A Preliminary Analysis on the Autonomic Nervous System Activities during Meditation by a Yoga Expert

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Abstract

Yoga is a traditional form of contemplative practice originated in the ancient India, and aims for improvement of both physical and mental control through multiple practices including asanas (sitting postures), pranayama (breathing techniques), and meditation. Empirical studies on yoga have suggested benefits of continued yoga practice at both psychological and physiological levels. The present study examined autonomic nervous activities while an advanced Japanese yoga expert engaged in 4-minute meditations on different themes, including focused attention on one's own breath and internally repeating a "mantra of love." Cardiovascular activities (photoplethysmogram) and skin conductance during meditation were measured by using a multisensor measurement system NeXus-4. Compared with attending to the breath, "mantra of love" meditation yielded significantly different physiological outcomes including less increase in heart rate, less decrease in time-domain heart rate variability, and less decrease in skin conductance. These results seem consistent with the expert's self-report that "mantra of love" meditation is associated with a calm and stable mental state rather than a dynamic or emotionally-driven state, and may suggest relatively decreased activity of not only sympathetic but also parasympathetic nervous system during "mantra of love" meditation as compared with attending to the breath. Such physiological states during everyday practice may be closely associated with the increased self-reported mindfulness and subjective well-being in long-term yoga practitioners. Limitations of the study design and potential technical improvements in future are discussed.

Keywords: yoga (ヨーガ), meditation (瞑想), autonomic nervous system activity (自律神経活動), breath (呼吸), mantra of love (愛のマントラ)

1. Introduction

There has been good empirical evidence during the past decades suggesting that contemplative practices in the Eastern traditions can cause desirable changes to the psychological and physiological status (for an overview see Goyal et al., 2014; Lutz et al., 2008). Mindfulness-based interventions including mindfulness-based stress reduction (MBSR) and mindfulness-based cognitive therapy (MBCT) programs that incorporate bodyscan, sitting meditation, and other contemplative techniques have also been effectively applied to patients with chronic pain and depression in order to reduce stress and to prevent relapse of mental disorders (Kabat-Zinn, 1990; Segal et al., 2002). In recent years, these mindfulness-based interventions have markedly helped to make contemplative practices gain popularity among people in general in addition to clinical populations and populations of traditional practitioners.

Yoga is one form of the contemplative practices that are becoming increasingly popular in all parts of the world (Balasubramaniam et al., 2013). Originated in the ancient India, yoga involves a wide variety of practices including asana (body postures), pranayama (breathing technique), and meditation (Javnbakht et al., 2009), in an attempt to heighten sophisticated control over one's mind and body. Empirical studies have suggested benefits of yoga practice on both physical and mental health in both healthy and clinical populations by enhancing control over the autonomic nervous functions. For example, Telles et al. (2013) reported that an effortless meditation in yoga that does not require focused attention (*dhyana*) elicited decrease in heart rate and breathing rate, suggesting reduced sympathetic activities. Among the Japanese population, Kato et al. (2013) measured the levels of amylase activity and showed that yoga therapy is effective in reducing stress for people with a high level of stress at workplace. Miyata et al. (2015) involved Japanese yoga practitioners whose practice period ranged from 0.3 to 34.0 years and showed that period and amount of practice predicts increase in self-reported mindfulness, well-being, positive affectivity, and empathy, and reduced depression and negative affectivity.

One question that has yet to be addressed in this literature is whether and how different styles of yoga meditation can cause different physiological outcomes in the same practitioner. That is, yoga meditation involves meditation on various themes that are usually combined during the actual practice in order to attain higher stages of expertise. For example, a most basic way of yoga meditation is to simply concentrate one's attention on one's own breath. By contrast, mantra meditation involves either overtly or covertly repeating typical short phrases (mantras) such as *Om Namah Shivaya*, which have traditionally been believed to have a psychological and spiritual power (Engström et al., 2010; Goyal et al., 2014). It is thus a challenge to examine how these different styles of meditation would be associated with differentiated autonomic nervous system activities in each expert to achieve higher self-control skills. In addition, it is of necessity to accumulate data on higher experts on contemplative practices in Japan, on whom empirical enquiries have been relatively scarce (Miyata et al., 2015). These data at the physiological level should help to understand the underlying mechanisms that result in relatively high self-reported scores of well-being in Japanese long-term yoga practitioners, despite the fact that scores of well-being in Japanese people are lower than those in many Western countries (OECD Publishing, 2011).

