Cogn Process
DOI 10.1007/s10339-017-0812-y

RESEARCH REPORT

EEG microstates during different phases of Transcendental Meditation practice

Pascal L. Faber[1] · **Frederick Travis**[2] · **Patricia Milz**[1] · **Niyazi Parim**[2]

Received: 9 June 2016 / Accepted: 24 April 2017

Abstract Two phases of Transcendental Meditation (TM)—transcending and undirected mentation—were compared to each other and to task-free resting using multichannel EEG recorded from 20 TM practitioners. An EEG microstate analysis identified four classes of microstates which were labeled A, B, C and D, based on their similarity to previously published classes. For each class of microstates, mean duration, coverage and occurrence were computed. Resting and transcending differed from undirected mentation with decreased prominence of Class A and increased prominence of Class D microstates. In addition, transcending showed decreased prominence of Class C microstates compared to undirected mentation. Based on previous findings on the functional significance of the microstate classes, the results indicate an increased reference to reality and decreased visualization during resting and transcending compared to undirected mentation. Also, our results indicate decreased saliency of internally generated mentations during transcending compared to undirected mentation reflecting a more detached and less evaluative processing. It is proposed that the continuous cycling through these two phases of meditation during a TM session might facilitate and train the flexible modulation of the parameters of these microstates of these particular classes which are known to be altered in psychiatric disorders. This might promote beneficial stabilizing effects for the practitioner of TM.

Keywords Electroencephalography · Attention · Brain mapping · Resting state · Cognition

Introduction

The Transcendental Meditation^{TM} (TM^{TM}) technique can be superficially described as thinking or repeating a mantra—a word without meaning—and going back to it when it is forgotten (Raffone and Srinivasan 2010). This description is similar to descriptions of focused attention during concentration techniques. A deeper analysis reveals, however, that TM practice is a process of *transcending*—appreciating the mantra at "finer" levels in which the mantra becomes increasingly secondary in experience and ultimately disappears as self-awareness becomes more primary (Maharishi 1969; Travis and Pearson 2000). During the process of transcending, the mind sometimes becomes engaged in an undirected stream of thoughts ("undirected mentation"). When this happens and is noticed by the practitioner, they learn how to effortlessly return to the mantra. This fluctuation between transcending and undirected mentation is the natural flow of a TM practice. Contrary to focused attention meditation practices, undirected mentation is not considered to be off-task but an integral part of the meditation process.

Earlier research reports higher frontal alpha coherence, slower breath rate, lower sympathetic activity and higher parasympathetic activity during transcending compared to

---

Handling editor: Narayanan Srinivasan (University of Allahabad); Reviewers: Antonino Raffone (Sapienza University of Rome), Alexander Fingelkurts (BM-SCIENCE, Finland).

✉ Pascal L. Faber
pfaber@key.uzh.ch

[1] The KEY Institute for Brain-Mind Research, Department of Psychiatry, Psychotherapy and Psychosomatics, University Hospital of Psychiatry, Lenggstr. 31, 8032 Zurich, Switzerland

[2] Center for Brain, Consciousness and Cognition, Maharishi University of Management, Fairfield, IA, USA

periods of undirected thoughts (Travis 2001). These periods were chosen by experimenter-initiated bell rings, which participants later identified as either transcending or undirected thoughts, here referred to as "undirected mentation." These periods occurred at different times throughout the 20-min meditation session.

To better compare periods of undirected mentation and transcending, the present study asked participants to press a button when they noticed that they became engaged in an undirected stream of thoughts and to then return to the process of transcending during TM practice. This design has been used in neural imaging research to compare mind wandering and focused attention to one's breath (Hasenkamp et al. 2012).

