IS DEEP BREATHING ALONE ENOUGH?

THE EFFECT OF CONTEMPLATIVE PRACTICES AND SOCIAL CONTEXT ON VAGAL RESPONSE TO CO2 INHALATION CHALLENGE

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ABSTRACT

Both contemplative practices and social context have been demonstrated beneficial to our mental and bodily well-being, yet little is known about the interplay between the two. This study explores the difference between deep breathing and meditation and how social context influences their effect on vagal nervous activity, before, during, and after the 7.5% carbon dioxide (CO_2) enriched air inhalation challenge. We conducted a within-subjects 2 (deep breathing and meditation) by 2 (alone and with a partner) design on 128 college students (84 female). Participants first did contemplative practice either alone or with a partner, then took the CO_2 inhalation challenge. Time-domain heart rate variability (HRV) indexed by the root mean square of successive differences between normal heartbeats (RMSSD) increased after the contemplative practice, and no difference between alone group and with-a-partner group was found. In the CO_2 stress task, reactivity HRV (the difference between pre-challenge and during-challenge HRV) did not significantly differ between groups. A significant positive relationship was found between subjective distress and RMSSD across the experiment. Results of the current study suggest that we could benefit from solely deep breathing, and it has a similar impact on the vagal tone as meditation.

Keywords: heart rate variability, RMSSD, meditation, social support, anxiety sensitivity

BIOGRAPHICAL SKETCH

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Introduction

Taking deep breathing (DB) has been shown to be an uncomplicated yet effective method to adjust the vagal activity, and further increase relaxation and reduce stress (Perciavalle et al., 2017; Van Diest et al., 2014). The application of meditation has also been proven to have a positive impact on people's vagal tone and well-being (Kok et al., 2013; Huppert et al., 2010). In addition, recent evidence suggests that meditation practice can reduce anxiety and depression during times of pandemic (Behan, 2020), as well as improve performance at the workplace (Hyland et al., 2015). With the unique advantage of low-cost and easy-to-implement, DB and meditation are both beneficial methods that people could utilize before stressful events. However, whether the effect of DB and meditation differ remains unclear.

When studying the reaction to stressful events, another important component is social support. It is suggested by the social buffering theory that when facing stressful events, social support can attenuate the adverse effects (Cohen & Wills, 1985). The presence of others can promote a perception that there are available resources and may reduce the potential harm caused by stressful events. This phenomenon happens not only in humans but also in several other species including rats and guinea pigs (Kiyokawa et al., 2018; Hennessy et al., 2000; Coan et al., 2017). A recent study reveals the underlying physiological mechanism – social buffering is mediated via the oxytocin system (Sicorello et al., 2020). Oxytocin is a hormone and a neurotransmitter involved in childbirth and breastfeeding, which plays an important role in social bonding. When facing stressful events, the body goes through a series of physiological responses to preserve biological homeostasis. When stressors are frequent, intense, or long-lasting, they cause body use and tear, which is linked to the same health problems seen in those with poor relationship quality (Juster et al., 2010). There has been a gap between the research of meditation and social context. It remains unclear how the presence of a partner impacts the effect of contemplative practice.

Given the benefit of contemplative practice and the importance of social support, we investigated how different contemplative methods and social context might impact young people's subjective distress and their vagal reaction to psychobiological stress tasks.

Deep breathing and meditation

Both deep breathing and meditation have been shown to improve vagal tone, positive emotions, and stress reduction (Van Diest et al., 2014; Lin et al., 2014; Gruzelier et al., 2014; Fredrickson et al., 2008; Huppert et al., 2010; Kok et al., 2013). Solely deep breathing does not include the cognitive process and benefits people by improving vagal tone. When practicing meditation, cognitive component is included compared with deep breathing. Previous research has shown that loving-kindness mediation can increase positive emotions, which in turn promotes positive social connections, and then improve people's vagal tone (Kok et al., 2013).

Compared with solely deep breathing, will the cognitive element boost the benefit of contemplative practice? If social context is added, will the effect of deep breathing be similar to the effect of meditation? These are part of the questions that the current study is exploring.

Social context and vagal tone

Mental resources are needed to process the information that we receive in our daily environment, which is normatively rich with other humans. When facing stressful event, changing environment is noticed by cognitive process or physiological reaction. Thus, more than usual mental resources are need to deal with the environment. Close social interactions and perceived social support have been discovered to have a buffering impact on physiological stress responses, potentially enhancing health and counteracting negative organismic effects (e.g., Uchino, 2006; Uchino et al., 1999). When people sense comparable high levels of social support, there is evidence for reduced cardiovascular stress responses and lower ambulatory blood pressure (e.g., Bowen et al., 2014; Uchino et al., 2011).

