effect of contemplative practice on length of friendship (F(1) = 7.52, p=.0072). Further analysis (Table 9) shows the only statistically significant difference exists between the meditate+alone group and the deep-breathing+alone group such that the meditation+alone group had known their friend for a significantly less time than the deep-breathing+alone group t(107)=-2.72, p=.0076).

Subjective Units of Distress

Table 10

Mean and standard deviation of SUDS across phases

Contemplative Condition	Social Context	Baseline		Pre-CO2		CO2		Recovery	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Meditation	Alone	20.05	13.88	16.92	15.24	28.88	21.27	15.12	13.97
	With Friend	22.55	15.56	20.71	12.95	36.02	21.17	19.41	15.91
Deep-breathing	Alone	15.50	14.16	17.98	16.75	30.50	23.26	16.34	16.32
	With Friend	17.43	16.07	16.91	14.28	26.94	20.45	16.80	13.46

Table 11

Linear mixed effects model: SUDS

	SSE	*MSE*	*NumDF*	*DenDF*	*F-ratio*	*p*
Social Context	46	46.5	1	97.29	0.3413	0.5605
Contemplative Practice	28	28.4	1	97.25	0.2082	0.6492
IOS	249	248.7	1	97.53	1.8262	0.1797
ASI	370	369.7	1	98.32	2.7144	0.1026
ECRR_avoid	116	116.4	1	97.49	0.8550	0.3574
Gender	32	32.0	1	97.59	0.2350	0.6289
Phase	45725	11431.3	4	1078.34	83.9352	**<.0001*** **

Social:Contemplative	268	267.8	1	97.25	1.9660	0.1641

Note: Linear mixed model (Type III Analysis of Variance) fitted by restricted maximum likelihood (REML). t-tests use Satterthwaite's method. In this model, SUDS is the dependent variable and social context and contemplative practice are independent variables, with phase and gender as categorical predictors. IOS (Inclusion of other in self index), ASI (Anxiety sensitivity index), and ECRR_avoid (Experience in close relationships scale) were continuous covariates. Participants were identified as random variables.

