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Default mode network activation and Transcendental Meditation practice: Focused Attention or Automatic Self-transcending?

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ABSTRACT

This study used subjective reports and eLORETA analysis to assess to what extent Transcendental Meditation (TM) might involve focused attention—voluntary control of mental content. Eighty-seven TM subjects with one month to five years TM experience participated in this study.

Regression analysis of years TM practice and self-reported transcendental experiences (lack of time, space and body sense) during meditation practice was flat (r = .07). Those practicing Transcendental Meditation for 1 month reported as much transcending as those with 5 years of practice.

The eLORETA comparison of eyes-closed rest/task and TM practice/task identified similar areas of activation: theta and alpha activation during rest and TM in the posterior cingulate and precuneus, part of the default mode network, and beta2 and beta3 activation during the task in anterior cingulate, ventral lateral and dorsolateral prefrontal cortices, part of the central executive network. In addition, eLORETA comparison of rest and TM identified higher beta temporal activation during rest and higher theta orbitofrontal activation during TM.

Thus, it does not seem accurate to include TM practice with meditations in the catgory of Focused Attention, which are characterized by gamma EEG and DMN deactivation. Mixing meditations with different procedures into a single study confounds exploration of meditation effects and confounds application of meditation practices to different subject populations.

1. Introduction

The brain exhibits a large-scale intrinsic network, which is more active during periods of rest and is deactivated during cognitively demanding tasks (Golland et al., 2007). This network, called a default mode network (DMN), includes ventral medial prefrontal cortices, the medial temporal lobe, the precuneus, and the posterior cingulate gyrus (Greicius, Krasnow, Reiss, & Menon, 2003; Raichle et al., 2001).

DMN activation is lower during goal-directed behaviors requiring executive control (Gusnard, Raichle, & Raichle, 2001; Raichle & Snyder, 2007), and higher during self-referential mental activity (Gusnard et al., 2001; Kelley et al., 2002; Vogeley et al., 2001), higher during tasks involving self-projection (Buckner & Carroll, 2007), and higher when attending to stories containing 1st person pronouns (Decety, Chaminade, Grezes, & Meltzoff, 2002; Kjaer, Nowak, & Lou, 2002). DMN activation systematically varies with level of cognitive load—systematically decreasing from eyes-closed rest, to simple eyes-open, and to eyes-open simple fixation (Raichle et al., 2001; Yan et al., 2009).

The default mode network comprises sub-systems that interact and contribute to cognitive functioning. Medial temporal areas add details from past experiences. Ventral-medial prefrontal areas use past details to construct the ongoing self-relevant narrative. Output from both of these areas are integrated in the precuneus and posterior cingulate cortex (Buckner, Andrews-Hanna, & Schacter, 2008).

DMN activation patterns could give insight into the mental procedures during different meditation practices. To date, research reports that most meditation practices—Mindfulness meditation, focused attention, Loving-Kindness, and Choiceless Awareness—lead to *deactivation* of the anterior (medial prefrontal) and posterior (posterior cingulate cortices) subsystems of the DMN in experienced meditators (Brewer et al., 2011; Simon & Engstrom, 2015). Deactivation of the DMN is consistent with the understanding that these meditation procedures involve goal-oriented attentional control.

In contrast, DMN activity is reported to remain high during practice of the Transcendental Meditation® (TM®) technique, compared to eyes-closed rest (Travis et al., 2010). Also, unique to

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Transcendental Meditation practice are the findings that frontal alpha coherence and power are reported to be higher, and beta and gamma power are reported to be lower during TM compared to rest (Travis & Wallace, 1999; Travis et al., 2010). Based on analysis of the EEG research literature, Transcendental Meditation has been placed by some authors in the category of Automatic Self-Transcending (Travis & Shear, 2010). Other authors have placed this technique into the category of Focused Attention (Raffone & Srinivasan, 2010). This paper was designed to clarify this issue.

