Complex Correlation Method Identifies Efficacy of One-week Mindfulness Training in College Students

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Abstract

College students face a variety of stressors, including academic pressure, social challenges, and financial concerns. Mindfulness training by applying breathing and self-reflecting mantras has been shown to be a useful tool for reducing stress as part of compassion mindfulness training (CMT). Physiological measures of these methods are lacking. Heart rate variability (HRV) captures stress and anxiety by changes in the sympathovagal balance and hence may provide insight into the effectiveness of mindfulness on psychopathology. Thirty-nine students were recruited and answered the depression, anxiety, and stress questionnaire (DASS-21) prior to and following 90 days after CMT. Heart rate was recorded for 5 minutes before CMT and following the 1-week intervention. HRV features included time-frequency domain, nonlinear features, and complex correlation measures. Long-term improvements in DASS-21 were not reflected by all HRV features. However, changes in HRV patterns indicate an increase in complexity reflecting the higher adaptability and flexibility of the autonomic nervous system. The research outcomes indicate the beneficial effect of short, self-compassion mindfulness training. Yet, further research is required to explain its effect on heart rate variability.

1. Introduction

College students face a variety of stressors, including academic pressure, social challenges, and financial concerns. And while stress itself is a short-term response, college students have also shown high rates of depression and anxiety [1]. A variety of interventions have been considered including mindfulness practices [2]. The ability of mindfulness practices such as emotion labelling, diaphragmatic breathing, and self-compassion mantras, to modify emotions has been demonstrated in mindfulness practitioners [3]. Mindful emotion labelling has been shown to reduce subjective stress and is a technique of cognitively responding to emotional states by applying a linguistic descriptor to the state [2]. Such practices also teach self-compassion involving the mindful repetition of mantras or self-affirmations, but whether these correlate with improved vagal tone and HRV is still controversial [4, 5]. The current research investigated whether combining emotional labelling, diaphragmatic breathing, and self-compassion practices would reduce stress and lead to improved changes in HRV following a one-week intervention.

2. Methods.

2.1. Subjects

Thirty-nine engineering students, comprising 29 females (22.3±3.5 years) participated in this study. Subjects were screened for psychiatric or neurological diseases, cognitive deficits, and ongoing psychoactive drug therapies. All subjects provided written informed consent. The experimental protocol was approved by Khalifa University Institutional Review Board.

2.2. Experimental Protocol

The participants underwent a home-based compassion mindfulness training (CMT) program over the course of one week. The subjects were instructed to undertake the training any time they felt stressed. This consisted of identifying how they felt and naming their emotions by consulting the emotion wheel. Then they were instructed to do deep breathing whilst reciting the self-affirmation text.

To evaluate the impact of the training, the heart rate signal was measured twice: once for a five-minute period before the commencement of the CMT program and about 90 days following the one-week training. The emWave system (HeartMath) was utilized to record heart rate data (sampling rate of 370 sps). Subjects filled out the DASS questionnaire pre- and 90 days post-training. The DASS-21 is a self-reporting survey with 21 questions that are used to assess psychological well-being [6].

2.3. HRV measures

Heart rate signals were preprocessed to remove ectopic noise from the signal using the hybrid filter, SDROM-ADF, based on the single dependent rank order mean (SDROM) algorithm and adaptive filtering algorithm (ADF) [7]. A sample segment of 700 beats was extracted from the denoised HRV signal and the HRV features were extracted using the MATLAB toolbox [8,9]. The HRV features extracted were SDSD (standard deviation of RR intervals), RMSSD (square root of the mean squared differences between successive RR intervals), SDNN (standard deviation of successive normal beats), pNN50 (number of successive RR interval pairs that differ more than 50 ms divided by the total number of RR intervals), and TRI (HRV triangular index).