Table 12

Post-hoc pairwise comparison SUDS across phases

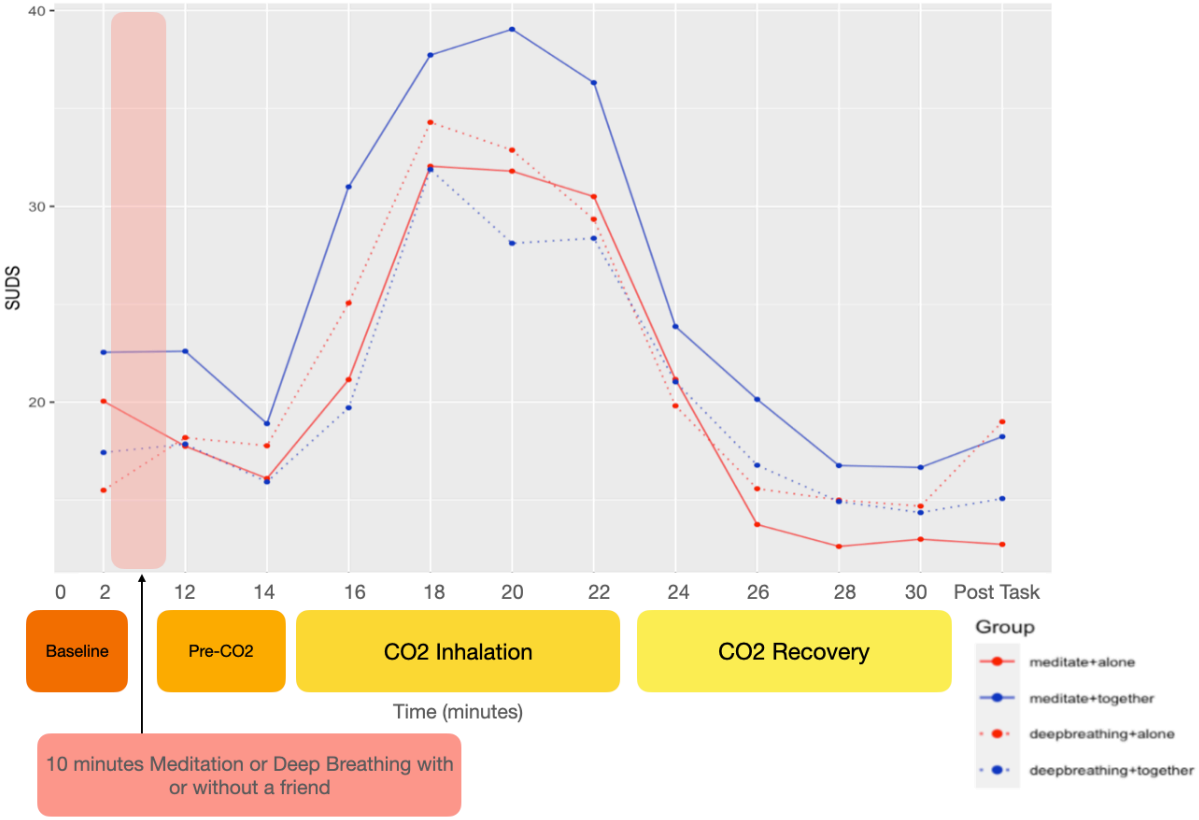
Contrast			*estimate*	*SE*	*df*	*t-ratio*	*p*
Contemplative Condition	Social Condition	Phase					
Meditate	Alone	Pre-CO2 - CO2	-11.95	2.26	1064	-5.294	<.0001***
		Baseline - CO2	-8.8250	2.91	1064	-3.029	0.2183
	Friend	Pre-CO2 - CO2	-15.98	2.21	1065	-7.227	<.0001***
		Baseline - CO2	-13.4773	2.78	1064	-4.851	0.0003***
Deep-breathing	Alone	Pre-CO2 - CO2	-12.30	1.80	1067	-8.827	<.0001***
		Baseline - CO2	-15.8223	2.38	1067	-6.658	<.0001***
	Friend	Pre-CO2 - CO2	-10.35	1.94	1066	-5.341	<.0001***
		Baseline - CO2	-9.3708	2.48	1065	-3.779	0.0232*

There were no main effects found for SUDS for the social support condition or the contemplative practice variable. Similarly, there was a main effect found for the experimental phase (F(4,1078.34)=83.9, p<.0001) (Table 11), but there was no interaction found between social support and contemplative practice. SUDS did not significantly change for any groups from baseline to the pre-CO2 stage.

As expected from the baseline phase to the CO2 inhalation phase (Table 12), SUDS increased for the following groups; meditation+friend (t(1064)=4.85, p=.0003), deep-breathing+alone (t(1067)=6.65, p<.0001), and deep-breathing+friend (t(1065)=3.78, p=.0232). Although the meditation+alone group did not show a statistically significant increase in SUDS from baseline to the CO2 phase, it did show a significant increase in SUDS from the contemplative practice stage to the CO2 phase (t(1064)=5.294, p=<.0001).

Figure 6

Visualization of SUDS changes over phases



DISCUSSION

This analysis sought to further reveal how social support from a trusted conspecific could help strengthen vagal tone and psychobiological resilience to stressors. Contemplative practice and social context did not differ from each other in the strength of their impact on HRV and

SUDS. However, there was an interaction effect found, such that when meditating, having a friend present predicted the highest HRV outcome across experimental stages. SUDS data across groups was as expected, with an increase in distress when CO2 was inhaled, and a decrease when normal air was returned. However, during CO2 inhalation, HRV increased across groups.