Electroencephalographic (EEG) microstate analysis was used to compare the periods before (undirected mentation) and after (transcending) the button presses and to compare both against a task-free resting condition. Why is the EEG microstate analysis especially suited to detect the brain electric idiosyncrasies of the different phases of meditation? Multichannel brain electric signals measured on the scalp can be displayed as spatial maps of momentary electric potential distributions on the head surface. When looking at these sequences of topographic maps, it becomes apparent that the potential distributions do not change continuously. Rather, they form brief temporal epochs of quasi-stable spatial distributions of brain electric activity. Lehmann termed these epochs "microstates" (Lehmann et al. 1987). Due to the very high time resolution of the EEG, the microstate analysis allows the isolation of microstates with a typical duration of 60–120 ms. Cluster analyses of the microstate topographies showed that in eyes-closed resting EEG, four classes of microstate topographies explain a large amount (up to 90%) of the variance in the data (Khanna et al. 2015; Koenig et al. 2002; Wackermann et al. 1993); they also replicate well over a large age range (from 6 to 80 years) and over different studies (see Koenig et al. 2002). In addition to their duration, the EEG microstates are characterized by the parameters coverage and occurrence that describe the percentage of time spent and the number of occurrences per second, respectively, of microstates of a given class. Different potential distributions on the scalp must have been generated by different spatial distributions of neuronal electric activity in the brain. It is therefore reasonable to assume that different microstates embody different modes, contents or steps of information processing (Lehmann et al. 1998). Consequently, the EEG microstates have been proposed to represent the "atoms of thought and emotion," basic psychophysiological units of cognition and emotion (Lehmann 1990, 2013; Lehmann et al. 1998). The subjective experience termed "stream of consciousness" by William James (1892) is thus constituted by discernible elements. Subjectively, the two phases of TM meditation differ in content with the appreciation of the mantra in one phase and the engagement in an undirected stream of thoughts in the other. The ability of the microstate approach to discern mind states in the sub-second range should therefore allow to detect these mental differences on the level of the underlying brain electric activity.

The EEG microstate analysis has been applied to normal and pathological states of consciousness and seems especially well suited for the study of attention (Faber et al. 2005; Katayama et al. 2007), mentation modality (Milz et al. 2016) and reality-testing processes (Brodbeck et al. 2012; Katayama et al. 2007; Koenig et al. 2002; Lehmann et al. 2005). Typically attention, awareness and emotion processes are modulated by meditative practices in general (Raffone and Srinivasan 2010; Shapiro and Walsh 2003). Consequently, we hypothesize that the EEG microstate parameters differ between two phases of TM meditation—undirected mentation and transcending—and no-task resting.

Materials and methods

Participants

Multichannel EEG was recorded from a group of 20 TM practitioners. The participants had a mean age of 33.1 years (SD = 14.5, range 20–64 years) and a mean TM experience of 11.6 years (SD = 16.1, range 1 month–43.3 years). There were 14 men and 6 women. All participants were right-handed. This study was carried out in accordance with the Helsinki Declaration and the Institution Review Board approved the research before data collection. All participants gave their informed consent prior to the experiment after receiving detailed information on the experimental procedure.

Recording conditions

Participants came to the laboratory for EEG recordings during the afternoon. Thirty-two EEG active-sensors were applied according to the 10/10 system using the BIOSEMI ActiveTwo system (www.biosemi.com). Potentials at the left and right ear lobes were also measured to calculate a linked-ears reference offline. Following sensor application, EEG was recorded at 256 samples/s during a 5-min no-task resting and a 10-min TM session. During both sessions, the participants had their eyes closed. Participants were instructed to press a button when they noted that their mind was lost in undirected thought. After the button press, they then went back to the process of transcending during TM practice.

Data preprocessing

The 32-channel EEG data were visually inspected using the BrainVision Analyzer Software (Brain Products, Munich, Germany). EEG containing eye movement, muscle movement and/or technical artifacts was manually detected and removed from analysis. Noisy channels were linearly interpolated. For the eyes-closed resting condition, the first artifact-free 20 s after 1 min of resting was selected. On average, there were 19.4 (SD = 1.3) seconds of EEG data available for no-task resting. For the TM condition, 22 s before and 22 s after each button press were exported and parsed into 2-s epochs omitting epochs containing parts marked as artifacts. The time surrounding the button press is most likely contaminated by reorientation processes; therefore, the last 2 s before and the first 4 s after the button press were also omitted. There were on average 3.3 button presses per participant (SD = 0.8). On average, 51.1 s (SD = 13.0) of EEG data was available per participant before the button press and 44.1 s (SD = 14.0) after the button press. All available, artifact-free data epochs were recomputed against the average reference and FFT-filtered from 2 to 20 Hz.