A widely used index of biological adaptiveness is heart rate variability (HRV). It reflected the activity of the autonomic nervous system (ANS), which essentially automatically regulates bodily functions including heart rate, blood pressure, breathing, and sexual arousal. It is usually thought ANS has mainly two divisions – the sympathetic nervous system (SNS) and parasympathetic system (PSNS). The SNS initiates the fight-or-flight response and the PSNS initiates the rest-and-digest process. Approximately 75% of the parasympathetic nerves are vagus nerves. The vagus nerve may have a role in the control of numerous behaviors by enabling a flexible interaction with the environment due to its strong linkages with other cranial nerves (i.e., facial expressions, looking, listening, vocalizing, and self-soothing). Vagal activity, more specifically, is thought to help the organism adjust to the dynamic nature of social communication.

Multiple research have linked social aspects to HRV and discovered that higher HRV is linked to improved relationship quality (e.g., Butler et al., 2006; Diamond et al., 2011; Horsten et al., 1999). A recent study has shown that people who receive higher coworker support have higher HRV in the time domain (Baethge et al., 2020). Similarly, another research observed that when accompanied by perceived social support, HRV significantly increased during rumination (Gerteis & Schwerdtfeger, 2016).

Carbon dioxide (CO_2) enriched air as a psychobiological stressor

The inhalation of CO_2-enriched air has been used to provoke a panic-like response in the laboratory over the decades (Zvolensky & Eifert, 2001; Seddon et al., 2011). Typically, the CO_2 levels in outdoor air only range from 0.03% to 0.04%. When utilized in the experimental environment, both lower concentrations of 7% and higher concentrations of up to 35% has been shown to be safe and effective psychobiological stressor (Martino et al., 2020; Perna et al., 2003). Both frequency domain and time domain of HRV measures have been shown to be affected by CO_2 inhalation challenge (Brown et al., 2007; Tzeng et al., 2007; Martino et al., 2020).

HRV is generated by heart-brain interactions and dynamically changing ANS processes (Shaffer & Ginsberg, 2017). It is a noninvasive index of interconnected regulatory systems that work on various time scales to aid in our adaptation to environmental and psychological challenges. Subjective distress is usually considered to correspond with lower HRV and higher heart rate during mental stress tasks (Renna et al., 2021; Jump & Dockray, 2020). Being an index of the parasympathetic nervous system, HRV decreases when we are in a more mentally stressful state. However, when the stress is physiological, HRV changes differently. As a previous study demonstrates, when exposed to 9% CO_2, healthy participants showed decreased heart rate (Leibold et al., 2016). According to the results of this study, CO_2 causes a strong fear response, which is accompanied by a rise in blood pressure, an adaptive reduction in heart rate, and an increase in respiration rate in healthy people. Although HRV was not reported in this work, the parasympathetic system is working to decrease heart rate (Appelhans & Luecken, 2006), thus we can infer vagal tone increased in that previous study. The results of these studies suggest that HRV changes show differently depending on the stress task type.

Current study

With this study, we aimed to investigate how social context impacts the benefit of contemplative practice and whether the benefit of DB and meditation on vagal activity across the CO2 stress task differs. There are three categories of meditative practices that have been scientifically studied, focused attention, open monitoring, and kindness and compassion (Kok et al., 2013). In the current study, focused attention practice is used for the meditation group.

Our broadest hypothesis, given previous work on social context and contemplative practice, is that social context will boost the benefit of contemplative practice. If true, it should be possible to find evidence that HRV might increase more among the with-a-partner group after contemplative practice. Furthermore, we expect that meditation will improve vagal tone more than deep breathing. We expect to see greater vagal tone improvement after contemplative practice in the meditation group.

We also intended to explore the relationship between subjective distress and objective vagal activities among college participants. Recently researchers have found that high-frequency HRV is negatively related to cannabis intoxication, but not related to subjective anxiety (Pabon et al., 2021). Another recent work also showed HRV remained at the same level when subjective burnout decreased (Orosz et al., 2021). However, one of the key outcomes of stress-reduction *is* subjective change. Understanding how HRV and subjective changes in distress are related can help us better understand the mechanisms by which contemplative practice and social context impact health and wellbeing.