Furthermore, nonlinear detrended fluctuation analysis (DFA) was evaluated, measuring α1 for short-term fractal correlations over windows sizes from 4 to 11 beats and α2 DFAα1 evaluates short-term fractal correlations by partitioning the signal into non-overlapping windows and calculating root-mean-square fluctuations, unveiling local patterns. DFA Alpha 2 extends this analysis to long-term correlations, using varying window sizes to reveal broader temporal relationships [10]. Moreover, Poincree plot analysis was done evaluating SD1, SD2, and SD1/SD2. SD1 quantifies short-term HRV dynamics by assessing point spread relative to the identity line. In contrast, SD2 examines long-term trends from the same plot. The SD1/SD2 ratio offers insights into the balance between short-term and long-term. Additionally, to better quantify the dynamic changes in HRV over time we utilized the complex correlation measure (CCM). The CCM measure is a function of multiple lag correlation of the signal [11]. Specifically, it is calculated as the SD1 and SD2 normalized area of the fitted ellipse over n-lagged consecutive points on the Poincare plot (here, lag=1, capturing insights about consecutive RR intervals).

Statistical significance was determined for the pre-and post-training using the Wilcoxon signed-rank test (one-sided).

3. Results

3.1. DASS-21 scores

Results show that CMT had a positive long-term effect on student mental health as illustrated by DASS-21 scores on all three dimensions (Fig. 1; Table 1). On average, stress, anxiety, and depression were reduced by about 3.26 ($p<0.0001$), 3.39 ($p<0.0001$), and 1.59 ($p<0.01$), respectively.

Figure 1. DASS-21 Pre-Post Average Subscale Scores

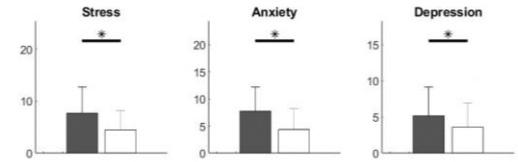

Table 1. DASS-21 scores Pre- and Post- CCM

Variable	*Before*	*After*	*p*
Stress	7.72 ± 4.97	4.46 ± 3.71	<0.0001***
Anxiety	7.72 ± 4.47	4.33 ± 3.85	<0.0001***
Depression	5.13 ± 4.00	3.54 ± 3.33	0.005**

3.2. HRV measures

CMT had a significant effect on some of the HRV measures. Specifically, SDNN ($p<0.001$), DFAα2 ($p<0.05$), and CCM ($p<0.05$) values increased showing greater HRV complexity. While the normalized low-frequency component ($p<0.05$), pNN50 ($p<0.05$), and SD1 to SD2 ratio ($p<0.05$) decreased (Fig. 2; Table 2).

Figure 2. HRV Measures Pre-Post Average

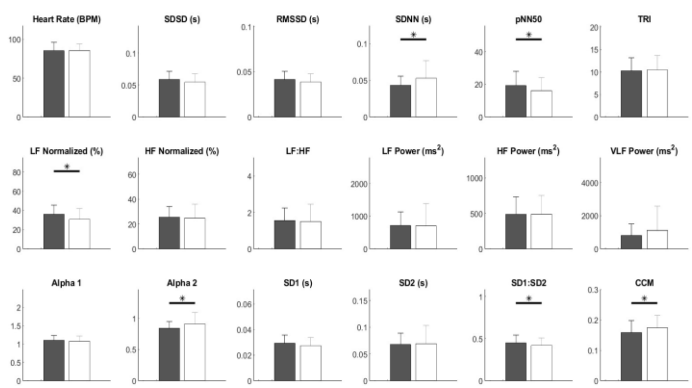

Table 2. HRV Pre- and Post- CMT

Variable	*Before*	*After*	*p*
Heart Rate (BPM)	85.27 ± 10.64	85.52 ± 8.38	0.6799
SDSD (ms)	58.41 ± 12.85	54.43 ± 12.92	0.0535
RMSSD (ms)	41.30 ± 9.08	38.49 ± 9.14	0.0535
SDNN (ms)	43.43 ± 12.21	52.87 ± 23.90	0.0001***
pNN50	19.25 ± 8.69	16.13 ± 7.91	0.0408*
TRI	10.24 ± 2.92	10.44 ± 3.29	0.2958
LF Norm (%)	35.99 ± 9.36	30.69 ± 11.47	0.0112**
HF Norm (%)	25.65 ± 8.40	24.69 ± 11.13	0.1661
LF:HF	1.56 ± 0.68	1.49 ± 0.95	0.1661
LF Power (ms^2)	712.71 ± 421.90	704.92 ± 686.45	0.3454
HF Power (ms^2)	486.03 ± 243.72	488.14 ± 266.67	0.5417
VLF Power (ms^2)	801.25 ± 713.42	1108.14 ± 1467.18	0.0743

