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Performance in the Stroop Task and Simultaneously Recorded Heart Rate Variability before and after Meditation, Supine Rest and No -Intervention

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Abstract In an earlier study heart rate variability (HRV) recordings after cyclic meditation (CM) suggested a shift towards vagal dominance. In a separate study, CM improved the performance in a task for attention. Generally, attention tasks result in sympathetic activation. The present study was intended to assess whether CM would change the autonomic status when practitioners performed an attention task, with simultaneous HRV recording Methods: Twenty-five male volunteers with group average age ± S.D., 23.9 ± 5.0 years were each assessed on three separate days in three sessions, (i) CM, (ii) supine rest (S R), and (iii) quiet sitting (QS). Each session was for 23 minutes. Simultaneous assessments were made before and after each of the three sessions and included the HRV, respiratory rate and performance in the Stroop task. Results: Following CM the LF power increased and HF power decreased ($P < 0.05$). There was an increase in the word scores, color scores and color-word scores of the Stroop task ($P < 0.001$, Repeated measures ANOVA, followed by Bonferroni adjusted post-hoc analyses). Conclusion: The results suggest that there was reduced parasympathetic activity after CM and possibly increased sympathetic activity, when participants simultaneously performed the Stroop task. Their improved performance in the Stroop task suggests better response inhibition, interference resolution, word reading and activation along with reduced physiological arousal based on HF power of the HRV.

Keywords Stroop, HRV, Yoga

1. Background

Meditation has been described as a state of consciousness in which deep relaxation and increased internalized attention co-exist [1]. Meditation is not always easy for novices to practice, and in yoga texts meditation has been described as the seventh of eight stages required to reach ultimate mental transcendence, called Samadhi, in Sanskrit [2]. A meditation technique called CM, which has its' origin in ancient yoga texts [3, 4], was derived especially for novices. CM has alternating cycles of practicing yoga postures slowly, with deep awareness, interspersed with periods of SR. CM differs from other meditation techniques as it includes the practice of yoga postures practiced slowly with heightened internal awareness. Tai-Chi-Qui-Gong is a comparable technique and these practices have been called 'moving meditations' [5].

Despite the fact that CM includes the practice of yoga postures, following twenty-three minutes of the practice there was a reduction in heart rate, as well as in the low frequency power of the HRV, while the HF power increased, suggesting a shift in cardiac autonomic balance towards vagal dominance after the practice (Cohen's d = 0.87) [6]. The LF band of the HRV is believed to be chiefly but not entirely related to sympathetic activity when expressed in normalized units [7], while efferent vagal activity mainly contributes to the HF band [8].

Sympathetic activation is of interest in the present study since it is associated with increased vigilance and hence may be considered essential for performing an attentional task [9]. An early study showed improvement in different aspects of attention in practitioners of Transcendental Meditation [10].

More recently studies on practitioners of CM have shown improved performance in tasks requiring attention and other executive functions. In forty-two experienced meditators the P300 was measured before and after a session of CM on one day, and similarly before and after a comparable duration of SR on another day (Cohen's d = 0.85) [11]. The P300 is an event related potential which reflects fundamental cognitive events requiring attentional and immediate memory-processes [12]. Following CM there was a decrease in the P300 peak latency and an increase in the P300 peak amplitude suggesting a greater improvement in cognitive processes after CM compared to SR [11].

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Similarly the performance in a cancellation task was assessed in sixty- nine volunteers immediately before and after sessions of CM and SR on separate days [13]. Cancellation tasks assess attention, concentration, and visuo-spatial scanning abilities [14]. The net scores improved after both CM (by 24.9 percent) and SR (by 13.6 percent). These results also suggested that CM favorably impacts attention, concentration, visual scanning abilities and a repetitive motor response. It was speculated that the improvement in attention in these studies was related to a reduction in anxiety, as anxiety affects performance in tasks requiring attention [15].