Methods

Participants

Participants (n = 128) were divided into four groups including deep breathing alone group, deep breathing with a partner group, meditation alone group, and meditation with a partner group. Of all participants, 66% (n = 84) were female and 34% (n = 44) were male; ages ranged from 18 to 24 years. Approximately 70% of participants identified as White, 29% identified as Asian, 5% identified as Black or African American, 0.7% identified as Native Hawaiian or Other Pacific Islander, and 2 participants preferred not to provide the information (participants could choose more than one option). In the meditation group (including meditation alone group and meditation with a partner group), participants were recruited from the Buddhism in the Modern World class offered through the Religious Studies Department at the University of Virginia. In this class, undergraduate students learn mindfulness-based techniques and practice at least one hour of meditation a week with a smaller group. Students were informed starting at the beginning of class that they have the option to participate in a program evaluation for $15 or 2 course credits. In the deep breathing group, meditation-naïve participants were recruited from the broader School of Arts and Sciences at the University of Virginia. Participants were screened for a self-reported consistent experience with contemplative practice. Only those who engage in an hour or less of practice per week were invited to participate in the deep breathing comparison group.

Participants were excluded from the study if they were less than eighteen years old, might be pregnant, had asthma, had a serious illness, experienced psychosis, experienced any seizures without a clear cause, or had any kind of psychiatric medication or non-psychiatric medications with psychological effects within the past 4 weeks.

Measures

Subjective measures:

Subjective Units of Distress Scale: The Subjective Units of Distress Scale (SUDS; Wolpe, 1969) assesses one's current subjective intensity disturbance or distress. Participants indicate the intensity of their feelings and other internal experiences on a 100-point scale (0 = *no more anxiety of any kind about any particular issue*, 100 = *feels unbearably bad, overwhelmed*).

The Anxiety Sensitivity Index: The Anxiety Sensitivity Index (ASI; Reiss, Peterson, Gursky, & McNally, 1986) measures to what extent a person believes that anxiety experiences have negative effects. There are 16 items in ASI, including "it scares me when my heart beats rapidly" and "it scares me when I become short of breath".

Objective measures:

Heart Rate Variability: Heart rate variability data were collected upon participants' arrival and continuously across the CO2 task. BIOPAC data acquisition unit (MP150: BIOPAC Systems Inc., US) and accompanying equipment were used to collect raw Electrocardiogram (ECGs) data. The sampling rate was 1,000 Hz. ECG raw data was then clipped based on the epochs using MATLAB (Version R2021a). The time length for each epoch is 120 seconds for baseline epoch, 240 seconds for pre-challenge epoch, 480 seconds for during-CO2 challenge epoch, and 420 seconds for recovery epoch. Clipped ECG data were then cleaned and processed using ARTiiFACT software (Kaufmann et al., 2011). For the peak detection method, the global threshold was used, and the threshold was 200 microvolts. For artifact processing, we selected cubic spline interpolation as the correction method. In the automated HRV analysis module, the interpolation rate was 4 Hz. Window widths chosen were 120 seconds for baseline, 240 seconds for pre-challenge epoch, 480 seconds for during-CO_2 challenge epoch, and 420 seconds for recovery epoch. Window overlap was 50 %. Resultant time-domain HRV - the root mean square of successive differences between normal heartbeats (RMSSD) was obtained.

Experimental Procedures

Participants arrived in pairs. Upon the arrival of participants, consent forms and screening questions were shown and asked by the research assistants to ensure participants were still eligible to attend the experiment. After confirming the eligibility, the whole process of the experiment was told by the research assistant, and participants were told they could halt the study at any time in the event if they were too uncomfortable or became distressed. After this, 2-minutes baseline SUDS and baseline HRV were measured in a seated position. Following the baseline measurements, participants were instructed to practice meditation or deep breathing for 10 minutes either alone or with a partner. After the contemplative practice, participants were presented the consent addendum for the CO_2 breathing challenge and were reassured they could stop the task without penalty if they hoped so. After the participants signed the addendum, they entered another room for the CO_2 breathing challenge. The CO_2 period was 20 minutes in total. During the first 5-minutes pre-challenge period, participants were exposed to normal air. Then for the following 8-minutes during-challenge period, participants were exposed to 7.5% CO_2 enriched air. For the last 7-minutes recovery period, participants were exposed to normal air again. During the whole process, ECG data were collected using the BIOPAC data acquisition unit and accompanying equipment. SUDS data were collected every 2 minutes. Upon the task completion, a post-challenge SUDS was obtained. The procedure in the library is shown in

Figure 1. A battery of questionnaires was emailed to the participants and was completed within 24 hours after the experiment.