Superficially, Transcendental Meditation can be described as "thinking" a mantra—a meaningless sound—and going back to it when the mantra is forgotten. This process could be understood as focused attention. However, Transcendental Meditation practice is not a technique of keeping the mantra clearly in awareness. Rather, one learns how to use the mantra as a vehicle for transcending. The sound of the mantra is such that the attention easily entertains it, and one learns during TM how to appreciate the mantra at "finer" levels in which the mantra becomes secondary in experience and ultimately disappears, while self-awareness becomes more primary (Maharishi Mahesh Yogi, 1969;Travis & Pearson, 2000). Thoughts other than the mantra can arise during TM practice. They are part of the process of exploring deep inner silence. During TM practice, thoughts are not actively suppressed, and losing track of the mantra is not seen as a failure. TM does not involve contemplation, focused attention, or monitoring ongoing experience. Rather, TM practice is the process of transcending, coming out onto thought, and transcending again using the "natural tendency of the mind" (Maharishi Mahesh Yogi, 1969; Travis & Pearson, 2000). (The concept of the natural tendency of the mind is discussed in detail in the discussion, Section 4.1.)

Subjects quickly master Transcendental Meditation practice. While significant differences are reported in brain patterns during meditation practice in novice and expert Buddhist meditators (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007), no significant differences are reported between novice and expert TM subjects during the meditation session, as suggested by data from an one-year longitudinal study (Travis & Arenander, 2006), and from two cross-sectional studies: one comparing individuals with 4-months' versus 8-years' Transcendental Meditation practice (Travis & Pearson, 2000), and the other comparing individuals with 7 years' versus 32 years' Transcendental Meditation practice (Travis, Tecce, Arenander, & Wallace, 2002). While no differences are reported during the practice, novice/expert differences are reported during tasks *after* Transcendental Meditation practice. Namely, the high levels of EEG alpha coherence seen during the session begins to be integrated and displayed with waking EEG after the meditation session (Travis & Arenander, 2006; Travis et al., 2002).

The current study explores whether and to what extent focused attention may be part of Transcendental Meditation practice as evidenced by subjective experience and brain patterns. This study explores subjective ratings of the frequency of transcendence in subjects with a range of Transcendental Meditation experience. In this research, transcendence is described as a perfectly peaceful state in which the mind is very awake, but still—a state in which awareness seems expanded beyond the boundaries of thought, beyond the limits of time and space, without the sense of body or environment. Also, this study explores brain patterns during Transcendental Meditation practice and two comparison conditions, namely an eyes-open choice reaction-time task, which is reported to lead to default mode network *deactivation*, and eyes-closed rest, which is reported to lead to default mode network *activation*. These data were analyzed with eLORETA to compare 3-D cortical activation during these three conditions with special attention to frontal and posterior areas included in the default mode network. If Transcendental Meditation practice involves focused attention, then we hypothesize that (1) the subjective ratings of transcendence during TM practice should increase as the person masters the practice over time—with practice controlled cognitive processes can be transformed to an automatic process, (2) greater cortical deactivation of the default mode network during Transcendental Meditation, as compared to eyes-closed rest, and (3) little or no differences in cortical activation in the task/TM comparison.

2. Materials and method

2.1. Subjects

At Maharishi University of Management, students have been encouraged to have their EEG recorded as freshman and as seniors. This research initiative was started in 2010. Presentations are made during orientation meetings to invite students to have their EEG recorded. Data from 87 individuals who participated in this research and so were part of the database in the Center for Brain, Consciousness and Cognition in Fairfield, Iowa were used for this study. This included all subjects, who had both freshman and senior recordings and had been practicing TM from one month to five years. Their mean age was 30.3 ± 9.4 years, and their mean years Transcendental Meditation practice was 1.3 ± 0.9 years. There were 42 females and 45 males. The research was compliant with the Code of Ethics of the World Medical Association and the study was approved by the University's Institutional Review Board. All subjects signed consent forms before beginning the study.

2.2. Procedure

A standard protocol is used to record EEG at the Brain Center. Participants come in the late afternoon after their classes. After completing consent and demographic forms, 32 active-sensors are applied in the 10–10 system with a forehead ground, and left and right earlobe sensors for re-referencing offline. Resistance was <10 kΩ at each sensor. Subjects complete the *Survey of Peak Experiences* to measure frequency of transcending while sensors were applied.

EEG was recorded with the BIOSEMI ActiveTwo System (www.BIOSEMI.COM) during (1) five minutes eyes-closed rest when they were told to "Close the eyes and sit easily, and not begin their TM practice," (2) a 4-min choice reaction-time task, and (3) a five-minute Transcendental Meditation session. All signals were digitized on line at 256 points/s, with no high or low frequency filters, and stored for later analyses using eLORETA.

