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ARTICLES

Relación entre meditación, regulación emocional y expresión vocal: estudio de intervención

Relação entre meditação, regulação emocional e expressão vocal: estudo de intervenção

The relationship between meditation, emotional regulation and vocal expression: interventional study

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Abstract

Introduction: The voice is an indicator of emotional states, influenced by factors such as vagal tone, breathing and heart rate variability. This study explores these factors and their relationship with emotional regulation and meditative practice as a self-regulation technique. **Purpose:** To investigate the difference in vocal characteristics and heart rate variability in experienced (EM) and novice (NM) meditators before and after a meditation practice and in non-meditators - control group (CG), before and after a control test. **Methods:** 3 x 2 quasi-factorial study. Three groups were evaluated (experienced meditators EM; novice meditators NM; and control group CG, non-meditators) at two points in the experimental manipulation - before and after a meditation session for meditators, and before and after a word search task for the control group. The fundamental frequency, jitter, shimmer, harmonic-to-noise ratio and the first (F1), second (F2) and third (F3) formants of the vowel [a]; heart rate variation (SDNN, RMSSD, LF/HF, SD1 and SD2); anxiety state and vocal self-perception, were investigated, before and after the

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Authors' contributions:
ML: conception, design and writing of the article.
ACG: guidance, revision and final approval of the published version of the article.
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intervention. **Results:** The EM group achieved optimal vocal tract relaxation. The NM and CG groups showed changes in F1. Long-term meditative practice was associated with a large difference in F3, SDNN and SD2 in heart rate variation. **Conclusion:** The results suggest that meditation practice influences vocal expression and emotional reaction, and that experience in meditation practice favors this relationship.

Keywords: Voice; Speech acoustics; Autonomic nervous system; Emotional regulation; Meditation.

Resumo

Introdução: A voz é um indicador de estados emocionais, influenciada por fatores como o tônus vagal, a respiração e a variabilidade da frequência cardíaca. O estudo explora esses fatores e a relação com a regulação emocional e a prática meditativa como técnica de autorregulação. **Objetivo:** Investigar a diferença nas características vocais e na variação da frequência cardíaca em meditadores experientes (EM) e novatos (NM) antes e depois de uma prática meditativa e em não praticantes de meditação – grupo controle (CG), antes e depois de um teste controle. **Métodos:** Estudo quase-fatorial 3 x 2. Três grupos foram avaliados (meditadores experientes EM; meditadores novatos NM; e grupo controle CG, não praticantes de meditação) em dois momentos da manipulação experimental – antes e depois de uma sessão meditativa para praticantes de meditação, e antes e depois de uma tarefa de busca de palavras para o grupo controle. A frequência fundamental, jitter, shimmer, relação harmônico-ruído e o primeiro (F1), o segundo (F2) e terceiro (F3) formantes da vogal [a]; a variação da frequência cardíaca (SDNN, RMSSD, LF/HF, SD1 and SD2); estado de ansiedade e autopercepção vocal, foram investigados, antes e após a intervenção. **Resultados:** O grupo EM alcançou ótimo relaxamento do trato vocal. Os grupos NM e CG apresentaram mudanças em F1. Prática meditativa, de longa duração, está associado com grande diferença em F3, SDNN e SD2 na variação da frequência cardíaca. **Conclusão:** Os resultados sugerem que prática meditativa influencia a expressão vocal e reação emocional, e que a experiência em prática meditativa favorece esta relação.

Palavras-chave: Voz; Acústica da fala; Sistema nervoso autônomo; Regulação emocional; Meditação.

Resumen

Introducción: La voz es un indicador de los estados emocionales, influida por factores como el tono vagal, la respiración y la variabilidad de la frecuencia cardiaca. Este estudio explora estos factores y su relación con la regulación emocional y la práctica de la meditación. **Objetivo:** Investigar la diferencia en las características vocales y variabilidad de la frecuencia cardiaca en meditadores experimentados (EM) y novatos (NM) antes y después de una práctica de meditación y en no meditadores - grupo control (GC), antes y después de una prueba control. **Métodos:** Estudio cuasi-factorial 3 x 2. Se evaluaron tres grupos (meditadores experimentados EM; meditadores novatos NM; y grupo control CG, no meditadores) en dos momentos - antes y después de una sesión de meditación para los meditadores, y antes y después de una tarea de búsqueda de palabras para el grupo control. Se investigaron la frecuencia fundamental, jitter, shimmer, relación armónico-ruido y los formantes primero (F1), segundo (F2) y tercero (F3) de la vocal [a]; la variación de la frecuencia cardiaca (SDNN, RMSSD, LF/HF, SD1 y SD2); el estado de ansiedad y autopercepción vocal, antes y después de la intervención. **Resultados:** El grupo EM consiguió una relajación óptima del tracto vocal. Los grupos NM y CG mostraron cambios en F1. La práctica de meditación a largo plazo se asocia con una gran diferencia en F3, SDNN y SD2 en la variación de la frecuencia cardiaca. **Conclusión:** Los resultados sugieren que la práctica de meditación influye en la expresión vocal y reacción emocional.

Palabras clave: Voz; Acústica del habla; Sistema nervioso autónomo; Regulación emocional; Meditación.

Introduction

The voice is an indicator of emotional state. Fundamental frequency (f0) is associated with vagal tone, as it controls the contraction or relaxation of laryngeal muscles. Respiration also modulates phonation, decreasing the efferent action of the vagal nerve at the sinoatrial node. Likewise, the efferent vagal influence on the heart is also greater during exhalation, influenced by respiration[1].