The present study included a high-level Japanese yoga expert and compared two different styles of sitting meditation, a basic focused attention on the breath and "mantra of love" meditation. "Mantra of love" meditation refers to one form of the mantra meditation in which the meditator continuously repeats a phrase "I love..." either aloud or silently throughout the period, while intending that the meditator and the mantra phase would become as one unity (e.g., Engström & Söderfeldt, 2010). The present study used a case study approach, considering the limited number of advanced Japanese contemplative experts and the possibility that each advanced expert may have his/her own specialized style of meditation by which s/he can best demonstrate his/her expertise. Specifically, the expert participating in this study stated that "mantra of love" usually elicits a calm and stable mental state while concentrating on a single state of "love" rather than a dynamic or emotionally-driven state. On the basis of these self-reports, the present study predicted that "mantra of love" meditation may be associated with physiological responses that more strongly suggest reduced activation of the sympathetic nervous system and enhanced activation of the parasympathetic nervous system, as compared with focused attention on the breath.

2. Methods

2.1 Participant

A healthy Japanese yoga expert (female, 43 years) participated. Based on her self-report, the expert had practiced and taught classical hatha yoga and raja yoga for 24 years. Mean practice time per day accounted for approximately 2 hours, and specific content of daily practice included various asanas (body postures), pranayamas (breathing techniques), and different styles of meditation involving focused attention on the breath and mantra meditation. The Edinburgh Handedness Inventory (Oldfield, 1971) indicated that the participant was right-handed. The participant provided written informed consent to prior to participation. Specifically, she had agreed that the experimental data would be open to the public only for academic purposes without specifying an individual. The participant was not compensated for participation in the study.

2.2 Settings

The experiment was conducted in a quiet carpeted room in which the participant usually practiced and taught yoga. A multisensor physiological measurement system NeXus-4 (Mind Media B.V., Roermond-Herten, Netherlands) was placed at one side of the participant, who sat in the lotus position (Padma asana) during measurement sessions. The NeXus-4 is a portable system that allows for simultaneous measurement of up to two peripheral physiological signals by attaching different sensors. The present study used two sensors each for measuring cardiovascular activities (Blood Volume Pulse [BVP]) and skin conductance (SC), in order to indicate autonomic nervous activities. The BVP sensor is based on the principle of photoplethysmography (Allen, 2007). The sensor emits near-infrared light through the skin and measures the absorption of the light by the blood flowing through the vessels. For every heart beat the sensor detects a peak in the absorption, which is used to calculate heart rate (HR) and heart rate variability (HRV). The SC sensor measures the electrical conductance of the skin, or sweat gland activity. The SC level is suggested to increase with sympathetic arousal (Boucsein, 1992). During measurement, these sensors were attached on the fingertips of the participant's left/right hand, respectively.

To set up, execute, and analyze the data, a Japanese version of the BioTrace+ software installed in a laptop computer (CF-SX2JE2DU, Panasonic, Kadoma, Japan; CPU: Intel, CoreTM 2.60 GHz.) was used. The laptop was placed in front of the experimenter (HM), who sat adjacent to the participant. A connection between the computer and the measurement system was made wirelessly by using Bluetooth.