Microstate analysis

Computation of the microstate classes

For each condition and each participant, global field power (GFP) curves of all available artifact-free 2-s epochs were computed. The global field power (Lehmann 1987; Lehmann and Skrandies 1980) at each time point is a measure of the global strength of electric activity in the brain at that moment in time. Maps with maximal GFP have an optimal signal-to-noise ratio (Koenig et al. 2002); they were collected for further analysis and are called “original maps.” For each condition and each participant, a modified k-means clustering algorithm (Pascual-Marqui et al. 1995) determined the four classes of map topographies (“individual classes”) that best explain the variance of all original maps (Koenig et al. 1999, 2002). For each condition, these individual classes were then averaged across participants, resulting in four “condition classes.” The averaging was done using a randomization procedure that permutes the four individual classes per participant, computes for each class the first principal component over all participants, and then computes the explained variance of these four mean classes across participants. From all randomization runs, the four classes that explain most of the variance across participants were retained as condition classes. In order to be comparable to the four normative classes published by (Koenig et al. 2002), the condition classes were labeled as classes A, B, C and D based on their best fit to these four normative classes using Global Map Dissimilarity (Lehmann and Skrandies 1980).

Computation of the microstate parameters

Each original map was assigned to one of the four condition classes using lowest map dissimilarity (Lehmann et al. 1987; Lehmann and Skrandies 1980) as fitting criterion. A microstate is defined as the time period of consecutive original maps with the same class assignment. Each 2-s epoch (of each participant and condition) can thus be regarded as a sequence of alternating microstates of the four condition classes. For the four microstate classes, three parameters were computed per epoch and then averaged across epochs per participant and condition: their coverage (time covered per second), their mean occurrence (number of occurrences per second) and their mean duration (in milliseconds).

Statistics

For each of the three microstate parameters coverage, occurrence and duration, a repeated measures ANOVA was computed using condition (resting, undirected mentation and transcending) and microstate class (A, B, C and D) as repeated measures. A Greenhouse-Geisser correction for sphericity violations was applied. For each parameter, and each class, post hoc paired *t* tests compared the three conditions pairwise.

Correlation analyses

To explore the effect of meditation experience on the microstate parameter differences between transcending and undirected mentation, Pearson product-moment correlations were computed between these parameter differences and the meditation experience of the practitioners. Additionally, partial correlations were computed to partial out the effect of the age of the participants. Corrections for multiple testing were applied (Benjamini and Hochberg 1995).

Results

Microstate classes

Figure 1 shows the four microstate class topographies for resting, undirected mentation and transcending. The four classes are very similar to the four normative classes reported by Koenig et al. (2002). The four condition classes for both undirected mentation and transcending explained on average 80% (SD = 4 and 5%, respectively) of the

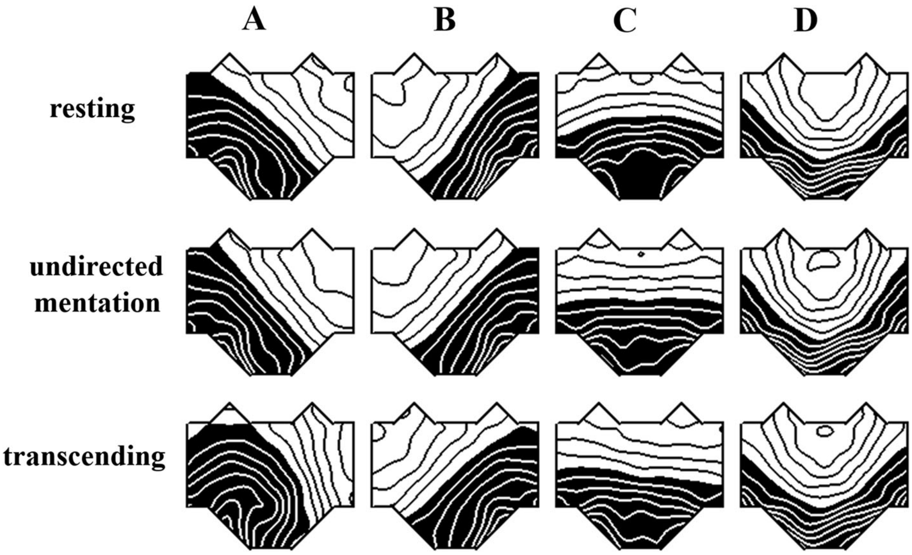

Fig. 1 Condition microstate class topographies. Equipotential area maps are shown. *Head* seen from *above*, *nose up*, *left ear left*. The isopotential *contour maps* show the (arbitrarily assigned) areas of opposite polarity in *black* and *white* (normalized voltage values)

variance in the data and the four condition classes for resting explained on average 79% (SD = 5%) of the variance in the data.