However, as already mentioned attention is generally associated with increased sympathetic activity [16], which normally decreases when anxiety levels are low [17]. The association between HRV and trait anxiety was assessed in 92 healthy persons along with self- rating of trait anxiety and perceived emotional stress [18]. In an earlier study on healthy participants there was a shift towards vagal dominance in the HRV after CM [6]. Till now, the HRV has not been recorded in meditators in the same session as the attention task. Hence the present study was designed to record the HRV and respiratory rate before and after the Stroop task, in the same session [19]. The hypothesis being tested was that CM would improve Stroop task performance while reducing sympathetic activity.

2. Methods

Participants

There were twenty- five self-reported healthy male participants with ages ranging between 18 and 38 years (group mean ± S.D., 23.9 ± 5.0 years). The participants did not report any history of hospitalization or medication in the past six months. The temperature and blood pressure of the subjects were normal on the days of their participation in the study. The sample size was not determined prior to designing the study. However post-hoc analyses based on the effect size showed that the power of the tests used was 0.95 [20]. Participants were staying at a residential yoga c enter located in south India. For inclusion in the study participants had to meet the following criteria: (i) they had to be healthy based on a standard medical examination, (ii) literate and able to understand and perform the Stroop task, and (iii) have adequate experience of both CM and relaxation while supine i.e., 3 to 6 months. Exclusion criteria included: (i) color blindness based on the Ishihara charts, (ii) consumption of caffeine, nicotine containing substance s or any medicine which could influence cognition or autonomic function, and (iii) presence of extra systoles in the EKG. Participants were recruited by flyers on the notice board of the institution. The method of the study was explained to the participants, but not the hypothesis. No incentive was given to the participants for participation in the study. None of the participants was involved in any other ongoing yoga research at the center.

Design

Every participant was assessed in three types of practice sessions (CM, S R and QS sessions). The assessments were made on three different days for every participant. The sequence of practice was randomly allocated to balance the effect of the order of the sessions. The study design was explained to the participants and their signed informed consent was obtained. The study had the approval of the institutional ethics committee.

Time allocation within the sessions

The Stroop task, HRV and respiratory rate were measured 'before' and 'after' the interventions. The first 5 minutes of the 'before' period was in the sitting position, followed by 23 minutes of the 'd uring' period, where participants were given (i) CM practice using taped instructions, or (ii) SR in the corpse posture (= *shavasana*, in Sanskrit) without instructions or (iii) in the QS session participants were seated at ease. This was followed by 5 minutes of the 'after' period. In (i) 'd uring' periods of S R and QS session and (ii) 'before' and 'after' periods of all 3 sessions the participants were not given any specific instructions. The study design and assessment schedule are given schematically in Figure 1.

Assessments

The twenty-five participants were assessed before and after three types of sessions, (i) CM, (ii) SR, and (iii) QS. Assessments were made in a dimly lit, sound attenuated room (sound level 26 dB) with ambient temperature 24±2℃ while being observed throughout on a closed circuit television. The HRV and respiratory rate were recorded for 5 minutes using the Standard Limb Lead II configuration and volumetric pressure transducer respectively. The recordings were made immediately before the Stroop task prior to the intervention and after the Stroop task on completion of the intervention. There were no differences in results based on the order of the sessions, when the 'after' values were compared ($P > 0.05$, t-test for unpaired data).

Heart rate variability and Respiratory rate

HRV and respiratory rate were assessed using a MP100 BIOPAC data acquisition system (BIOPAC S ystems, Inc., U.S. A.). The EKG was recorded using Ag/AgC l pre-gelled electrodes. The recording was made with a standard limb Lead II configuration and an AC amplifier with 1.5 Hz low cut filter and 99 Hz high cut filter settings. The data were acquired at the sampling rate of 1024 Hz. Respiratory rate was recorded with a volumetric pressure transducer fixed around the trunk about 8 cm below the lower costal margin when the participants sat erect.

Stroop Task

The Stroop task consisted of a worksheet of 3 pages, each page having 100 items printed as 20 rows and 5 columns arranged randomly over a 8.5" 11" white sheet. The task used three colors, viz., b lue, green, and red. There were the standard Word page, Color page and Color- Word page. Instructions given were based on the Stroop task manual [21].