2.3 Procedure

Measurement was conducted during meditation on two different themes, both of which were involved in the participant's everyday practice. First, focused attention on the breath is a most basic form of meditation in yoga as well as in mindfulness-based interventions (e.g., Kabat-Zinn, 1990; Segal et al., 2002). In this meditation, the meditator sustains selective attention moment by moment on the sensations of his/her own breathing. When the meditator finds that the his/her mind wanders and is distracted by thoughts or other sensations, the meditator's task is to simply notice that such distraction occurred and to bring his/her attention back to the breath. Second, "mantra of love" meditation is one form of mantra meditation in which the meditator either overtly or covertly repeats a selected mantra (short phrase) (e.g., Engström et al., 2010; Goyal et al., 2014). In the "mantra of love" meditation, the meditator internally repeats a single phrase meaning "I love..." (i.e., "*Ai-shite imasu*" in Japanese) throughout the meditation period.

For each test session, a 2-min resting period was followed by a 4-min meditation period, which was repeated four times resulting in each session lasting for 24 minutes. During the resting period, the participant was instructed to rest in a non-meditative state. The experimenter verbally instructed the start and the end of each period to the participant. The theme of meditation was fixed within each session. There were 4 test sessions in total, such that 2 sessions of focused attention on the breath was followed by another 2 sessions of "mantra of love" meditation. In order to reduce artifacts, the participant was instructed to minimize body movements with no vocalization during each session, unless she preferred to terminate the session. After all the test sessions finished, the experimenter asked the participant to determine the scores of each test session on a scale of one hundred.

2.4 Data processing

In the first session, there were 3 rest-meditation blocks with the meditation periods lasting for 4.0-4.8 min because the construction of the blocks was not fixed as a beginning stage of measurement. Because data from this session was consistent with those from the later session(s), these data were included in the analysis by using the first 4 minutes of the meditation period. Rejection of the period with motion artifact was made by using the BioTrace+ software. Excluded data over the 4 sessions accounted for 6.0 % of the resting period and 2.3 % of the meditation period on average.

Physiological data for each period and session were then calculated. For the resting period, average data of 60 s immediately before the start of meditation was used. For the meditation period, averaged data of 0-1 min, 1-2 min, 2-3 min, and 3-4 min after the start of meditation were each used to indicate the timecourse of physiological responses during meditation. For each measure, the difference between data for each minute of meditation and those for the resting period was used to indicate changes of physiological responses. In addition to the skin conductance measure (SC sensor), the following measures were examined based on the BVP data: (1) HR (hear rate) in beats per minute (bpm), (2) SDNN (standard deviation of normal-to-normal R-R interval) and (3) RMSSD (root mean square of successive heart beat interval) as measures of time-domain HRV, and (4) low frequency (LF) and high frequency (HF) components based on the power spectral analysis of HRV by Fast Fourier Transform (FFT), and the ratio between them (LF/HF). The LF/HF ratio is suggested to be an indicator of sympathovagal balance (e.g., Pagani et al., 1984; 1986).

For each measure, a two-way repeated measures analysis of variance (ANOVA) with time interval (5) as a within-block factor and meditation type (2) as a between-block factor compared the timecourse of physiological responses between the two meditation types. Where an interaction between time interval and meditation type was statistically significant ($\alpha = 0.05$), post-hoc comparisons by independent samples *t*-tests with Bonferroni correction made comparisons between the meditation types for each minute of meditation.

3. Results

The participant's self-reported scores for the meditation performance were 65 for the two sessions with focused attention on the breath, and 90 for the two sessions with "mantra of love" meditation. **Table 1** summarizes physiological outcomes during the meditation period, with results from the ANOVA analyses further shown in **Table 2**. For SC, both main effect of time interval and interaction between time interval and meditation type were statistically significant. Thus, whereas skin conductance overall decreased with time for both meditation types, the amount of change was smaller for "mantra of love" meditation than for focused attention on the breath. Post-hoc *t*-tests showed that there were no significant differences between the

Table 1 Physiological measures during meditation.