Microstate parameters

For each parameter (coverage, occurrence and duration), the repeated measures ANOVAs revealed a significant main effect for "class" and a significant interaction between "condition" and "class" (see Table 1). The interactions between condition and class were further investigated using post hoc paired *t* tests, and the means, standard deviations and *p* values of the post hoc *t* tests are listed in Table 2.

Table 1 Repeated measures ANOVAs for microstate parameters with condition and class as repeated measures using Greenhouse-Geisser correction

	df	*F*	*p* value
Coverage			
Condition	1.81, 42.23	1.125	.332
Class	1.96, 45.41	6.144	.005
Condition * class	4.04, 70.21	6.357	<.001
Occurrence			
Condition	1.91, 31.77	.689	.502
Class	2.61, 58.97	6.959	.001
Condition * class	3.46, 78.04	5.965	.001
Duration			
Condition	1.82, 31.84	.681	.499
Class	1.61, 36.49	4.717	.022
Condition * class	3.11, 77.55	3.716	.015

On the one hand, there were no significant differences in microstate parameters between resting and transcending. On the other hand, the pattern of microstate differences between resting and undirected mentation and between transcending and undirected mentation shared some characteristics but differed in others. This is seen graphically in Table 3. Also, the level of significance of the differences between conditions was higher in comparisons with transcending.

- Class A microstates are reportedly related to visualization (see "Discussion" section). Coverage and occurrence of these microstates were significantly higher during undirected mentation compared to both resting ($p = .01$ and .02) and transcending ($p = .002$ and .005).
- Class B microstates are reportedly related to verbalization (see "Discussion" section). There were no differences in coverage, occurrence or duration of this class of microstates.
- Class C microstates are reportedly related to interoceptive and autonomic processing (see "Discussion" section). Coverage and occurrence of these microstates were significantly higher during undirected mentation compared to transcending ($p = .01$ and $p < .001$). There were no significant differences of this class of microstates between undirected mentation or transcending and resting.
- Class D microstates are reportedly related to reality testing (see "Discussion" section). Coverage and occurrence of these microstates were significantly lower during undirected mentation compared to both resting ($p < .001$, and $p = .003$) and transcending ($p < .001$ and $p < .001$). Duration of these microstates was also significantly lower during undirected mentation compared to resting ($p = .01$).

Table 2 Microstate parameters of the four classes for undirected mentation and transcending

	Coverage (percent time covered)				Occurrence (occurrences/second)				Duration (milliseconds)			
	A	B	C	D	A	B	C	D	A	B	C	D
Undirected mentation	.22 (.06)	.23 (.05)	.30 (.06)	.25 (.06)	3.23 (.78)	3.30 (.67)	3.75 (.45)	3.31 (.48)	69.43 (7.13)	69.27 (7.18)	80.72 (15.86)	74.34 (14.56)
Transcending	.19 (.06)	.24 (.06)	.27 (.06)	.30 (.11)	2.82 (.82)	3.35 (.78)	3.53 (.43)	3.68 (.73)	66.81 (8.97)	72.24 (10.72)	77.26 (17.25)	82.92 (29.95)
Resting	.19 (.06)	.23 (.07)	.27 (.08)	.31 (.10)	2.86 (.71)	3.28 (.99)	3.52 (.64)	3.64 (.64)	65.57 (11.49)	72.43 (10.19)	76.10 (18.00)	85.67 (27.68)
t tests												
RE vs UM	**.01**	.61	.07	**≤.001**	**.02**	.86	.07	**.003**	.12	.13	.22	**.01**
RE vs TR	.92	.62	.77	.47	.73	52	.93	.74	.52	.95	.68	.13
TR vs UM	**.002**	.11	**.01**	**≤.001**	**.005**	.58	**≤.001**	**≤.001**	.10	.10	.29	.08

Listed are means, standard deviations (in parentheses) and p values for post hoc paired t tests*