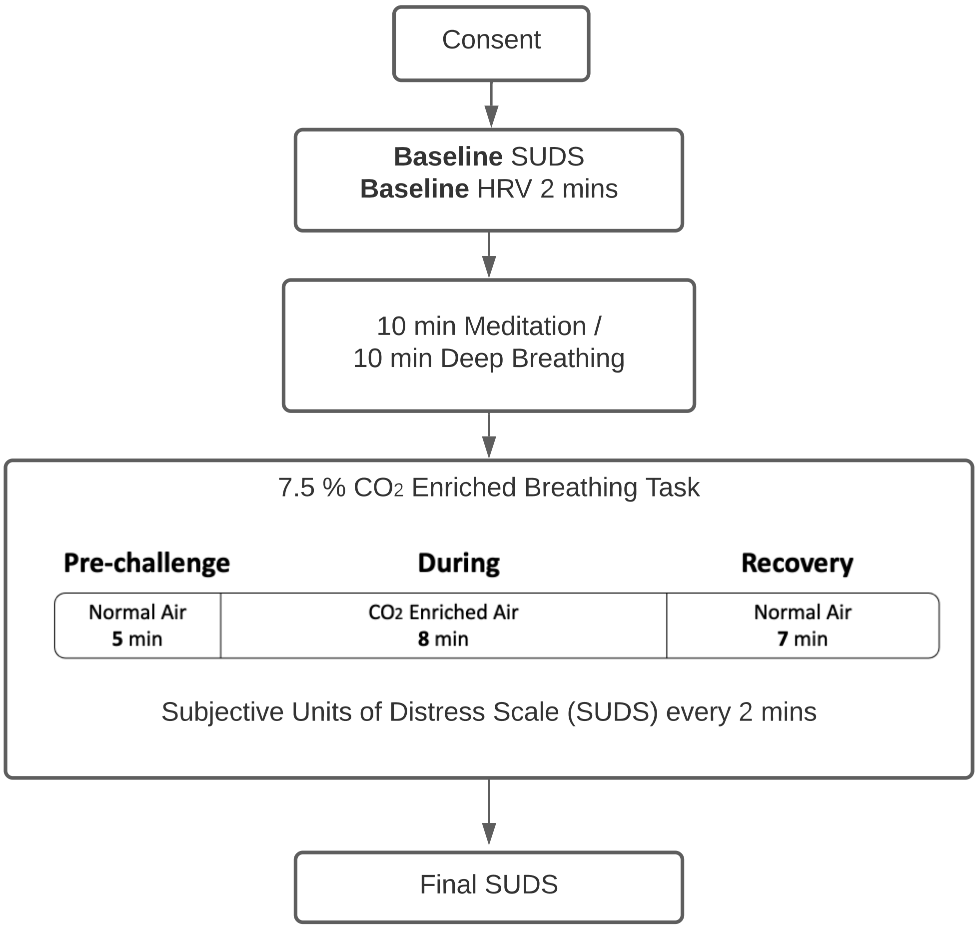

Figure 1. The flow chart of the study.

Results

Subjective measures

According to the scores of SUDS across the experiment (Figure 2), participants felt more stressed during the CO2 enriched phase. Even though they were not informed when enriched

CO_2 was administrated, the physiobiological response still caused mental distress. After the CO_2 challenge ended, the SUDS gradually returned to the baseline level.

To investigate the effects of social context and contemplative practice on participants' subjective distress across the experiment, we conducted linear mixed-effect (LMER) model analysis in R (version 1.4.1717). We set SUDS as the dependent variable and added fixed effects of social context, contemplative practice, epoch (bold words shown in Figure 1), anxiety sensitivity, gender, as well as the interaction between social context and contemplative practice. Participant was included as a random effect. Significance was calculated using Satterthwaite's method. The model specification was as follows: Model_SUDS <- lmer(SUDS ~ Social*Contemplative + Epoch + ASI + gender + (1|Participant)). There were no significant main effects of social context (beta = -0.78, t = -0.21, p = .84), where social context is coded as 1 when participants were with a partner, 0 when participants were alone, nor contemplative practice (beta = 0.49, t = 0.13, p = .90), where it was coded as 1 when participants did meditation, 0 when participants did deep breathing. No interaction was found between social context and contemplative practice (p = .15). There were no significant main effects of gender (beta = -0.21, t = -0.07, p = .95). ASI showed close to being statistically significant (beta = 0.30, t = 1.95, p = .055). Epoch during-challenge showed significant main effect (beta = 12.13, t = 9.28, p < .001).