A decrease in vagal tone is associated with the contraction of the cricothyroid muscle and changes in fundamental frequency and pitch as the vocal folds are stretched. On the other hand, an increase in vagal action contracts the thyroarytenoid muscle, functionally decreasing vocal pitch[1].

The acoustic parameters of voice quality provide information regarding the speaker's emotional state[2]. A review showed that the increased fundamental frequency (f0), and decreased jitter are the most common acoustic effects associated with stress[3]. Furthermore, under stressful conditions, voice and prosody may be related to physiological events, such as increased heartbeat[3], increased perilaryngeal muscle tension and vocal fold tension[4].

The relationship between heart rate and voice is based on the neuromodulation of the heart and the laryngeal and pharyngeal muscles through efferent pathways of the vagus nerve that originates in the ambiguous nucleus. Therefore, the increase in vagal activity via myelinated branch is associated with calmness and vocalizations characterized by lower and more variable fundamental frequencies[5]. However, there is little evidence in the scientific literature showing that these two systems (vocal and vagus systems) interact with each other in human behavior considering that the aforementioned study[5] was conducted with animals.

The increase of the sympathetic branch of the autonomic nervous system, related to greater stress excitation, may be associated with increased laryngeal tension, influencing the increase in fundamental frequency (f0), subglottic pressure, jitter, shimmer, vocal intensity, speech rate and bronchodilation, as well as reduction of airflow[6]. In stressful situations, speech rate is increased and the voice is tense, unstable and tremulous[3]. In addition to heart rate, the voice can also be investigated by its association with heart rate variability (HRV), an indirect and non-invasive marker of autonomic nervous system activity[7].

The heart rate variability (HRV) modulates heart rate influencing respiration, and is defined as the variations in the duration of consecutive R-R (time interval expressed in milliseconds between R waves of electrical activity of the heart) intervals of heartbeats. HRV enables the analysis of vagal action, with the investigation of indices that suggest the interaction of the sympathetic and parasympathetic branches of the autonomic nervous system[8]. For instance, the decrease in heart rate variability is related to difficulties in adapting the body to environmental demands, psychiatric illness, stress, pain, heart and respiratory diseases, Chagas' disease and diabetes. Increased cardiac variability is associated with emotional and behavioral adaptation, and with cardiovascular health[8, 9, 10].

A study by Park et al.[2] (2011) showed that the LF/HF index (LF indirectly represents the joint action of the vagal and sympathetic components on the heart, and HF is an indirect indicator of the parasympathetic branch), related to sympathetic balance over the heart, was associated with fatigue in men and women, and LF/HF was related to depression and anger in women. The acoustic parameters of shimmer and the standard deviation of the fundamental frequency (SDf0) were indicative of tension and depression in men, and SDf0 was indicative of tension in women. Thus, the emotional state was related to autonomic function and voice parameters, suggesting that sympathetic and parasympathetic activation interferes with the effect of emotion on vocalization. However, it is still difficult to accurately determine which factors predispose the relationship between mood, autonomic regulation and voice parameters.

Taken together, these studies suggest voice parameters relate to emotional expression in the context of emotional excitation, especially in increased levels of stress. However, to our knowledge, the relationship between voice parameters and emotional regulation outcomes has not been investigated. This study aimed to verify how voice parameters behave in a context in which individuals try to regulate their emotions through meditation.

Meditation is considered a self-regulatory technique, consisting of systematic directing selective attention and prolonging sustained attention in the awareness of the present moment in order to develop a non-reactive behavior towards internal experiences[11]. Meditation interventions seem to decrease negative affect, pain, anxiety and depression symptoms[12], as well as to modulate heart rate variability[14].

This study investigated the parameters of voice and HRV in meditation practitioners with different levels of previous experience before and after a single 20 minute meditation practice, and compared these findings with a control group of non-meditators. We hypothesized that (1) meditators would show improvements in the modulation of vocal parameters, heart rate variability and state anxiety after an acute meditation session when comparing to non-meditators; (2) within the meditation group, the greater degree of previous experience would favor a greater control of emotional experience after the meditation session.

Methods

Experimental design

This was a 3 x 2 factorial quasi-experimental study, in which three groups were evaluated (experienced meditators EM; novice meditators NM; and control group CG, who were not meditation practitioners) at two moments of the experimental manipulation (before vs after a meditation session for meditation practitioners, and before vs after a word search task session for the control group). The following outcomes were investigated before and after the intervention: acoustic voice parameters (f0, jitter, shimmer, harmonic-to-noise ratio (HNR), and the frequency of the first three formants (F1, F2 and F3) of the vowel [a]); heart rate variability (SDNNms, RMSSD, LF / HFms², SD1ms and SD2ms indices); levels of state anxiety; and voice self-perception.

Participants

The meditation group included individuals who practiced either focused attention (PA), open monitoring (MA) or reflexive meditation. These subjects should have a minimum experience of 6 weeks of meditation practice, considering that a previous study showed that an intervention of six weeks of meditation practice is already capable of improving control of emotional experience[12].