Measure		Meditation type	0-1 min	1-2 min	2-3 min	3-4 min
SC		Breath	0.02 (0.10)	-0.13 (0.17)	-0.31 (0.24)	-0.45 (0.28)
(μS)		Mantra of love	-0.04 (0.06)	-0.09 (0.13)	-0.14 (0.19)	-0.18 (0.25)
HR (BVP)		Breath	7.21 (3.32)	9.67 (2.40)	9.13 (2.95)	7.86 (3.16)
(bpm)		Mantra of love	4.47 (3.02)	4.71 (1.41)	3.05 (2.12)	2.27 (2.23)
HRV (BVP)	SDNN	Breath	-13.61 (12.21)	-24.45 (8.82)	-25.05 (9.01)	-23.24 (10.26)
	(ms)	Mantra of love	-6.91 (19.43)	-5.72 (11.40)	-1.25 (13.05)	-5.14 (14.31)
	RMSSD	Breath	-17.25 (9.36)	-15.65 (9.82)	-16.96 (8.39)	-18.82 (8.36)
	(ms)	Mantra of love	-13.40 (19.41)	-13.65 (12.27)	-8.95 (17.46)	-5.91 (15.35)
	LF power	Breath	-98.91 (44.36)	-97.37 (44.78)	-71.49 (58.82)	-90.24 (39.56)
	(ms^2)	Mantra of love	-97.59 (88.36)	-70.16 (118.00)	0.07 (131.48)	-69.53 (94.16)
	HF power	Breath	-39.36 (31.56)	-37.31 (31.80)	-36.43 (32.19)	-33.94 (36.71)
	(ms^2)	Mantra of love	-23.78 (46.50)	-33.95 (24.94)	-9.05 (70.11)	8.03 (57.29)
	LF/HF	Breath	-0.46 (1.09)	-1.33 (1.68)	0.41 (2.30)	-1.41 (1.54)
		Mantra of love	-0.49 (1.59)	0.59 (1.63)	2.10 (3.63)	-0.70 (2.24)

Differences from the resting period (mean [*SD*]) are shown for each meditation type and minute of meditation.

Table 2 Results of the two-way ANOVAs.

Measure		Source	*df*	*F*	*p*
SC		Time interval	1, 18	18.144	**<0.001*** **
(μS)		Time interval * Meditation type	1, 18	4.161	**0.046***
HR (BVP)		Time interval	4, 52	36.072	**<0.001*** **
(bpm)		Time interval * Meditation type	4, 52	7.226	**<0.001*** **
HRV (BVP)	SDNN	Time interval	4, 52	6.988	**<0.001*** **
	(ms)	Time interval * Meditation type	4, 52	4.402	**0.004** **
	RMSSD	Time interval	4, 52	6.535	**<0.001*** **
	(ms)	Time interval * Meditation type	4, 52	1.096	0.368
	LF power	Time interval	3, 43	8.220	**<0.001*** **
	(ms^2)	Time interval * Meditation type	3, 43	1.048	0.386
	HF power	Time interval	4, 52	2.949	**0.029***
	(ms^2)	Time interval * Meditation type	4, 52	1.067	0.382
	LF/HF	Time interval	4, 52	3.390	**0.015***
		Time interval * Meditation type	4, 52	0.954	0.440

Main effect of time interval and interaction between time interval and meditation type are shown for each physiological measure. *P* values with statistical significance are shown in bold characters (*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$).

meditation types for either minute of the meditation period (t_{13} = -1.808—1.316, all *ps* > 0.05). HR overall increased during meditation from the resting period, even though the amount of change was again smaller for "mantra of love" meditation than for focused attention on the breath. Post-hoc comparisons revealed that changes in HR were significantly larger during "mantra of love" meditation for 1-2 min (t_{13} = 4.605, $p <$ 0.01), 2-3 min (t_{13} = 4.307, $p < 0.01$), and 3-4 min (t_{13} = 3.714, $p < 0.05$), although no significant difference between the meditation types was found for 0-1 min (t_{13} = 1.559, $p > 0.05$).