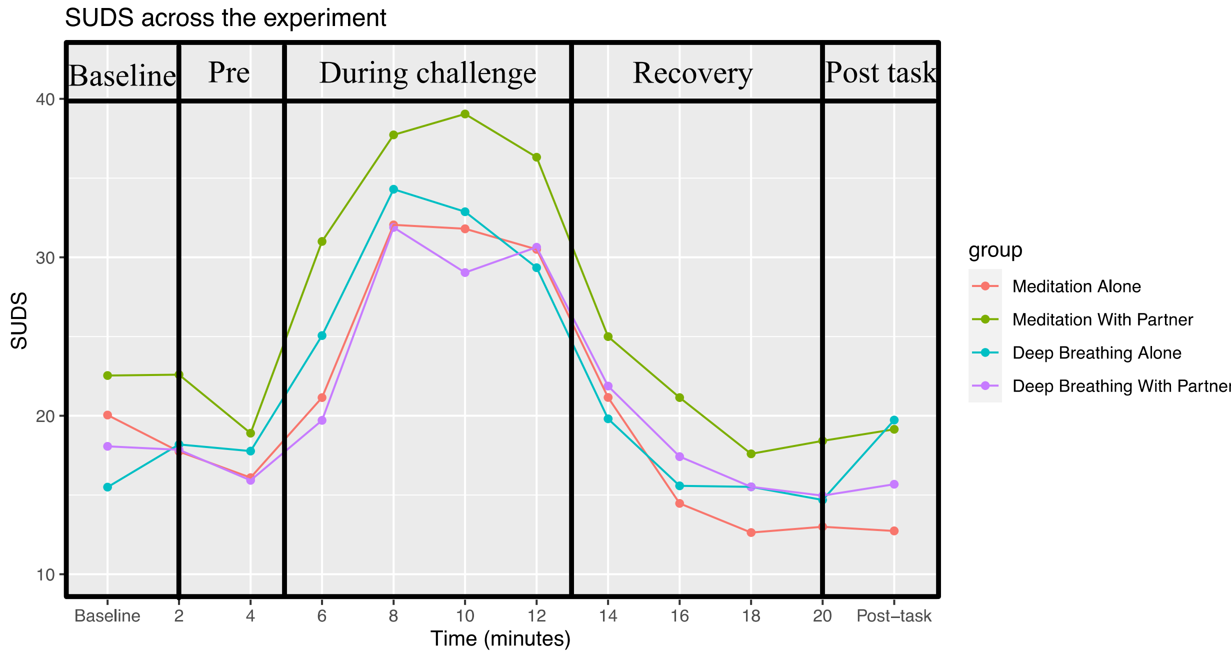

Figure 2. The subjective units of distress across the experiment.

HRV

Generally, HRV increased from Baseline to the Pre-challenge phase, which indicated the effect of contemplative practice. From Pre-challenge to the During-challenge phase, results align with a former study (Martino et al., 2020) that time-domain HRV generally increases during the CO2 challenge. After the enriched CO2 air stopped, participants' HRV decreased while was still higher than the baseline.

Table 1

HRV indexed by RMSSD over experiment epochs

Social context	Contemplative method	N	Baseline		Pre-challenge		During		Recovery	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Alone	DB	27	31.17	17.00	45.83	23.21	54.35	29.14	41.46	20.80
	Meditation	19	31.26	13.64	46.20	20.79	42.72	17.94	37.74	15.63
With a partner	DB	22	39.49	22.62	55.17	39.36	57.58	41.13	45.39	23.24
	Meditation	20	54.45	39.84	65.23	40.95	70.72	51.64	60.11	40.84

Note: DB stands for deep breathing.