The control group was matched by gender, age and socioeconomic status, and included participants with no prior experience with meditation, Yoga and / or Tai Chi. Participants were not included if they: had previous diagnosis of psychiatric and/ or neurological diseases, aphasias or voice disorders; used psychiatric and/or neurological, and/or vascular, and/or pulmonary drugs; smoked; had a diagnosis of Chagas' disease, diabetes Mellitus and/or asthma; and/or had previous diagnosis of autonomic dysfunction. These data were verified in an interview, conducted before the data collection session.

The total sample included 55 participants, 46 of whom were meditation practitioners and 9 from the control group. The number of participants, especially from the control group, was reduced due to the Covid-19 pandemic. It was not feasible to continue recruiting participants and conducting the experiments in this context.

Meditators were classified as novices or experienced practitioners according to the number of hours of meditation practice throughout their lives. The median hours of meditation practice was calculated (Median = 500), and those who practiced meditation for less than 500 hours were characterized as novices, and those who practiced for 500 hours or more were characterized as experienced.

Intervention with acute meditation session or control task

Participants in the meditation group underwent a guided 20-minute meditation session. Participants were instructed to focus on their natural breathing (a focused attention meditation technique). They could be seated on a chair or on the floor (according to the participant's preference), keeping their spines erect and their eyes closed (supplementary material). The control group asked to perform a word search task, and instructed to remain silent for the same time as the meditation group (20 minutes). The word-search task was chosen as a paired attentional control task, in which participants hold the same posture, in silence and with no physical movements. By matching and controlling these characteristics we were able to verify whether possible changes in voice indices were exclusive to the meditation practice itself, and not due to confusing variables. The word-search task was guided and available on an A4 sheet, with the theme of Brazilian states and flower names.

Instruments

Screening

Sociodemographic questionnaires: to investigate individual variables, such as age, sex, education, health condition, use of medication, meditation experience, meditation technique, and previous experience with meditation/yoga/tai chi (for the control group).

Pre and post intervention assessment

State Anxiety Inventory (STAI)[14]: this scale indicates the current state of anxiety feelings; the Brazilian version showed a Cronbach's alpha of 0.89[15].

Voice parameters: The voice signal was captured using a Sennheiser e835 condenser microphone, with frequency response of 60 - 20,000Hz. The transmitter base of this microphone was connected to a Samsung Intel Core i5-7200U 7th Generation notebook with integrated sound card, with SoundAlive ™ HD (High Definition) Audio technology. Voice recording was performed in an acoustically treated room at a Radio Studio in the Journalism Center of Universidade Federal de Santa Catarina, Florianópolis, Brazil. Voice recordings were performed using Reaper v5.95 with a sampling frequency of 44100 Hz, and 16bit resolution, and saved in .wav format. Acoustic analysis was performed using the PRAAT software version 6.0.33[16]. The tasks for voice sample recording were performed immediately before the meditation practice (voice task 1) and immediately after the meditation practice (voice task 2) in both groups of meditation practitioners. The same procedure was used for the control group, who underwent the same recordings before and after completion of the 20-minute word search task.

Voice TASK 1 and TASK 2 consisted of the following procedures: the participant was asked to say their name and the date of the recording. Then, they were asked to talk for about two to three minutes about their activities and professional routine (in task 1) and about their hobbies (in task 2). Then, they performed three repetitions of the sustained vowel / a / for approximately five seconds, and then three repetitions of the vowel / a /. Finally, participants were asked to read the six vehicle phrases proposed in the Brazilian-Portuguese translated version of the Consensus Auditory-Perceptual Evaluation of Voice – CAPE-V[17] (2020) protocol. These phrases generate the stimuli that serve as basal voice control.

Heart rate variability (HRV): Polar® equipment, model S810i, was used for this measurement. To acquire the signal of the R-Rms intervals, the cardiac recording was performed by placing a water humidified polar cardiac strap on the participant's chest. HRV was recorded at rest prior to meditation (6 minutes), during meditation (21 minutes), and after meditation (6 minutes).

Voice self-perception: Participants were asked to evaluate their voice quality before and after each voice task on a scale from 0 (= bad) to 10 (= excellent).

Procedures and Data Registration

Each participant was individually evaluated in an acoustically treated room deemed appropriate for the recording of voice samples. Initially, the Anxiety State Inventory was completed. Next, the cardiac belt was placed on the participant's chest and the microphone was positioned at a 6 cm distance from the participant's lips. Voice task 1 (pre-intervention) was then started to record voice samples. After task 1, participants answered the voice self-assessment scale, after which they sat at their meditation position in order for the heart rate variability to be recorded at rest for 06 minutes (rest 1). For the control group, the same procedure was adopted. After recording rest 1, the meditation or the control task began. Immediately after the intervention session, rest 2 of the heart rate variability was recorded for 06 minutes. Then the participants performed the voice task 2 (post-intervention) to record new voice samples, which followed the same procedures as voice task 1. After the voice task 2, participants self-evaluated their voice qualities and, finally, completed the anxiety state questionnaire.

Treatment of physiological data

Short-term acoustic parameters were evaluated, such as fundamental frequency (f0) as well as frequency and amplitude disturbance (shimmer and jitter, respectively), the harmonic-noise ratio (HNR) and the first three formant frequencies (F1, F2, F3) of the vowel / a /.

The f0 was extracted from the vowel / a / in usual pitch, from a stable section of the sustained emission, containing at least 30 cycles to obtain the mean and standard deviation of the f0. The measurement was confirmed through visual inspection of the acoustic waveform, of the pulse determination by the software's automatic extractor and later by observing a spectrum obtained by Fast Fourier Transform (FFT) generated from an isolated point of the same waveform selection used for analyzing the other parameters. After confirmation of the f0, the jitter, shimmer and HNR were obtained through the automatic extractor and recorded in a spreadsheet for further analysis.