The participants were instructed to read the words, name the colors, and finally, name the color of the ink printed words which did not match, as quickly and as accurately as possible in the three tasks within 90 seconds for the complete task. All tasks were conducted and scored by a person who was unaware whether the participant was in a (i) CM or (ii) S R or (iii) QS session.

Inte rvention

Cyclic meditation session (CM)

During CM practice, participants kept their eyes closed and followed pre-recorded instructions. The instructions emphasized carrying out the practice slowly, with awareness and relaxation. The practice began by repeating a verse (0:40 min) from the yoga text, the *Mandukya Upanishad* [4]; followed by isometric contraction of the muscles of the body ending with supine rest (1:00 min.); slowly coming up from the supine position and standing at ease (called tadasana) and 'balancing' the weight on both feet, called centering (2:00 min.); then the first actual posture, bending to the right (*ardhakaticakrasana*, 1:20 min.); with 1:10 min. in *tadasana* for instructions about relaxation and awareness; bending to the left (*ardhakaticakrasana*, 1:20 min.); 1:10 min. as before; forward bending (*padahastasana*, 1:20 min.); another 1:10 min.; backward bending (*ardhacakrasana*, 1:20 min.); and slowly coming down to the supine position with instructions to relax different parts of the body in sequence (10:30 min.). The postures were practiced slowly, with awareness of all the sensations experienced. The total duration of the practice was 23 min. [6].

Supine rest session (SR)

SR was practiced as traditional *shavasana* (the corpse posture), which meant lying supine, with the legs apart, and arms away from the sides of the body, with the palms facing upwards, while the eyes were closed [22]. This practice lasted 23 min., so that the duration was the same as for CM. Participants were not given any instructions.

Quiet sitting session (QS)

Subjects were seated at ease and their thoughts were allowed to wander at random. They were not given any specific instructions except for the fact that they were told that they were to avoid meditating. The session was also at the same time of the day as the CM and SR sessions.

Thus in the present study, comparing the effects of practicing CM, SR and a QS session in the same subjects on separate days reduce d the possibility of bias. F urther, the order of the sessions (CM, S R and QS) was randomized to eliminate the effect of the order of sessions influencing the results.

Data extraction

Heart rate variability and Respiration

The frequency domain and time domain analys es of HRV data were carried out for 5 minute recordings for each of the following sessions CM, SR and QS. These 5 minutes epochs were recorded before and after each intervention. The data recorded were visually inspected off- line and only noise free data were included for analysis. None of the data had to be excluded due to noise. The heart rate was obtained based on R-R inter-beat interval analysis. The HRV power spectrum was obta ined using Fast Fourier transform analysis (FF T). The data were analyzed with an HRV analysis program developed by the Biosignal Analysis and Medical Imaging Group, University of Eastern F inland, Kuopio, F inland [23]. The energy in the HRV series in the following specific frequency bands was studied viz., the VLF band (0.0 - 0.04 Hz), LF band (0.04 - 0.15 Hz) and HF band (0.15 - 0.4 Hz). The LF and HF band values were expressed as normalized units. The following components of time domain HRV were analyzed: (i) mean RR interval (the mean of the intervals between adjacent QRS complexes or the instantaneous heart rate), (ii) RMSSD (root mean square of successive differences), (iii) NN50 (the number of interval differences of successive NN intervals greater than 50 ms), and (iv) pNN50 (the proportion of NN50 divided by total number of NN intervals). Mean respiratory rate was calculated before and after the sessions.

Stroop Task

As per the manual the correct responses were scored as '1' depending on the response of the participant and if the responses were incorrect it was scored as '0' [21]. Hence, the outcome measures were color scores, word scores, and color-word scores.