Table 2. HRV Pre- and Post- CMT

Variable	Before	After	p
Alpha 1	1.10 ± 0.12	1.07 ± 0.14	0.1840
Alpha 2	0.84 ± 0.11	0.91 ± 0.18	0.0303*
SD1 (ms)	29.22 ± 6.43	27.24 ± 6.47	0.0535
SD2 (ms)	67.88 ± 21.31	69.30 ± 33.83	0.5139
SD1:SD2	0.45 ± 0.09	0.42 ± 0.09	0.0387*
CCM	0.16 ± 0.04	0.17 ± 0.04	0.0132*

p<0.05*; p<0.01**; p<0.001***

4. Discussion

In this paper, we have examined the long-term effect of one-week compassion mindfulness training on college students considering the perceived emotional response with reference to physiological changes following the CMT. We assessed changes in the emotional aspect using the three subscales of the DASS-21 scoring system; stress, anxiety, and depression. To have better insights into the physiological response, we measured changes in the heart variability signal using time-frequency domain features, non-linear variables, and complex correlation measures.

Mindfulness-based interventions including CMT are effective in addressing psychopathology and self-management of disease by promoting behavioral changes. This was apparent from the DASS-21 results indicating improvement in stress, anxiety, and depression scores. Our results combine a neuroscience-based mindfulness model that included HRV features with behavioral change [12]. Hence, CMT has been implicated in changes to parasympathetic activity through an ascending neural pathway including nucleus accumbens, and ventromedial PFC control of the amygdala that is associated with vagal activity [13].

Our results show an overall increase in complexity illustrated by SDNN, DFAα2, and CCM that may indicate improved functionality and better resilience to stress [14]. Particularly, an increase in SDNN reflects improved autonomic adaptability. Also, an increase in DAFα2 suggests stronger long-term correlations and enhanced autonomic flexibility. These metrics deepen our understanding of heart rate variability, capturing short-term and long-term dynamics and the intricate interplay of factors shaping cardiac rhythms with respect to mindfulness training [15].

Parasympathetic tone, however, was lower Taken together, the pattern of an increase in SDNN and DFAα2, along with decreases in LF%, pNN50, and SD1:SD2, suggests increased complexity and adaptability in the autonomic nervous system.

We note that although DASS-21 shows long-term improvement with mindfulness training this was not seen in all HRV features. Not many long-term follow-ups of short mindfulness training interventions have been reported. A one-week program similar to the current one showed lasting improvement at 2 weeks follow-up. These results are similar to the current study [16]. The use of a mobile app – Calm – has shown promise following an eight-week program [17]. Calm use by college students led to a reduction in stress and improved mindfulness and self-compassion. An eight-week mindfulness training course, which is the standard time for mindfulness training showed improvement in HRV features. The current intervention differs from this standard model in that it was a seven-day intervention based on breathing and a self-compassion mantra aimed at providing students with a means of regulating academic stress-related outcomes.

Future research is planned to investigate the dynamic changes associated with each mindfulness training session on HRV and evaluate the HRV reactivity associated with a stressor such as the Stroop test [18].

Finally, the current work indicated that a minimal mindfulness training program showed a significant long-term effect on depression, anxiety, and stress.

5. References

[1] A. Shearer, M. Hunt, M. Chowdhury, and L. Nicol, “Effects of a brief mindfulness meditation intervention on student stress and heart rate variability.,” *Int. J. Stress Manag.*, vol. 23, no. 2, pp. 232–254, 2016.

[2] J. E. Boyd, R. A. Lanius, and M. C. McKinnon, “Mindfulness-based treatments for posttraumatic stress disorder: a review of the treatment literature and neurobiological evidence.,” *J. Psychiatry Neurosci.*, vol. 43, no. 1, pp. 7–25, Jan. 2018.