The first three formant frequencies of the vowel / a / were obtained by analyzing the voice samples derived from the CAPE-V protocol vehicle phrases. Vowels in tonic position were selected and tagged for analysis. Similarly to the extraction of f0, the selected vowel was analyzed through visual inspection of selected parameters as well as of a broadband spectrogram. An isolated point of the sound signal waveform was then selected so that the frequencies were generated by the automatic extractor. The formant frequencies were confirmed by analyzing the sound spectrum representing the same point.

The heart rate variability (HRV) was analyzed in the rest periods before and after the intervention of meditation or word search. The data were processed in Kubios HRV with reduction of medium artifact, removal of the trend components through the smooth prior's method (lick 500fc = 0.035hz), with RR interpolation of 4Hz, FFT spectral window of 2048 (s), 25% overlap window, 16 AR order model spectrum using factoring. HRV indicators were selected from the last 5 minutes of both baselines (rest 1 and rest 2). The following HRV parameters were analyzed: time domain (SDNNms, RMSSDms), frequency domain analysis (LF / HFms² ratio) and Poincaré analysis (SD1ms and SD2ms)[18].

Statistical Analysis

All data were organized and tabulated numerically in SPSS.20 (Statistical Package for Social Sciences). The distribution of variables measured at the interval level was analyzed using histograms and tested using the Kolmogorov-Smirnoff normality test.

Nonparametric tests were used, since the assumptions of normality and homogeneity of variances were not met due to sample sizes. The Friedman test was used to compare the outcomes between pre and post intervention in each group (experienced meditators, novice meditators and control group) for the following outcomes: voice parameters (F0, jitter, shimmer, PHR, F1, F2 and F3), heart rate variability parameters (RMSSD, SDNN, LF / HFms², SD1 and SD2), state anxiety and self-perception of the voice. Kendall's agreement coefficient was also used to calculate the effect size.

The Kruskall-Wallis test was used to compare groups (experienced meditators, novice meditators and control group) in each step separately, that is, only in the pre-intervention and only in the post-intervention stage, considering the voice variables (F0 , jitter, shimmer, HNR, F1, F2 and F3), heart rate variability (RMSSD, SDNN, LF / HFms², SD1 and SD2), state anxiety and voice self-perception. Subsequent comparisons by pairs of groups were performed using the Mann-Whitney test for the same variables.

In order to conduct Spearman's correlations, the voice, heart rate variability and state anxiety indices were first computed. For this purpose, pre-intervention variables were subtracted from the post-intervention variables. With this index created for each voice variable (F0, jitter, shimmer, HNR, F1, F2 and F3), heart rate variability (RMSSD, SDNN, LF / HFms², SD1 and SD2) and state anxiety, the following correlations were studied: voice indexes with heart rate variability indexes for the 3 groups; state anxiety index and voice self-perception for the three groups; the heart rate variability indices with the state anxiety and voice self-perception index in the three groups; voice indexes with practice time (meditators only); the variability indices correlated with the practice time (meditators only); For all analyses, a significance level of .05 and a 95% confidence interval were considered.

Ethical Aspects

This research was conducted according to the ethical parameters in accordance with CNS Resolution No. 510, of April 7, 2016, of the National Health Council and was approved by the Ethics Committee under number CAAE 02047618.5.0000.0121e registered in the UFSC SIGPEX system under number 201823182. All subjects signed the ''Free and Informed Consent Term'' and agreed to participate of this study.

Results

Sample characteristics

The groups were divided into experienced meditators (n = 24; 4 male and 20 female; mean age = 35.54 years, SD = 6.84), and novices (n = 22; 7 male and 15 female; mean age = 31.09 years, SD = 5.07), and control group (n = 9; 4 male and 5 female; mean age = 31.11 years old, SD = 8.38). The Kruskall-Wallis test showed that the groups did not significantly differ in terms of age [χ 2 (2) = 5.47, p = .06], and Fisher's exact test also showed no differences between groups for sex (Fisher = 3,008, p = .23), or years of education (Fisher = 8.73, p = .27).

Among meditators, the experienced group reported an average of 71.67 (SD = 57.09) months of practice, 22.46 (9.03) minutes per session, 6768.7 (SD = 9579.35) hours of practice during life, and 4.92 retreats (SD = 5.03). The novice group reported an average of 22.73 (SD = 13.81) months of practice, 20 (8.80) minutes per session, 148.86 (SD = 108.78.35) hours of practice during life, and 1.67 retreats (SD = 2.45).

Voice parameters

Table 1 shows the descriptive analysis of the voice parameters and Friedman's analysis for the fundamental frequency (f0), jitter, shimmer, harmonic-to-noise ratio (HNR) and the frequency of the formants (F1, F2 and F3) of the vowel [a], pre and post intervention. Kendall's coefficient of agreement was also used to calculate the effect size (which varies from 0 to 1, the higher the stronger the ratio).