UM undirected mentation, *TR* transcending, *RE* resting

* $p < .05$ underlined and bold

Table 3 Microstate parameter changes from resting (RE) to undirected mentation (UM), from RE to transcending (TR) and from TR to UM for the 4 microstate classes for p values <.05

	Coverage				Occurrence				Duration			
	A	B	C	D	A	B	C	D	A	B	C	D
RE to UM	↗	–	–	↘	↗	–	–	↘	–	–	–	↘
RE to TR	–	–	–	–	–	–	–	–	–	–	–	–
TR to UM	↗	–	↗	↘	↗	–	↗	↘	–	–	–	–

Correlation results

The difference of class C and D coverage between undirected mentation and resting correlated significantly with meditation experience ($r = 0.50$ and $r = -0.46$, respectively, at uncorrected $p < .05$). Increased TM experience was associated with reduced condition differences. However, these correlations were not significant after correction for multiple testing (36 correlations, $N = 20$). Moreover, partial correlations that controlled for participant age also did not reveal any significant interrelationships of TM experience with EEG microstate class differences between conditions irrespective of multiple testing correction.

Discussion

Two subjectively different phases of TM—undirected mentation and transcending—were compared to each other and to task-free resting. The four microstate classes identified in each condition were very similar to the normative classes published by Koenig et al. (2002) and were labeled as A, B, C and D based on their best fit to these normative classes.

The applied microstate analysis revealed that undirected mentation, compared to both resting and transcending, was marked by higher coverage and occurrence of Class A microstates, and lower coverage and occurrence of Class D microstates. Also, compared to transcending only, undirected mentation was marked by significantly higher coverage and occurrence of Class C microstates. Contrary to our hypothesis, microstates during transcending did not differ from those during no-task resting before the meditation practice.

Why did microstate parameters not differ between resting and transcending?

While we cannot exclude the possibility that the present microstate analysis is not sensitive enough to reveal the electrophysiological differences, or that there are no electrophysiological differences between transcending and resting, there are other plausible interpretations.

Firstly, a statement often heard by meditators is that they habitually fall into a state of meditation upon closing their eyes. Also, resting EEG has been reported to be altered in experienced meditators (Aftanas and Golosheykin 2005; Lutz et al. 2004; Tebēcis 1975; Tei et al. 2009). Periods of transcending are initiated by effortlessly attending to a mantra. Periods of undirected mentation are presumably initiated by issues of the body or the mind generating the stream of thoughts away from transcending. Closing the eyes might favor the letting go of thoughts and sensations in experienced meditators, thus leading into a state very similar to transcending. Possibly, after a few minutes of eyes-closed resting, this state becomes increasingly influenced by preoccupations of the mind or sensations of the body. On the other hand, undirected mentation during TM is embedded in a global stance of going back to the mantra if noticed. Therefore, undirected mentation differs not only from the first couple of minutes of eyes-closed resting but possibly also from later stages of resting. In the present study, EEG data from within the second minute of resting were used for analysis.

Secondly, it is also conceivable that later stages of eyes-closed resting become increasingly different from transcending, as the meditative stance of going back to the mantra is missing. Considering the completely different mindset of transcending (effortlessly attending to a mantra) and eyes-closed resting (no task), it seems unlikely that the two states should share the exact same electrophysiological mechanisms. Future studies could test periods of transcending against later stages of longer periods of eyes-closed resting to clarify this issue.

Consideration of Class A microstate differences

Undirected mentation was characterized by significantly higher coverage and occurrence of Class A microstates. In the past, Class A microstates have been related to a network corresponding to the auditory-phonological system (Britz et al. 2010; Mantini et al. 2007). However, a more recent study (Milz et al. 2016) specifically targeted modalities of thinking in a large pool of 61 participants. Habitual thinking modalities as well as task-evoked modalities were studied. The results clearly related increased prominence of Class A microstates to increased visual thinking. It is conceivable that undirected mentation goes along with more visualizations than transcending or resting.

Consideration of Class B microstate differences

There were no significant differences in the parameters of Class B microstates between the phases of meditation and resting. Class B parameter changes have been reported during light hypnosis compared to resting (Katayama et al. 2007) and in acute, first-episode schizophrenics compared to healthy controls (Strelets et al. 2003) but also during Tibetan Buddhism self-dissolution, Ch'an Mo'chao and Vipassana meditation compared to resting (Faber et al. 2005). The latter report analyzed data from three participants only; nevertheless, this might be an indication that the practice of TM involves different processes than these Buddhist meditation practices.