Regarding HRV, the main effect of time interval was statistically significant for all the measures including time-domain HRV (SDNN and RMSSD) and frequency-domain HRV (LF power, HF power, and LF/HF), showing that HRV changed with time for both meditation types (**Table 2**). For SDNN, the interaction between time interval and meditation type was also statistically significant. This shows that, whereas SDNN overall decreased from the resting to the meditation period, the amount of change was smaller for the "mantra of love" meditation than for focused attention on the breath. Post-hoc *t*-tests further uncovered that decrease of SDNN was significantly smaller during "mantra of love" meditation for 1-2 min (t_{13} = -3.277, $p < 0.05$) and 2-3 min (t_{13} = -3.773, $p < 0.01$), even though there were no significant differences between the meditation types for 0-1 min and 3-4 min (t_{13} = -2.587—-0.732, all *ps* > 0.05). For the remaining HRV measures, interactions between time interval and meditation type failed to be statistically significant (**Table 2**), with no indication that the patterns of HRV changes differed between the two meditation types. Thus, the data did not suggest that the balance of LF and HF components as well as RMSSD was different between "mantra of love" meditation and focused attention on the breath.

4. Discussion

An initial prediction of the present study was to observe relatively reduced sympathetic and enhanced parasympathetic nervous system activities during "mantra of love" meditation. As compared with the most basic style of yoga meditation to keep one's attention on one's own breathing, "mantra of love" meditation yielded differentiated physiological outcomes including smaller increase in heart rate, smaller decrease in time-domain heart rate variability, and smaller decrease in skin conductance. Thus, changes in multiple physiological measures from the resting period were smaller during "mantra of love" meditation than during focused attention on the breath. According to the participant's self-report, "mantra of love" meditation is associated with a calm and stable mental state instead of an emotionally aroused state. In addition, performance on "mantra of love" meditation during measurement was highly self-evaluated by the participant. Considering these facts, the present results seem to support the notion that not only sympathetic but also parasympathetic nervous system activities were relatively reduced during "mantra of love" meditation compared with focused attention on the breath.

On the other hand, several measures of heart rate variability including frequency-domain HRV failed to show statistically significant differences between the two meditation types. These measures include the LF/HF ratio, which is used as a measure to indicate balance of sympathovagal activity (Pagani et al., 1984; 1986). These results may thus suggest that the balance between activities of sympathetic and parasympathetic nervous system was equivalent during both of these two meditation types. Because both these types of meditation were involved in the participant's everyday practice, the present results may further suggest that daily experience of such balanced autonomic nervous system status in different ways are closely related to the desirable psychological status such as enhanced mindfulness and well-being that is self-reported by long-term yoga practitioners (e.g., Miyata et al., 2015).

Despite these novel findings and suggestions, there are limitations of the present study regarding both study design and technical issues. First, the two types of meditation were not implemented in a counterbalanced order within each session, for which order effect is difficult to be totally eliminated. This seems unavoidable at the beginning stage of enquiry, considering the fact that experimental sessions with repeated periods of different types of meditation that are intermitted by resting periods are quite unusual situations for the participant's everyday practice. This improvement could be made after the participant becomes sufficiently used to the experimental procedure. Second, vocalization and body movement of the participant during measurement were restricted in order to minimize motion artifacts. This was also quite unnatural for the participant, because the participant's daily yoga practice essentially involves natural body movements and vocalizations during asanas, paranayamas, as well as meditation. Measurement techniques that allow for more flexible movement of the body should be more desirable. Based on these issues, it is undoubtedly a challenge to use improved experimental designs that are both well-controlled and are as close as possible to everyday yoga practice.

Finally, issues relevant to the case-study approach should be carefully considered. As mentioned above, a case study designed for each highly advanced expert like the present one should be advantageous in that it can uncover psychophysiological basis of each specialized form of expertise. Case studies also seem relevant considering the limited number of highly advanced Japanese contemplatives. Nevertheless, such case studies alone should have apparent limitations because it is left unclear whether the findings could be generalized to a larger population of practitioners. Designs that involve larger numbers of expert practitioners as well as novices should contribute to improving external validity of the study. These potential modifications and further enquiries should enable us to obtain a broader view regarding psychological and physiological mechanisms underlying various forms of contemplative practice in Japanese.

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