Table 1. Friedman analysis for voice parameters

Groups	Measure	Descriptive statistics of voice parameters				Chi square	p	Kendall
		Pre-intervention		Post-intervention		X^2 (1)		
		M	SD	M	SD			
Experienced meditators (N = 24)	f0 (Hz)	175.44	34.60	172.78	32.94	.66	.41	.028
	Jitter (%)	.40	.21	.32	.11	.16	.68	.007
	Shimmer (%)	3.45	2.37	2.50	1.60	1.50	.22	.06
	HNR (dB)	21.30	4.01	21.51	3.10	.16	.68	.007
	F1 (Hz)	847.63	126.55	824.29	106.75	1.50	.22	.06
	F2 (Hz)	1.45	.11	1.42	.13	2.66	.10	.11
	F3 (Hz)	2.66	.22	2.72	.23	6.0	.01	.25
Novice meditators (N = 22)	f0 (Hz)	165.72	44.20	164.08	45.92	.18	.67	.008
	Jitter (%)	.37	.16	.30	.10	1.63	.20	.07
	Shimmer (%)	2.85	1.79	2.64	1.83	.72	.39	.03
	HNR (dB)	20.22	4.06	21.83	3.99	2.90	.08	.13
	F1 (Hz)	832.75	127.83	773.88	129.85	6.54	.01	.29
	F2 (Hz)	1,40	.13	1.34	.15	2.90	.08	.13
	F3 (Hz)	2.67	.16	2.62	.20	1.63	.20	.07
Control Group (N = 09)	f0 (Hz)	154.28	50.72	153.98	51.85	.11	.73	.01
	Jitter (%)	.48	.19	.46	.22	1.0	.31	.11
	Shimmer (%)	2.87	1.03	2.86	1.67	.11	.73	.01
	HNR (dB)	20.26	2.84	18.50	3.30	.11	.73	.01
	F1 (Hz)	804.18	132.01	764.14	147.52	5.44	.02	.60
	F2 (Hz)	1.43	.21	1.41	.16	.11	.73	.12
	F3 (Hz)	2.70	.22	2.73	.27	.11	.73	.01

Key. M = mean. SD = standard deviation. f0 = fundamental frequency; HNR = harmonic-to-noise ratio.

Table 2 presents the results of Kruskal-Wallis test for comparison of groups within each time. For the group of experienced meditators, the Friedman test showed that the F3 increased after meditation practice. The Kendall W test showed an impact of .25, indicating a strong difference between conditions. For the group of novice meditators, a decrease in F1 after meditation practice was observed. The Kendall W test showed an impact of .29, indicating a strong difference between conditions. The control group showed a decrease in F1 after the word search intervention. The Kendall W test showed an impact of .60, indicating a strong difference between conditions.

Table 2. Kruskal-Wallis analysis for voice parameters between groups for each time separately

Steps	Measure	Descriptive statistics of voice parameters between groups				Control Group (N = 09)		Chi Square U	
		Experienced meditators (N = 24)		Novice meditators (N = 22)					
		Mdn	SD	Mdn	SD	Mdn	SD	H (2)	P
Pre- intervention	f0 (Hz)	183.42	34.60	177.19	44.20	174.34	50.72	1.23	.54
	Jitter (%)	.35	.21	.34	.16	.48	.19	2.14	.34
	Shimmer (%)	2.68	2.37	2.54	1.79	2.77	1.03	.43	.80
	HNR (dB)	21.41	4.01	19.86	4.06	20.85	2.84	1.30	.52
	F1 (Hz)	873.93	126.55	860.99	127.83	744.46	132.01	.83	.66
	F2 (Hz)	1.45	.11	1.38	.13	1.33	.21	1.95	.37
	F3 (Hz)	2.67	.22	2.68	.16	2.77	.22	.36	.83
Post- intervention	f0 (Hz)	178.00	32.94	166.71	45.92	176.05	51.85	.54	.76
	Jitter (%)	.31	.11	.28	.10	.41	.22	.42	.12
	Shimmer (%)	2.00	1.60	2.53	1.83	2.24	1.67	.33	.80
	HNR (dB)	21.85	3.10	21.84	3.99	18.83	3.30	5.75	.05
	F1 (Hz)	825.01	106.75	785.38	129.85	737.87	147.52	2.47	.29
	F2 (Hz)	1.42	.13	1.32	.15	1.35	.16	3.78	.15
	F3 (Hz)	2.68	.23	2.62	.20	2.67	.27	1.51	.46

Key. Mdn= median. SD = standard deviation. f0=fundamental frequency; HNR=harmonic-to-noise ratio.

The Kruskal-Wallis test showed a significant difference between groups only in the post-intervention time in HNR (harmonic noise ratio). The Mann-Whitney pair test indicated that the difference in post-intervention HNR was significant between experienced meditators and the control group, being the HNR higher in experienced meditators (mean rank = 19.29) than in the control group (mean rank = 10.89). The Mann-Whitney test also showed a significant difference between novice meditators and the control group, with higher HNR for the novice meditators (mean rank = 18.23) compared to the control group (mean rank = 10.56).

Heart rate variability

Friedman analysis for heart rate variability indices comparing each group before and after the intervention showed no significant differences ($p > .05$).

Table 3 presents data for the Kruskal-Wallis analysis comparing groups for each time.