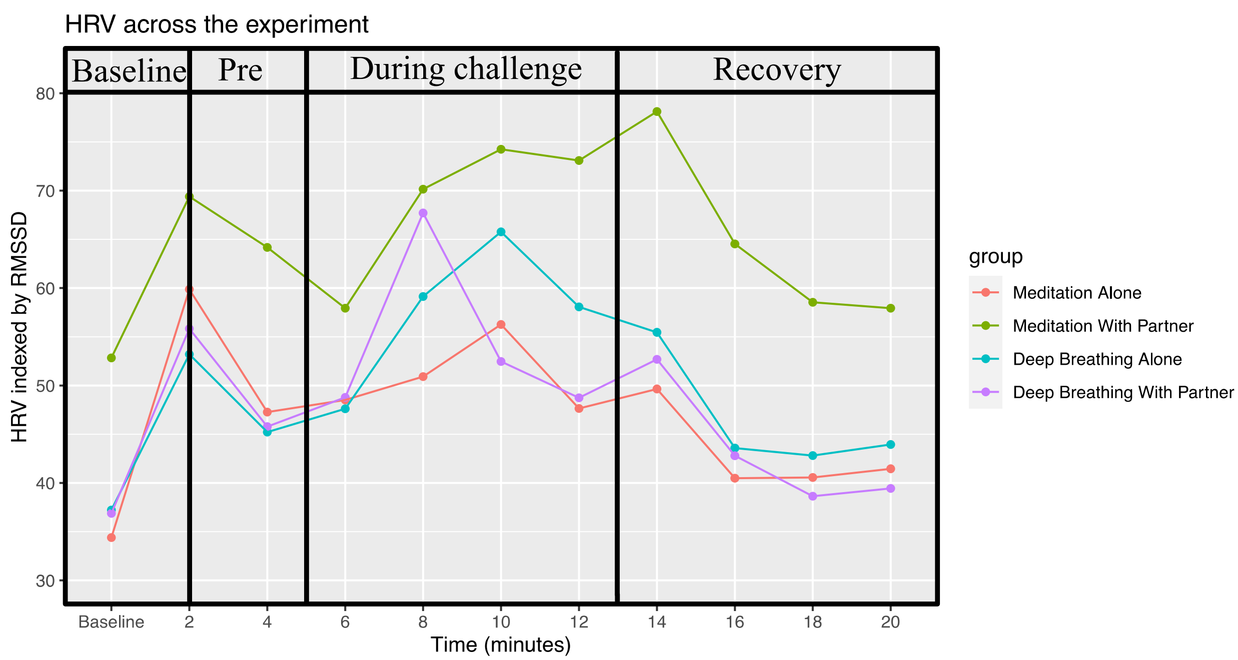

Figure 3. HRV indexed by RMSSD across the experiment.

To investigate the effects of social context, contemplative method and anxiety sensitivity during the contemplative practice, we conducted multiple linear regression analyses on the difference between pre-challenge HRV and baseline HRV. There was no significant effect of social context (beta = -5.43, $p = .18$) nor contemplative method (beta = -2.45, $p = .57$). Social context is coded as 1 when participants were with a partner, 0 when participants were alone. Contemplative method is coded as 1 when participants did meditation, 0 when participants did deep breathing. No interaction was found between social context and contemplative method. No significant effect of anxiety sensitivity (beta = 0.22, $p = .15$) was found in this stage.

Multiple linear regression analysis was used to test if reactivity HRV (the difference between during-challenge HRV and pre-challenge HRV) and recovery HRV (the difference between recovery HRV and during-challenge HRV) differ between groups or based on ASI scores. For the reactivity HRV, we did not find a significant effect of social context (beta = -4.31, $p = .48$), where social context is coded as 1 when participants were with a partner, 0 when participants were alone. No significant effect of contemplative method was found (beta = -5.99, $p = .36$) and it is coded as 1 when participants did meditation, 0 when participants did deep breathing. No interaction was found between social context and contemplative method. We found a significant relationship between reactivity HRV and ASI scores (beta = -0.46, $p < .05$), indicating that a lower ASI score is associated with higher reactivity HRV in the CO_2 challenge task. For the recovery HRV, results indicated no significant effect of social context (beta = 5.43, $p = .34$), nor the contemplative method (beta = 5.53, $p = .37$). Although anxiety sensitivity was a significant predictor of reactivity HRV, it did not yield a significant effect on recovery HRV (beta = 0.24, $p = .27$).

Subjective distress and HRV

In order to assess the impact of subjective distress on HRV, we used linear mixed-effect (LMER) model analysis. We included HRV from all epochs as dependent variable and added fixed effects of SUDS, ASI and sex. In addition, we included participants as a random effect. The results indicated the main effect of SUDS was significantly positively related (beta = 0.20, t = 3.87, $p < .001$). No significant effects were noted for ASI (beta = -0.16, t = -0.52, p = .60) and sex (beta = -0.35, t = -0.06, p = .95).