Interaction Effects

The meditation+friend group was unique in that the friends brought to the experiment were also members of the Introduction to Buddhism course and were fellow meditators in their course's weekly meditation group. This meant that there was a greater likelihood that the friend they brought was one that they had made recently while in the class. When compared to the deep-breathing+friend group, the meditation+friend group had known their friends for 15.2 fewer months. Despite the deep-breathing+friend group having brought friends they had known for much longer, it was the meditation+friend group that benefited most from social context.

The interaction may be explained in part by practice effects. The act of meditation is a practice that can be improved upon over time (Huppert & Johnson, 2017). Cardiovascular and mental benefits from meditating are also usually observed after a training period that ranges from a week to a month (Kok, Coffey, et al., 2013). Because the meditation+friend group was able to practice in their meditation course, the practice effects could, in part, account for the interaction. However, because the same effect was not found when the social condition was "alone", practice effects would only be one part of the puzzle.

The vagal nerve is anatomically connected to muscles that control eye gaze, create facial expressions, and tune hearing to the frequency of the human voice, all strongly tied to pro-social behavior and coined by Porges as the social-engagement system. While the practice of meditation incorporates breath control and deep-breathing, its core lies in directing attention; attention to and from emotions, bodily sensations, thoughts, awareness, and other people (Lutz et al., 2008). These aspects of meditation differentiate it from the deep-breathing control. By having been trained to direct attention, it's possible the meditation+friend group was better able to focus on their friend and activate their social engagement system than the deep-breathing+friend group. This interaction suggests the social aspect of meditation, potentially via the social-engagement system, is an important component of meditation-related improvements to HRV. It’s possible that by having meditated weekly with a certain friend, the sounds and social cues that arise during joint meditation enhanced HRV via the social-engagement system. By this logic, it was the implementation of a long-term meditation intervention coupled with a social trigger from the social-engagement system that may account for the meditation+friend group’s increased HRV. By meditating weekly with a friend, the practice could have tuned the social-engagement system for future socially-facilitated meditation.

Baseline HRV Measures

Although the difference was not found to be statistically significant, the baseline HRV measure for the meditation+social group was greater than that of the other three groups. No differences were found between the meditation+friend group and the other three groups when it came to sex, age, or racial distribution. Past exercise experience also did not differ between the meditation+social group and the other three groups. Because the meditation+alone group did not show the same elevated baseline HRV as the meditation+social group, this finding cannot be attributed to the practice effects of the meditation condition. Groups did differ drastically in terms of friendship length, with meditation-naive participants having longer relationships with the friend they brought in than the experienced meditators who brought in their classmates (Table 7). Therefore, familiarity can not explain baseline differences or the interaction. Baseline conditions were the same for all groups, so it remains to be seen if there was a variable unaccounted for that could be behind the heightened baseline. It's also possible this could be an effect of random sampling, and coincidentally people with higher HRV levels were randomly selected to the meditation+friend group.

HRV Increase During CO2 Inhalation

Unexpectedly, during the CO2 inhalation phase, HRV increased in all groups. Current literature measuring vagal tone using the CO2 task has shown frequency domain measures to be sensitive to the CO2, and time-domain measures to be resilient to changes in respiration rate and heart rate (Grossman & Taylor, 2007; Laborde et al., 2017). It's thought that because CO2 inhalation induces rapid and fast-paced breathing, frequency domain measures, like HF which are very sensitive to changes in respiratory rate, will be affected. Unlike frequency-domain HRV measures, time-domain measures (in our case RMSSD) are thought of as resilient to changes in heart rate and respiration rate. However, it appears uncommon for time-domain measures to be reported in studies measuring HRV during CO2. Some studies have found time-domain measures unable to detect the changes in HRV caused by the CO2 task (Brown et al., 2007, 2014), therefore frequency domain measures are more often reported.