[3] Y.-Y. Tang, B. K. Hölzel, and M. I. Posner, “The neuroscience of mindfulness meditation.,” *Nat. Rev. Neurosci.*, vol. 16, no. 4, pp. 213–225, Apr. 2015.

[4] A. Natarajan, “Heart rate variability during mindful breathing meditation,” *Frontiers in Physiology*, vol. 13. 2023.

[5] U. Kirk and J. L. Axelsen, “Heart rate variability is enhanced during mindfulness practice: A randomized controlled trial involving a 10-day online-based mindfulness intervention.,” *PLoS One*, vol. 15, no. 12, p. e0243488, 2020.

[6] M. M. Antony, P. J. Bieling, B. J. Cox, M. W. Enns, and R. P. Swinson, “Psychometric properties of the 42-item and 21-item versions of the Depression Anxiety Stress Scales in clinical groups and a community sample.,” *Psychol. Assess.*, vol. 10, no. 2, pp. 176–181, 1998.

[7] S. Saleem, A. H. Khandoker, M. Alkhodari, L. J. Hadjileontiadis, and H. F. Jelinek, “A two-step pre-processing tool to remove Gaussian and ectopic noise for heart rate variability analysis.,” *Sci. Rep.*, vol. 12, no. 1, p. 18396, Nov. 2022.

[8] J. A. Behar *et al.*, “PhysioZoo: A Novel Open Access Platform for Heart Rate Variability Analysis of Mammalian Electrocardiographic Data,” *Frontiers in Physiology*, vol. 9. 2018.

[9] M. Vollmer, “HRVTool – an Open-Source Matlab Toolbox for Analyzing Heart Rate Variability,” in *2019 Computing in Cardiology (CinC)*, 2019, p. Page 1-Page 4.

[10] C. K. Peng, S. Havlin, H. E. Stanley, and A. L. Goldberger,

"Quantification of scaling exponents and crossover phenomena in nonstationary heartbeat time series.," *Chaos*, vol. 5, no. 1, pp. 82–87, 1995
[11] C. K. Karmakar, A. H. Khandoker, J. Gubbi, and M. Palaniswami, "Complex Correlation Measure: a novel descriptor for Poincaré plot," *Biomed. Eng. Online*, vol. 8, no. 1, p. 17, 2009.
[12] Z. Schuman-Olivier et al., "Mindfulness and Behavior Change.," *Harv. Rev. Psychiatry*, vol. 28, no. 6, pp. 371–394, 2020.
[13] S. W. Porges, "The Polyvagal Theory: phylogenetic contributions to social behavior.," *Physiol. Behav.*, vol. 79, no. 3, pp. 503–513, Aug. 2003.
[14] H. F. Jelinek, H. Md Imam, H. Al-Aubaidy, and A. H. Khandoker, "Association of cardiovascular risk using non-linear heart rate variability measures with the Framingham risk score in a rural population.," *Front. Physiol.*, vol. 4, p. 186, 2013
[15] B. Deka and D. Deka, "Nonlinear analysis of heart rate variability signals in meditative state: a review and perspective," *Biomed. Eng. Online*, vol. 22, no. 1, p. 35, 2023
[16] D. R. Jones, B. J. Lehman, A. Noriega, and D. L. Dinnel, "The effects of a short-term mindfulness meditation intervention on coping flexibility," *Anxiety, Stress. Coping*, vol. 32, no. 4, pp. 347–361, Jul. 2019
[17] J. Huberty, J. Green, C. Glissmann, L. Larkey, M. Puzia, and C. Lee, "Efficacy of the Mindfulness Meditation Mobile App ``Calm'' to Reduce Stress Among College Students: Randomized Controlled Trial," *JMIR Mhealth Uhealth*, vol. 7, no. 6, p. e14273, Jun. 2019
[18] Y.-H. Tung and J.-C. Hsieh, "The Impacts of Mindfulness on Heart Rate Variability: A Brief Review," *Int. J. Pharma Med. Biol. Sci.*, vol. 8, pp. 132–137, Oct. 2019.

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