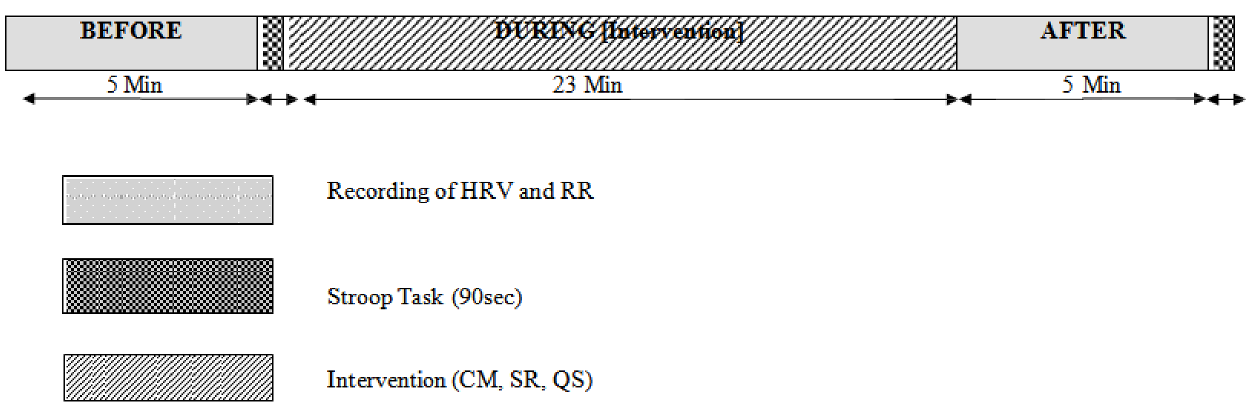

Figure 1. Schematic representation of the design of the study and assessment schedule

Table 1. Group mean values ± S.D. of Frequency domain, Time domain analyses of the HRV and Respiratory rate recorded before and after, sessions of Cyclic Meditation (CM), Supine Rest (SR) and Quiet Sitting (QS)

Frequency domain analysis of the HRV						
Sessions	**CM**		**SR**		**QS**	
	Before	**After**	**Before**	**After**	**Before**	**After**
VLF (ms^2)	26.82±12.38	29.59±17.85	29.56±18.97	28.22±14.12	32.53±15.74	32.32±17.33
LF (nu)	55.67±17.55	63.75±19.82*	61.50±22.21	64.78±16.89	58.98±22.88	63.19±18.14
HF (nu)	44.33±17.55	36.25±19.82*	38.50±22.21	35.22±16.89	41.02±22.88	36.81±18.14
LF/HF (ratio)	1.74±1.50	4.93±9.85	3.25±3.76	3.90±7.07	3.07±4.02	3.31±5.29
Time Domain analysis of the HRV spectrum						
Sessions	**CM**		**SR**		**QS**	
	Before	**After**	**Before**	**After**	**Before**	**After**
Mean RR (cpm)	806.55±104.73	800.54±124.69	794.70±105.99	811.78±98.72	781.80±114.57	795.28±84.57
Mean HR (bpm)	76.13±10.45	77.07±11.03	77.22±10.50	75.43±8.90	78.78±11.54	76.73±8.15
RMSSD (ms)	46.00±21.22	48.13±30.34	41.07±19.35	45.59±18.20	42.20±19.54	41.30±18.60
NN50 (count)	85.52±56.74	77.68±52.32	71.12±58.29	72.92±51.41	72.96±58.56	70.40±63.75
pNN50 (%)	24.44±17.76	22.40±17.45	20.48±18.71	20.94±16.70	20.92±18.71	20.23±19.51
Respiratory Rate						
	CM		**SR**		**QS**	
	Before	**After**	**Before**	**After**	**Before**	**After**
Respiratory rate (breaths/min)	17.60±0.81	17.45±0.59	17.30±0.65	17.52±0.76	17.46±0.81	17.31±0.54

$^{*}p < 0.05$ Repeated Measures ANOVA, with Bonferroni adjustment, before compared with after for the respective sessions

Table 2. Group mean values ± S.D. for the Stroop Task recorded before and after sessions of Cyclic Meditation (CM), Supine Rest (SR), and Quiet Sitting (QS)