Table 3. Kruskal-Wallis analysis for heart rate variability between groups for each time separately

Steps	Measure	Descriptive statistics of heart rate variability between groups				Control Group (N = 09)		Chi Square U	
		Experienced meditators (N = 24)		Novice meditators (N = 22)					
		Mdn	SD	Mdn	SD	Mdn	SD	H (2)	P
Pre- intervention	SDNN (ms)	45.40	27.91	46.88	28.74	35.95	18.17	3.99	.13
	RMSSD (ms)	35.52	22.21	42.00	23.73	27.18	11.15	4.53	.10
	LF/HF (ms²)	1.84	6.47	1.93	4.38	1.72	2.45	.00	1.0
	SD1 (ms)	25.16	15.72	29.74	16.22	19.25	7.95	5.14	.07
	SD2 (ms)	59.62	37.01	58.30	38.28	45.67	24.81	2.92	.23
Post- intervention	SDNN (ms)	42.33	25.46	47.67	35.82	41.49	8.75	3.90	.14
	RMSSD (ms)	33.38	21.62	38.18	24.15	31.04	8.48	3.04	.21
	LF/HF (ms²)	1.70	2.62	2.32	4.46	2.08	1.54	1.05	.58
	SD1 (ms)	23.64	15.31	27.04	17.10	21.99	6.00	3.04	.21
	SD2 (ms)	53.36	33.04	63.37	48.47	54.43	11.30	3.40	.18

Key. SD= standard deviation; HRV= heart rate variability; SDNNms= Standard deviation of all normal RR intervals recorded in a time interval, expressed in ms; RMSSDms= HRV measurement index that represents the square root of the mean of the successive squared differences between adjacent R-Rs; ratio LF/HFms²= Relation between LF (low frequency) and HF (high frequency) components. SD1ms and SD2ms=short and long term Poincaré analyses, respectively.

There were no significant differences among the groups at any time. However, the Mann-Whitney test for comparing pairs was also performed, considering that the descriptive values suggest possible differences in heart rate variability between groups.

The Mann-Whitney pair test indicated a significant difference between experienced meditators and the control group in the RMSSD index during pre-intervention, with a higher RMSSD among experienced meditators (mean rank = 19.04) compared to controls (mean rank = 11.56). Experienced meditators and the control group also significantly differed on the SD1 pre-intervention index, with higher SD1 among experienced meditators (mean rank = 18.96) compared to controls (mean rank = 11.78).

The Mann-Whitney test also showed significant differences between novice meditators and the control group during pre-intervention: higher SDNN for novice meditators (mean rank = 18.09) compared to controls (mean rank = 10.89); higher RMSSD for novice meditators (mean rank = 18.00) compared to controls (mean rank = 11.11); and greater SD1 for novice meditators (mean rank = 18.27) compared to controls (mean rank = 10.44).

State anxiety

Table 4 shows the descriptive analysis of the sum of the total score of state anxiety and the non-parametric analyses by Friedman and Kendall.

Table 4. Friedman analysis for state anxiety comparing each group between pre and post intervention

Groups	Measure	Descriptive statistics of state anxiety				Chi Square	p	Kendall
		Pre-intervention		Post-intervention		X^2 (1)		
		M	SD	M	SD			
Experienced meditators (N = 24)	State anxiety	33.08	6.83	27.04	6.49	14.72	<.001	.61
Novice meditators (N = 22)	State anxiety	33.82	10.94	28.55	6.99	13.76	<.001	.62
Control group (N = 09)	State anxiety	39.00	9.01	35.56	6.61	4.5	.03	.50

The three groups decreased state anxiety after the intervention. The Kendall test indicated a strong difference between the pre and post intervention conditions for the three groups (experienced meditators Kendall = .61; novice meditators Kendall = .62; control group Kendall = .50).

Group comparison was also performed for each time separately with the Kruskal-Wallis test. A significant difference in state anxiety was found between groups only post-intervention, with a mean rank 23.63 for experienced meditators, 26.98 for novice meditators and 42.00 for the control group. Thus, the state anxiety was significantly lower for the meditation groups, compared to the control group, in the post-intervention.

Pairwise comparisons performed with the Mann-Whitney test showed a significant difference in state anxiety between experienced meditators and the control group only at post-intervention, with mean rank of 13.96 for experienced meditators, 25.11 for the control group, indicating greater state anxiety in the control group after intervention. Similar results were observed when comparing novice meditators (mean rank = 13.59) and the control group (mean rank = 21.89) only at post-intervention.

Voice self-perception

The Friedman test showed a difference in voice self-perception between pre and post intervention for the experienced meditators and for novice meditators as shown in table 5:

Table 5. Friedman analysis for voice self-perception comparing each group between times

Groups	Measure	Descriptive statistics of self-perception of voice				Chi Square	p	Kendall
		Pre-intervention		Post-intervention		X^2 (1)		
		M	SD	M	SD			
Experienced meditators (N = 24)	voice self perception	6.79	1.99	7.41	1.58	4.26	.03	.17
Novice Meditators (N = 22)	voice self perception	6.36	2.03	7.34	1.70	8.00	.005	.36
Control Group (N = 09)	voice self perception	7.61	1.11	7.58	1.65	.14	.70	.01

Key. M = mean. SD = standard deviation.

The results indicate that meditation participants perceived an improvement in vocal quality after meditative practice. The Kendall test indicated a strong difference between pre and post intervention conditions for both meditation groups (experienced meditators Kendall = .17; novices Kendall = .36). This difference between pre and post intervention was not found in the control group. The Kruskall-Wallis test showed no significant difference between groups.