Consideration of Class C microstate differences

Compared to transcending only, undirected mentation was marked by significantly higher coverage and occurrence of Class C microstates. Class C microstates have been associated with activity in two important hubs of the default mode network (DMN, Raichle et al. 2001): the anterior cingulate cortex (ACC) and the posterior cingulate cortex (PCC) (Pascual-Marqui et al. 2014). Class C microstates also showed correlations with positive BOLD signals in the ACC, the bilateral frontal gyri and the right insula (Britz et al. 2010). These regions are comparable to the resting state network 6 in Mantini et al. (2007), and they overlap with the saliency network and were linked to subjective interoceptive–autonomic processing. Class C processing thus might be involved in the integration of interoceptive information with emotional salience to form a subjective own body representation (Britz et al. 2010). This would fit the interpretation that during undirected mentation the mind is caught up in internal experiences to a higher degree than during transcending, which is more detached and less evaluative.

Consideration of Class D microstate differences

Transcending and resting were characterized by higher coverage and occurrence of Class D microstates. Class D microstates have been related to reality testing, the updating of mental content and attention reorientation (Milz et al. 2016; Rieger et al. 2016). Possibly higher Class D prominence relates to greater alertness to mental processing during transcendence and resting. Undirected mentation lacks direction which may in turn be associated with fewer instances of context updating. Rather, the current context would guide the stream of mentation without updating the thinking process based on internal plans or motivation. And undirected mentation has no sense of attention reorienting since there is no thinker comparing or directing attention—each thought is leading to the next thought without the mind directing this flow. The thought process is moving by itself.

Clinical Comparisons

Increased coverage of Class A microstates was reported in individuals at high risk for psychosis (Andreou et al. 2014) and in patients with panic disorder (Kikuchi et al. 2011). Interestingly, the practice of TM is known to reduce anxiety (Eppley et al. 1989; So and Orme-Johnson 2001). In the present study, Class A microstate coverage was modulated by the phases of TM. The cycling through the two phases thus went along with an increase in the coverage of Class A microstates during undirected mentation and a return to baseline during transcendence. We propose that this continuous cycling may train the flexible modulation of the brain networks underlying Class A microstates, thus possibly promoting the reported anxiety reducing effects of TM practice and a subsequent general effect of psychological stabilization. It has been shown that microstate parameters can be modulated using medication (Kikuchi et al. 2007) but also using neurofeedback (Hernandez et al. 2015). Meditation could be an additional promising approach to willfully modulate microstate parameters.

A recent study (Tomescu et al. 2014) compared a group of adolescents affected by a genetic mutation, the 22q11.2 deletion syndrome, to an age-matched control group. Individuals affected by this genetic mutation have a 30-fold increased risk for later developing schizophrenia. In this group, duration, occurrence and coverage were increased for microstates of Class C and decreased for microstates of Class D. Our data yielded the opposite result for transcending compared to undirected mentation: Class C microstates showed decreased and Class D microstates increased presence (occurrence and coverage). Again, we propose that the cycling through these two phases of meditation during a TM session might facilitate and train the flexible modulation of the parameters of these two microstate classes and their underlying brain networks, thus possibly promoting beneficial stabilizing effects for the practitioners of TM.

On a side note, differences in microstate parameters have been reported for light and deep hypnosis compared to resting (Katayama et al. 2007). Light hypnosis was characterized by a decreased prominence of Class C microstates. Deep hypnosis was associated with a decrease in Class D prominence and an increase in coverage and occurrence of Class A microstates. Interestingly, undirected mentation mirrors the pattern of microstates seen during deep hypnosis.

The correlations found between experience and microstate Class C and D coverage differences between undirected mentation and resting seem to indicate that the more experienced a practitioner is, the smaller the difference between undirected mentation and resting becomes. However, these results were only significant before multiple testing corrections and/or before the variance of age was partialled out. Additional studies with higher statistical power are needed to shed more light on the possible influence of experience on microstate parameters during TM meditation phases.

Limitations of the study

Unfortunately, the present study did not include subjective reports about the actual experiences during the two phases of meditation or the resting condition. Therefore, all interpretations about the functional significance of the microstate classes remain indirect and are based on previous findings reported in the literature. Future studies should include subjective reports as they potentially could further our understanding of the functional significance of the microstate classes.