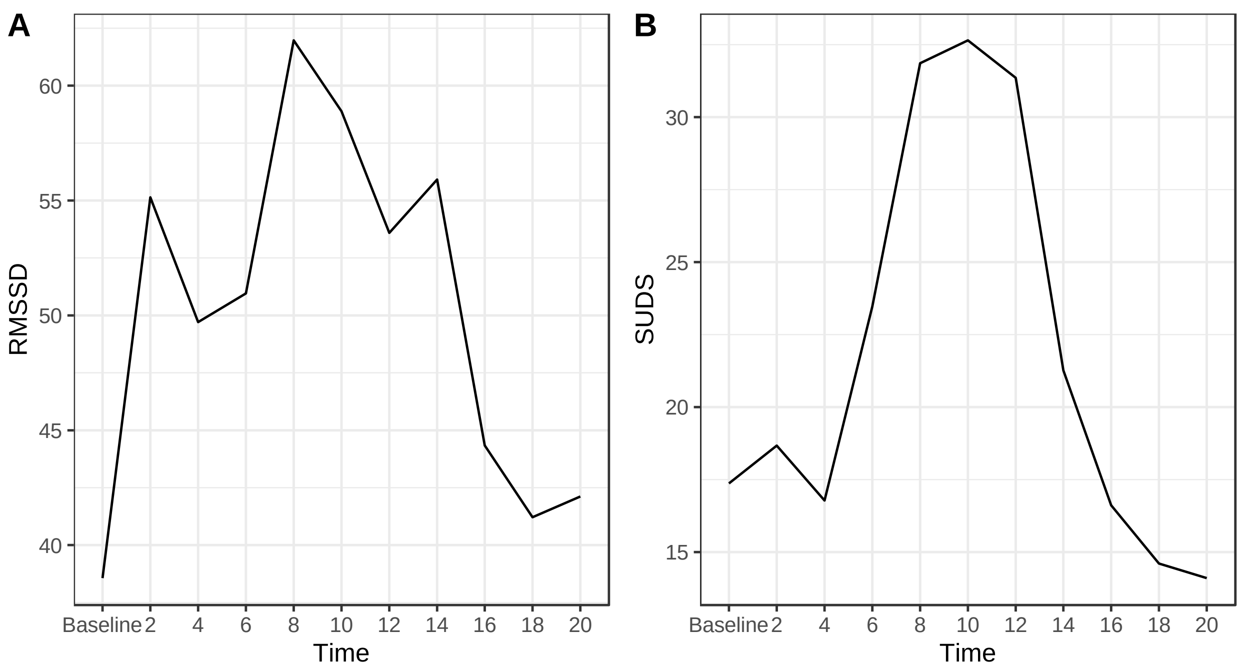

Figure 3. HRV and the subjective units of distress from all groups across the experiment.

Discussion

Our results suggest that social context does not show a main effect on the vagal tone after contemplative practice, on reactivity HRV nor recovery HRV. For the comparison between DB and meditation, we were unable to find significant evidence that meditation improves vagal tone more than deep breathing. Furthermore, a significant positive relationship was found between subjective distress and RMSSD across the experiment. These observations are noteworthy for several reasons. First, to the authors' best knowledge, the interplay between social context and meditation on the CO2 inhalation challenge was not studied before. Moreover, although the difference between groups is not significant, it might indicate that we can get similar benefits like meditation together by simply deep breathing alone, which is much easier to implement during the time of pandemics. Below, we provide some possible explanations for the associations we have found.

Contemplative practice with a partner or alone

Contrary to expectations, we were unable to find significantly different vagal responses between doing contemplative practices with a partner and doing these practices alone. Furthermore, the results have been unable to demonstrate that social context has a positive influence on the vagal reactivity to 10-minutes contemplative practices. The results of subjective distress did not show a significant difference between with-a-partner group and alone group. To some extent, these results corroborate the findings of previous work in failing to find higher mindfulness levels in group meditation (Mantzios & Giannou, 2014).