Correlations

The results of Spearman's correlations for each proposed objective are presented:

- Voice rates with time of practice (meditators only); a significant correlation was found between the number of hours of meditation and F3 (r = .35, p = .01).
- Variability indices correlated with time of practice (meditators only): a significant correlation was found between the number of hours of meditation and SDNN (r =.-35, p = .01) and SD2 (r =.-35, p = .01).

Discussion

This study investigated voice parameters, heart rate variability, state anxiety and voice self-perception before and after a single 20-minute meditation intervention in two groups of meditators (experienced and beginners) and before and after a word-search task in a control group (non-meditators). Secondary outcome variables, such as positive and negative Affect and mindfulness skills, were also investigated, but in a cross-sectional manner. The three hypotheses presented in this study were confirmed for some of the voice variables (F1, F3, PHR), heart rate variability (RMSSD, SDNN, SD1, SD2), state anxiety, voice self-perception and secondary outcomes (affect and mindfulness skills).

Study limitations comprise the number of participants in all groups, especially in the control group. A limited number of subjects may have affected the comparison of findings, even though the statistical analyses should control for these differences. Another aspect is that we included meditators from different meditation modalities (focused attention, open monitoring and reflexive). Nonetheless, all participants from the experimental group were tested after performing the same guided and standardized focused attention technique. Another limitation of this study design was the lack of randomization and blinding. However, these two procedures could not have been carried out for the present investigation because participants in the experimental group were not naïve to meditation, whereas in the control group participants had no prior meditation experience; in addition, our objective was to compare experienced and novice practitioners and naïve subjects, which hindered the possibility of randomization. In addition, behavioral interventions, such as meditation, make it impossible to blind subjects to their condition.

Some variables that were not controlled during data collection procedures and that may also have influenced the physiological characteristics were: the time of data collection sessions (morning and afternoon); coffee consumption prior to the experiment; performing physical exercise prior to the experiment; the number of hours of sleep the previous night; women's menstrual cycle; the distribution of men and women in each group; and body mass index (BMI).

The two hypotheses presented in this study were partially confirmed for some of the voice parameters (F1, F3, HNR), heart rate variability parameters (RMSSD, SDNN, SD1, SD2), state anxiety, and self-perception of voice.

Vocal Parameters

Our results showed a significant increase in F3 after a meditation practice in the group of experienced meditators. The increase in the F3 parameter only in experienced meditators may indicate an effect of the amount of practice, since this change was not found in the novice meditators or in the control group. A study by Taylor et al.[19](2011) with experienced meditators and novice meditators also showed an effect of time of practice in an experiment that investigated the processing of emotional stimuli, indicating that greater experience in meditation leads to greater emotional stability and greater awareness of the present moment. Regarding our study, the potential effect of meditation experience on the modulation of F3 considers that this vocal parameter may be related to lip expansion and lowering of the larynx and can be associated with emotional expression. In other words, the increase in F3 after intervention in experienced meditators may have been related to a probable general "relaxation" of the muscles of the neck, tongue, shoulder girdle, which enlarge the vocal tract. This interpretation is corroborated by the increase in emotional stability in experienced meditators, observed in the reduction of anxiety and in the improvement of self-perception of vocal quality.

Importantly, only meditators reported improved self-perception of voice quality. Experienced meditators reported feeling greater vocal comfort and less tension during voice production after meditation. Two hypotheses may help explain this result: meditators presented an increase in the perceptual process of the voice, considering that the meditation expands the integration of internal (for example, proprioceptive) and external (for example, tactile, visual and auditory) information[20]; and/or the occurrence of a greater state of psycho-physiological relaxation, with an increase in vagal activity, as already demonstrated by other studies that also investigated the impact of a meditation session[13, 21], These hypotheses are in line with the Polyvagal Theory[22], which states that emotional experience is associated with multiple physiological states, influencing social behavior, facial and vocal expression.

We also found a decrease in F1 after a meditation practice in the group of novice meditators, as well as in the control group after a control task. The formant F1 is more related to the positioning of the tongue and the roundness of the lips, with an acoustic-articulatory characteristic[23]. The fact that the F1 parameter has decreased in the group of novice meditators and also in the control group after the intervention may indicate that remaining silent for the duration of the tasks may have caused the tongue to reposition inside the oral cavity - perhaps related to a relaxation state brought on by voice rest when people were not speaking. In this case, it is unlikely that the change in F1 was caused by the practice of meditation in novices, but it may have been associated with the period of rest/silence. Vocal rest favors muscle recovery after long periods of speech.

Aoki, Santos, and Brasolotto[24] (2020) proposed a guide that presents strategies and actions that contribute to the vocal health of teachers (Teacher's Vocal Health Guide). Among these actions, the authors suggest the importance of silence as a strategy for vocal cool-down and voice recovery in communication. The accumulation of vocal rest greater than 3.16 seconds can benefit the recovery of vocal fatigue by relaxing vocal muscles, while smaller accumulations of silence may suggest an inadequate redistribution of fluids in the tissue of the vocal folds[25]. Other studies involving singers showed that vocal relaxation techniques used for cool down are favorable for stretching the muscles of the larynx, influencing the improvement and precision of vocal tone production and reduced perceived phonation effort, with benefits perceived 12-24 hours later[26, 27].

Regarding the comparison of groups, results of paired comparisons (experienced meditators vs control group; novice meditators vs control group; experienced meditators vs novice meditators) showed an increase in HNR after the intervention for experienced meditators and novice meditators relative to the control group.