Conclusion

In summary, the microstate analysis performed on EEG data from no-task resting and two phases of meditation during TM practice—transcending and undirected mentation—revealed a similar pattern in Class A and Class D microstates between transcending and undirected mentation and between rest and undirected mentation. In addition, transcending also significantly differed in Class C microstates compared to undirected mentation. These results agree with several aspects of the subjective experiences during TM meditation. Furthermore, they indicate decreased salience of internally generated mentations, i.e., more detached and less evaluative processing (Class C parameter was lower) during transcending compared to undirected mentation, and that both resting and transcending—compared to undirected mentation—are characterized by decreased visualization (Class A parameter was lower) and increased reality testing—context updating—processes (Class D parameter was higher). It is proposed that the continuous cycling through these two phases of meditation during the practice of TM may train the flexible modulation of the microstate parameters of Classes A, C and D, for which deviations have been reported in psychiatric disorders. This might promote beneficial effects of regular TM practice.

Acknowledgements We thank Dr. Alarik Arenander for early discussions on the conceptual framework of the paper.

References

Aftanas L, Golosheykin S (2005) Impact of regular meditation practice on EEG activity at rest and during evoked negative emotions. Int J Neurosci 115:893–909

Andreou C et al (2014) Resting-state connectivity in the prodromal phase of schizophrenia: insights from EEG microstates. Schizophr Res 152:513–520

Benjamini Y, Hochberg Y (1995) Controlling the false discovery rate: a practical and powerful approach to multiple testing. J R Stat Soc Series B Stat Methodol 57(1):289–300

Britz J, Van De Ville D, Michel CM (2010) BOLD correlates of EEG topography reveal rapid resting-state network dynamics. Neuroimage 52:1162–1170

Brodbeck V et al (2012) EEG microstates of wakefulness and NREM sleep. Neuroimage 62:2129–2139

Eppley KR, Abrams AI, Shear J (1989) Differential effects of relaxation techniques on trait anxiety: a meta-analysis. J Clin Psychol 45:957–974

Faber PL, Lehmann D, Barendregt H, Kaelin M, Gianotti LR (2005) Increased duration of EEG microstates during meditation. Brain Topogr 18:131

Hasenkamp W, Wilson-Mendenhall CD, Duncan E, Barsalou LW (2012) Mind wandering and attention during focused meditation: a fine-grained temporal analysis of fluctuating cognitive states. Neuroimage 59:750–760

Hernandez LD, Rieger K, Baenninger A, Brandeis D, Koenig T (2015) Towards using microstate-neurofeedback for the treatment of psychotic symptoms in schizophrenia. A feasibility study in healthy participants. Brain Topography 29(2):308–321

James W (1892) The stream of consciousness. In: Psychology, Chapter XI. Cleveland & New York, World

Katayama H, Gianotti LR, Isotani T, Faber PL, Sasada K, Kinoshita T, Lehmann D (2007) Classes of multichannel EEG microstates in light and deep hypnotic conditions. Brain Topogr 20:7–14

Khanna A, Pascual-Leone A, Michel CM, Farzan F (2015) Microstates in resting-state EEG: current status and future directions. Neurosci Biobehav Rev 49:105–113

Kikuchi M, Koenig T, Wada Y, Higashima M, Koshino Y, Strik W, Dierks T (2007) Native EEG and treatment effects in neuroleptic-naive schizophrenic patients: time and frequency domain approaches. Schizophr Res 97:163–172

Kikuchi M et al (2011) EEG microstate analysis in drug-naive patients with panic disorder. PloS one 6:e22912

Koenig T, Lehmann D, Merlo MC, Kochi K, Hell D, Koukkou M (1999) A deviant EEG brain microstate in acute, neuroleptic-naive schizophrenics at rest. Eur Arch Psychiatry Clin Neurosci 249:205–211

Koenig T et al (2002) Millisecond by millisecond, year by year: normative EEG microstates and developmental stages. Neuroimage 16:41–48

Lehmann D (1987) Principles of spatial analysis. In: Gevins A, Remond A (eds) Handbook of electroencephalography and clinical neurophysiology, Vol. 1: Methods of analysis of brain electrical and magnetic signals., vol 1. Elsevier, Amsterdam, pp 309–354