Sessions	**CM**		**SR**		**QS**	
	Before	**After**	**Before**	**After**	**Before**	**After**
Word Task [W]	99.68±23.75	108.20±23.11 ***	103.44±22.51	109.60±19.00*	105.24±17.69	110.24±16.96*
Color Task [C]	65.32±14.22	73.60±11.73***	71.44±9.84	72.52±8.77	69.96±8.95	74.88±11.47**
Color – Word Task [CW]	77.96±26.63	84.68±27.78***	81.04±27.05	84.24±28.96	81.88±25.11	83.84±23.98

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, RM ANOVA, with Bonferroni adjustment, before compared with after for the respective sessions

Data analysis

Statistical analysis was done using P ASW (Version 18.0). Repeated measures analyses of variance (ANOVA) were performed with two 'within subjects' factors, i.e., Factor 1: Sessions; CM, SR and QS and Factor 2: States; 'before', and 'after'. This was followed by a *post-hoc* analysis with Bonferroni adjustment for multiple comparisons between the mean values of different states, and after- values were compared to the respective 'before' values. Data recorded in the before states of CM, S R, and QS sessions were compared for baseline differences with a one-way ANOVA.

3. Results

The group means and standard deviations for scores obtained in the HRV and respiratory rate are shown in **Table 1**, Stroop task [i.e., word task, color task, and color-word task scores] taken before and after CM, S R, and QS sessions are shown in **Table 2**.

Repeated measures analyses of variance

Heart Rate Variability

Frequency domain analysis of the HRV spectrum

The repeated- measures analyses of variance (ANOVA) showed a significant difference between States ($F = 5.75$, $df = 1, 24$, Huynh-Feldt epsilon = 1, $P < 0.05$) for LF and HF. For VLF, LF, HF, and LF/HF, there were no significant differences between Sessions, or interaction between Sessions and S tates.

Time domain analysis of the HRV spectrum

There were no significant differences between Sessions, States or their interaction for mean RR, mean HR, RMSSD, NN50 and pNN50.

Respiratory Rate

For the respiratory rate there were no significant differences between Sessions, S tates or their interaction.

Stroop Task

The repeated- measures analyses of variance (ANOVA) of Stroop task scores showed a significant difference between (i) Sessions [for word scores, color scores and color-word scores] ($F = 24.67$, $df = 2.26, 54.26$, Huynh-Feldt epsilon = 0.28, $P < 0.001$) and (ii) S tates [Pre and Post] ($F= 44.97$, $df = 1, 24$, Huynh-Feldt epsilon = 1, $P < 0.001$). The interaction between Sessions and S tates was not significant for word scores, color scores or color-word scores.

Post-hoc analyses

Heart Rate Variability

Frequency domain analysis of the HRV spectrum

Post-hoc tests for multiple comparisons were performed with Bonferroni adjustment and all comparisons were made with the respective before states. After the Cyclic Meditation session, there was a significant increase in LF power ($P < 0.05$) and a decrease in HF power ($P < 0.05$). There were no significant differences after both supine rest and quiet sitting sessions.

Time domain analysis of the HRV spectrum

There was no significant difference between Sessions, States or their interaction for mean RR, mean HR, RMSSD, NN50 and pNN50, hence no further *post-hoc* analyses were performed.

Respiratory Rate

For the respiratory rate there were no significant differences between Sessions, S tates or their interaction, hence no further *post-hoc* analyses were performed.

Stroop Task

Post-hoc tests for multiple comparisons were performed with Bonferroni adjustment and all comparisons were made with the respective before states. After the CM session there was a significant increase in the word scores of the S troop task (P < 0.001), color scores ($P < 0.001$) and color-word scores ($P < 0.001$), compared to values of the before state. Also, after SR sessions there was a significant increase in word scores ($P < 0.05$) and after the QS session there was an increase in word scores ($P < 0.05$) and color scores ($P < 0.01$).

4. Discussion

Participants performed better in the Stroop task with increased color-word scores after CM but not after SR or QS. However the better performance was accompanied by an increased power in the LF component of the HRV, with a decrease in the HF component.