The higher HNR after intervention for meditators stands out, as it is a parameter more directly related to emotional expression in the voice[28]. The HNR is characterized by the relative amplitudes of the periodic vibratory glottic excitation and the aperiodic noise component of the excitation. This means that the HNR parameter indicates that the more harmonics and less noise the signal has, the greater the regularity, symmetry and vibratory harmony of the vocal fold. For example, when the voice sounds breathy and hoarse, the HNR is lower. The higher the HNR, the clearer the voice. For instance, expressions of joy are associated with a high level of disturbance (increased HNR), while low tones are related to decreased HNR[28].Thus, meditation may have influenced the rebalancing of the vocal fold vibration considering the increase in HNR in experienced meditators and novices compared to the control group. This indicates more muscular control, symmetry of the mucosa wave and the regularity of vibration, that is, a more harmonious voice and suggestive of greater emotional regulation.

According to Hakanpää et al.[28](2019), the increase in HNR is related to a clearer voice quality and more formants may be detected. However, it is important to highlight that this parameter is not related as a cause and effect with the formants (F1, F2, F3). HNR and formants are phenomena with different processes, but in a vocal analysis they complement each other in order to characterize the emotional expression in the voice. What we observed in this study is that HNR and F3 showed effects associated with relaxation, which might be related to a change in arousal since a greater decrease in state anxiety was also found in experienced and novice meditators compared to the control group.

However, despite the fact that the decrease in state anxiety was greater for meditators and that meditators had significantly lower levels of state anxiety at post-intervention, the control group also decreased state anxiety after intervention. This can be related to the fact that they were at rest and had completed the experiment (that is, were no longer in an evaluative situation), or that they have actually produced a state of relaxation associated with the task performed.

Based on the Polyvagal Theory Theory[22], we hypothesized that interventions that improve emotional regulation (such as meditation) may influence the increase in vagal activity of the autonomic nervous system, improve spontaneous social behavior and improve vocal communication (improvement of vocal quality and increase in prosody). This is because interventions that foster emotional regulation influence neuroception, mediating defensive circuits for the expression or interruption of behavior, and modulating the different forms of expression of emotions and visceral homeostasis[22].

Heart Rate Variability

The practice of meditation is associated with positive emotional regulation and the modulation of autonomous activity[21]. Therefore, changes in heart rate variability before and after a meditation session and in comparison to the control group were expected. Our results were not significant with regard to the change in heart rate variability before and after the meditation practice. Therefore, hypothesis (1) for heart rate variability has not been confirmed. From this result we can infer some explanations: the intervention should have been longer; the sample size was not sufficient. Other studies[29] have pointed out changes in heart rate variability after an acute meditation session, reflecting the increased parasympathetic action of the autonomic nervous system.

However, the values of the heart rate variability parameters were already higher at pre-intervention among meditators. This result was verified in the group comparisons, which indicated that experienced meditators had higher RMSSDms and greater SD1ms than the control group at pre-intervention. These higher values indicate greater parasympathetic activity at rest. The group of novice meditators also showed greater SDNNms, RMSSDms and SD1ms than the control group at pre-intervention, also indicanting greater parasympathetic activity in the resting state. Therefore, meditators showed greater parasympathetic activity at baseline, relative to controls, and perhaps that is why they did not produce significant changes after intervention. It may be hypothesized that meditation practitioners, due to their experience and continued practice, sustain more adaptive levels of variability, even at baseline levels.

Indeed, the regular practice of meditation can favor baseline levels of heart rate variability, which can decrease the prevalence of diseases. One study[30] analyzed data from the 2012 and 2017 National Health Interview Survey in the United States. The researchers collected data from 61,267 patients with hypercholesterolemia, systemic hypertension, diabetes mellitus, stroke and coronary artery disease, and from people who reported practicing meditation (n = 5,851), in order to analyze the association of meditation and the prevalence of cardiovascular risk. Confounding variables were adjusted and the results showed that meditation was associated with a lower prevalence of these clinical conditions.

The American Heart Association’s Scientific Statement (2017) on meditation and cardiovascular risk indicated the practice of meditation as a beneficial tool for the prevention of cardiovascular disease[30]. This is because regular meditation practice has shown lasting effects on emotional, behavioral and physiological patterns.

Finally, we partially confirmed the hypothesis of this study, in which we predicted that the degree of experience in meditative practice can favor a greater modulation of emotional reactivity. Within the meditation group, we observed a correlation between the amount of meditation practice with the F3 index and with the SDNN and SD2 indices. That is, the longer the experience with meditation practice, the greater the change between pre- and post-intervention in the F3 index of the voice, as well as in the SDNN and SD2 indices of heart rate variability. This finding is supported by the Polyvagal Theory[22], and suggests meditation practice can increase the parasympathetic activity of the autonomic nervous system (SDNN) and the sympathetic-vagal balance (SD2), and this is related to the increase in “relaxation” of the muscles of the neck, tongue, shoulder girdle, expanding the vocal tract (F3).

Conclusion

We observed that the voice can be an indication of emotional expression, through the possible relaxation of the vocal tract and vocal folds associated with meditation intervention in meditation practitioners. The results of HRV indices indicated that the practice of continued meditation may help practitioners to regulate, perhaps more permanently, their parasympathetic activity of the autonomic nervous system. Understanding these phenomena enable the development of techniques and interventions capable of acting in the management of speech-related disorders, especially from an emotional point of view, and in improving the detection of emotional states through physiological parameters.

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