Lehmann D (1990) Brain electric microstates and cognition: the atoms of thought. In: RJ E (ed) Machinery of the Mind. Springer, Berlin, pp 209–224

Lehmann D (2013) Consciousness: microstates of the brain's electric field as atoms of thought and emotion. In: Pereira A Jr, Lehmann D (eds) The unity of mind, brain and world: current perspectives on a science of consciousness. Cambridge University Press, New York, pp 191–218

Lehmann D, Skrandies W (1980) Reference-free identification of components of checkerboard-evoked multichannel potential fields. Electroencephalogr Clin Neurophysiol 48:609–621

Lehmann D, Ozaki H, Pal I (1987) EEG alpha map series: brain micro-states by space-oriented adaptive segmentation. Electroencephalogr Clin Neurophysiol 67:271–288

Lehmann D, Strik W, Henggeler B, König T, Koukkou M (1998) Brain electric microstates and momentary conscious mind states as building blocks of spontaneous thinking: I. Visual imagery and abstract thoughts. Int J Psychophysiol 29:1–11

Lehmann D et al (2005) EEG microstate duration and syntax in acute, medication-naive, first-episode schizophrenia: a multi-center study. Psychiatry Res: Neuroimaging 138:141–156

Lutz A, Greischar LL, Rawlings NB, Ricard M, Davidson RJ (2004) Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. In: Proceedings of the National academy of sciences of the United States of America 101:16369–16373

Maharishi (1969) Maharishi Mahesh Yogi on the Bhagavad-Gita. Penguin, New York

Mantini D, Perrucci MG, Del Gratta C, Romani GL, Corbetta M (2007) Electrophysiological signatures of resting state networks in the human brain. Proc Natl Acad Sci 104:13170–13175

Milz P, Faber P, Lehmann D, Koenig T, Kochi K, Pascual-Marqui R (2016) The functional significance of EEG microstates—associations with modalities of thinking. NeuroImage 125:643–656

Pascual-Marqui RD et al. (2014) The resting microstate networks (RMN): cortical distributions, dynamics, and frequency specific information flow arXiv preprint arXiv:14111949

Pascual-Marqui RD, Michel CM, Lehmann D (1995) Segmentation of brain electrical activity into microstates: model estimation and validation. IEEE Trans Bio-med Eng 42:658–665

Raffone A, Srinivasan N (2010) The exploration of meditation in the neuroscience of attention and consciousness. Cogn Process 11:1–7

Raichle ME, MacLeod AM, Snyder AZ, Powers WJ, Gusnard DA, Shulman GL (2001) A default mode of brain function. Proc Natl Acad Sci 98:676–682

Rieger K, Hernandez LD, Baenninger A, Koenig T (2016) 15 years of microstate research in schizophrenia–where are we? A meta-analysis. Front psychiatry 7:1–7

Shapiro SL, Walsh R (2003) An analysis of recent meditation research and suggestions for future directions. Hum Psychol 31:86–114

So K-T, Orme-Johnson DW (2001) Three randomized experiments on the longitudinal effects of the Transcendental Meditation technique on cognition. Intelligence 29:419–440

Strelets V et al (2003) Chronic schizophrenics with positive symptomatology have shortened EEG microstate durations. Clin Neurophysiol 114:2043–2051

Tebēcis AK (1975) A controlled study of the EEG during transcendental meditation: comparison with hypnosis. Psychiatry Clin Neurosci 29:305–313

Tei S et al (2009) Meditators and non-meditators: EEG source imaging during resting. Brain Topogr 22:158–165

Tomescu MI et al (2014) Deviant dynamics of EEG resting state pattern in 22q11. 2 deletion syndrome adolescents: a vulnerability marker of schizophrenia? Schizophr Res 157:175–181

Travis F (2001) Autonomic and EEG patterns distinguish transcending from other experiences during Transcendental Meditation practice. Int J Psychophysiol 42:1–9

Travis F, Pearson C (2000) Pure consciousness: distinct phenomenological and physiological correlates of "consciousness itself". Int J Neurosci 100:77–89

Wackermann J, Lehmann D, Michel C, Strik W (1993) Adaptive segmentation of spontaneous EEG map series into spatially defined microstates. Int J Psychophysiol 14:269–283