Surprisingly, no significant difference was found between the with partner group and alone group during the stress task. This outcome is contrary to the assumption based on the social buffering theory and former studies which showed social context have a buffering impact on physiological stress responses (Uchino, 2006; Uchino et al., 1999). A possible explanation or this might be that partners did not show during the challenge but before the challenge. If a partner is presented during the CO2 challenge, the social buffering effect might show a main effect. Another possible explanation for this result may be different oxytocin receptors. A recent study shows that genetic variation of the oxytocin system modulates the efficacy of social support (Kanthak et al., 2016). According to this mentioned study, the stress-buffering effect of social context showed on participants with specific oxytocin receptors (GG or GA) but not on another group with a different oxytocin receptor (AA).

However, we did find RMSSD increased in all groups after 10-minutes contemplative practice (both DB and meditation), indicating that no matter alone or with a partner, 10-minutes contemplative practice is beneficial enough to our vagal tone. Besides that, subjective distress also dropped in both alone group and with a partner group after contemplative practice, further supporting the benefit we can obtain from contemplative practice regardless of social context.

Practicing DB or meditation

This study set out with the aim of assessing the importance of meditation compared with solely DB. The results indicate that there is no significant difference between the vagal activity of the DB group and the meditation group. We also found that subjective distress dropped in both the DB group and meditation group after contemplative practice. These results match those observed in earlier studies (Van Diest et al., 2014; Gruzelier et al., 2014; Huppert & Johnson, 2010). Considering no difference was found between the subjective distress of the DB group and the meditation group, it is likely that our vagal nervous can benefit similarly from both DB and meditation.

According to these data, we can infer that during the meditation and DB process, the presence of a partner might not boost the benefit to our vagal activity. Additionally, we can benefit similarly from both DB and meditation. These findings encourage us to simply try deep breathing by ourselves, which is easy to implement especially during the time of the pandemic.

However, it is reasonable to consider whether the similar results from the DB group and meditation group came from the similarity of focused attention and BD. If the meditation group practiced more cognitive processes involving methods like open monitoring or kindness and compassion, the difference might change.

CO2 inhalation stress task induces distress and vagal adjustments

Consistent with the literature, this research found that during the CO2 stress task, participants' subjective distress levels significantly increased compared with the pre-challenge phase (Zvolensky & Eifert, 2001; Seddon et al., 2011). This indicates that even though participants were not notified about the CO2 level increased, the biological response was able to cause mental status changes.

Consistent with the literature (Martino et al., 2020), this research found that time-domain measures of HRV increased during the CO2 challenge. We also found that anxiety sensitivity is significantly and negatively correlated with reactivity HRV, meaning people with higher anxiety sensitivity tend to have less tendency of increasing HRV during the CO2 task. This result corroborates the findings of a great deal of the previous work in the relationship between lower HRV and higher anxiety levels (Gruzelier et al., 2014; Juster et al., 2010).

The increasing HRV during CO2 challenge is a noteworthy result. Being both a psychological and physiological stressor, CO2 can influence vagal tone from different perspectives. As a psychological stressor, CO2 induces increasing felt distress, impair parasympathetic nervous activity, and further causes decreasing HRV. However, as a physiological stressor, a previous study has shown that CO2 causes a strong fear response, which is accompanied by a rise in blood pressure, an adaptive reduction in heart rate, and an increase in respiration rate (Leibold et al., 2016). Although HRV was not reported in this work, the parasympathetic nervous system is working to decrease heart rate (Appelhans & Luecken, 2006), thus we can infer vagal tone increased in that previous study, which aligns with our results.

Limitation and future directions

When evaluating the results of the current study, txhere are several limitations to consider. Firstly, all the data and results from this study can be better discussed within the younger population since all the participants were college students. It might not be suitable for discussion among the mid-aged or elder population. Besides, all the HRV measurements in this study are time-domain values. The frequency-domain HRV index is not included, which causes missing information regarding the ratio between the sympathetic nervous system and parasympathetic nervous system (Shaffer & Ginsberg, 2017).

Another potential limitation is that when measuring pre-challenge HRV, we intended to measure the effect of DB or meditation. However, the pre-challenge HRV might be mixed results from both the contemplative practices and the reaction to the new CO2 task environment.

Finally, future research needs participants at different stages of the life span and with different socioeconomic statuses to check if the results of the current study are limited to the college young population. It would also be interesting to test if DB or meditation with a more intimate partner would boost the benefit of contemplative practice and further influence the reaction to the psychobiological challenge. Although many questions remain, the results of the current study suggest we can benefit from simply deep breathing alone, and it has a similar impact on vagal tone as meditation.

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