A recent article (Martino et al. 2020) also found increased RMSSD during the CO2 task when compared to baseline. While excessive breathing explains the jumps in HF, the changes in RMSSD are ambiguous. The authors suggested that this difference could be explained by the participants' sitting positions during HRV recording. In their case, and ours, participants' HRV was recorded in the sitting position rather than while laying on their backs (supine). RMSSD has been found to decrease at baseline when sitting compared to laying in the supine position (Young & Leicht, 2011). They suggest that because baseline measures of RMSSD are greater while in supine, increases will be less likely to be detected during the CO2 condition. It is possible that because participants were sitting down in our experiment, baseline RMSSD measures were lower than they would have been if participants were sitting in a supine position, allowing for the detection of more dynamic changes in RMSSD. The increase in RMSSD during the CO2 phase could have been a result of low baseline recordings.

Alternatively, the stress induced by CO2 could be a unique visceral threat that doesn't take the traditional fight or flight pathway and instead activates a freezing response. Freezing responses are often confused with involuntary immobility. It can be a precursor to immobility as well as fight-flight responses (flight more commonly) and shares the same pathway as fight-flight responses, only freezing evokes parasympathetic dominance via vagal innervations from the dorsal motor cortex (DMX), while fight-flight responses evoke sympathetic dominance (Roelofs, 2017).

Similar to the previously mentioned vagal brake, the ventrolateral periaqueductal grey matter (vlPAG) also serves as a brake for the sympathetic threat response system. During freezing, the vlPAG acts as a brake for threat-related systems, putting the fight-flight responses of the dorsolateral PAG (dlPAG) on hold, leaving the animal prepared for action until the brake is released. The vlPAG activates a vagal pathway via the dorsal motor nucleus (DMX), which regulates parasympathetic heart rate decelerations that are the autonomic equivalent of freezing response. The DMX is part of the dorsal vagal complex: the older, more ancient system of two vagal circuits. While the DMX has unmyelinated projections to the heart, the other vagal circuit, the ventral vagal complex which houses the nucleus ambiguus (NA), has myelinated projections to the heart. According to PVT, the development of the myelinated vagal projections is relatively new, unique to mammals, and is closely tied to social behaviors. Activation of this pathway is what we would expect to see during socially mediated meditation.

Activation of the vlPAG evokes a freezing response by increasing parasympathetic vagal control of the heart via the DMX while the dlPAG evokes a fight-flight response by sympathetic activation (Porges, 2007). It's possible that the jump in HRV during the CO2 induction phase was a result of parasympathetic vagal control over the heart via the DMX, instead of the socially mediated parasympathetic vagal control we'd expect from the NA. This means that the increase in HRV isn't socially mediated, but is instead a knee-jerk reaction to the visceral threat of breathing difficulty. While the Pre-CO2 phase may have been affected by the socially-mediated NA vagal pathway, it is doubtful that is this pathway is responsible for the increased HRV levels during the CO2 inhalation phase, which is more likely a stress response.

Further Work and Directions

This is the first study to our knowledge showing that social support has the potential to enhance the beneficial health effects of meditation. The interaction between meditation and social support should be further investigated to better understand the mechanisms driving this effect.

To further understand our data, we would need to further process high-frequency and low-frequency HRV measures. This would allow us to more accurately pinpoint vagal tone and compare our results to Martino et al., 2020. Regardless of what RMSSD was found to measure during the CO2 induction phase, with only one measure, we’re limited in what we can say is representative of vagal tone. Computing RSA by controlling for tidal volume and respiration rate by calculating HF and LF would help draw stronger conclusions.

How meditation can attune the social-engagement system and how the social-engagement system can improve meditation are still unexplored. Future studies should further investigate the effects of visual and auditory social stimuli, both of which direct the social engagement system, on the effectiveness of meditation. To further understand what structures could be responsible for the increase in HRV during the CO2 phase, neuroimaging studies could explore the difference in activation between the two vagal structures: the DMX, the NA, and their projections.

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