As already mentioned in the introduction the LF band of the HRV is believed to be chiefly but not exclusively due to sympathetic activity when expressed in normalized units [7], while efferent vagal activity contributes mainly to the HF band of the HRV [8]. The breath rate did not change after either of the interventions. This is relevant as it is known that there is an acute increase in LF, total spectrum HRV and in vagal baroreflex gain during slow breathing [24]. Training to increase the amplitude of respiratory sinus arrhythmia maximally increases the amplitude of heart rate oscillations at approximately 0.1 Hz [25]. However, considering that breath rate did not change in the present study, the breath frequency could not have influ enced the HRV. Hence the results suggest that after CM there was a shift in the autonomic balance towards parasympathetic decrease with a possible increase in sympathetic activity. As was already mentioned sympathetic activation is associated with increased vigilance considered necessary to perform an attentional task [6].

In an earlier study the LF band of the HRV reduced after CM, while the HF power increased [6]. However there were the following differences between that study and the present one: (i) in the earlier study participants were asked to practice CM and SR on two different days and the HRV and respiration were recorded. They were not given any task. In the present study participants were given the Stroop task to perform before and after the prac tice of CM or SR or QS, and the HRV and the respiration were recorded after the task. Hence, the earlier studies assessed practitioners of CM when they were doing the meditation without any task. The present results suggest that when given a task the physiologically relaxing effects of CM were not sufficient to reduce the sympathetic arousal associated with vigilance and performance of a task requiring attention in addition to other cognitive processes.

The absence of change in time domain measures which generally reflect parasympathetic tone, may be explained as follows: the sympathovagal balance is tonically and phasically modulated by at least three main factors, (i) central neural integration, (ii) peripheral inhibitory reflex mechanisms, and (iii) peripheral excitatory reflex mechanisms [26, 27]. While, variable phenomena such as the heart rate (recorded as the HRV) can be described as a function of time they may be better described as the sum of elementary oscillatory components [28]. Hence, the frequency domain may reflect those changes in the sympathovagal balance which are not detected by time domain analysis.

The S troop task requires the participant to suppress a habitual response and respond to an unusual one, in this case naming the color of the ink in which incongruously named color-words were printed [29]. The cognitive processes required to perform the Stroop task are complex. They include response inhibition, interference resolution, behavioral conflict resolution, word reading and production, and visual attention [30]. The present results suggest a possible benefit of practicing CM to improve abilities required to perform the Stroop task. Participants did not have any additional benefit of reduced sympathetic activation after performing CM and while doing the Stroop task. These results resemble those of a recent study in which Vipassana expert meditators showed greater P3b amplitudes to the target tones after meditation than they did both before meditation and after the no- meditation sessio n. They also simultaneously showed a larger LF/HF ratio during Vipassana meditation [31]. Hence Vipassana meditation was associated with better P3 potentials (suggestive of improved attention) along with increased sympathetic activity.

The limitations of the study are as follows: (i) in earlier studies [13, 32] the tasks used to assess performance before and after CM were different from the Stroop task used in the present study. The reason for this difference is that the participants in the present study had taken part in other studies in the residential yoga institution which used the tasks which were previously assessed. Hence, they would have approached the earlier tasks with a certain degree of familiarity and monotony. However in introducing a new task the results of the previous studies cannot be directly compared with the present results. (ii) All twenty- five participants were assessed in three types of sessions. Even though the order of the sessions was randomized the participants might have performed better after CM not merely because of the effects of CM per se, but because the CM session kept them busy and engaged while the other sessions did not. (iii) The sample size (n=25) in the present study was smaller than the sample sizes in the previous studies o n cancellation task performance (n=47), memory task performance (n=57) and HRV and respiration (n=47).

Despite these limitations the present results showed that when participants were given a task to perform following meditation, their perfor mance in the task which required focused attention was better, however there was also a shift in the autonomic balance towards decreased parasympathetic activity and possibly increased sympathetic activity.

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