There were natural breaks between each condition. The instructions and 10 practice trials for the choice reaction-time task gave a natural 4–5 min break between eyes-closed rest and the reaction-time task. Between the reaction-time task and TM practice, the subject discussed their experiences during the task and any strategies they used to perform at their best (3–4 min).

2.2.1. Choice reaction-time tasks

The choice reaction-time task included 24 trials. Each trial included a one or two-digit number (150 ms duration, 1 cm in height), a 1.5-s blank screen, and another one- or two-digit number (150 ms duration, 1 cm in height). Subjects were asked to press a left- or right-hand button to indicate which number was larger in value, i.e. a 10 is larger than a 5.

2.2.2. Survey of peak experiences

This survey consists of four items that assess frequency of experiences of transcendence during eyes-closed rest, during waking activity when engaged in tasks, during sleep, and a question on luck. Subjects were asked to circle the frequency of each

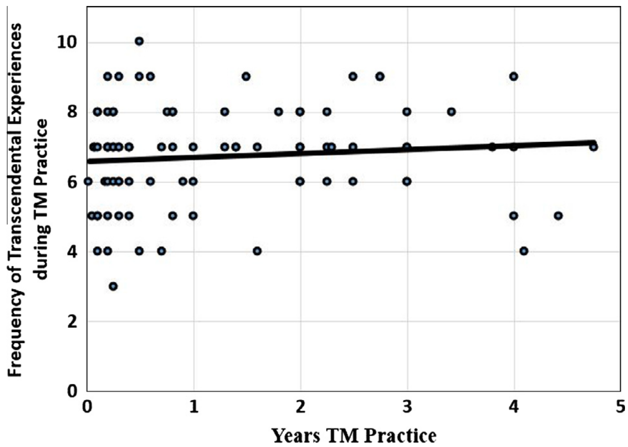

Fig. 1. Scatter plot of years TM practice (x-axis) and self-reported experiences of transcendental consciousness during TM practice (y-axis). The regression line is positive but very flat (r = 0.07). The frequency of "7" corresponds to "more than once per week."

experience on an 11-point Likert scale, from "0" (never to my knowledge) to "11" (all of the time). Cranson et al. (1991) created this scale from the State of Consciousness scale (Alexander, 1982) and the Daily Spiritual Experience scale (Underwood & Teresi, 2001). Although, there is no published data on the reliability and the validity of the Survey of Peak Experiences, frequency of transcendental experiences, as measured by this instrument, is correlated with higher moral development and greater integration of brain functioning in top-performing athletes, managers and musicians (Harung & Travis, 2012; Harung et al., 2011; Travis, Harung, & Lagrosen, 2011).

Responses on the first question of this survey were used for this study, since this question assesses frequency of transcendental experiences during meditation practice. This question reads:

During meditation practice have you experienced a perfectly peaceful state in which the mind is very awake, but still—a state in which awareness seems expanded beyond the boundaries of thought, beyond the limits of time and space?

2.3. Data selection

The first 60-s artifact-free periods during eyes-closed rest, the choice reaction-time task and Transcendental Meditation practice were exported in ASCII format for eLORETA analysis. Research suggests that physiological parameters in the first minute of Transcendental Meditation practice are similar to those in the middle and end of the session (Travis & Wallace, 1999). Thus, these 60-s epochs in the beginning of the TM session should be representative of these subject's EEG during Transcendental Meditation practice.

2.4. Data analysis: LORETA

LORETA was developed at the KEY Institute for Brain-Mind Research at the University of Zurich to calculate 3-D patterns of activation in known grey matter areas (Pascual-Marqui, Michel, & Lehmann, 1994). eLORETA or "exact LORETA" is the latest version of LORETA. While this software has low spatial resolution, as is characteristic of all EEG measurements, the eLORETA algorithms are asserted to have zero localization error (Pascual-Marqui, 2002). The current implementation of eLORETA uses a realistic head model calculated by Fuchs (Fuchs, Kastner, Wagner, Hawes, & Ebersole, 2002) and electrode coordinates provided by Jurcak (Jurcak, Tsuzuki, & Dan, 2007). eLORETA was used to explore 3-D cortical distribution of sources of scalp-recorded electrical potentials in eight frequency bands: delta (1–4.5 Hz), theta (5–7.5 Hz), alpha1 (8–10 Hz), alpha2 (10.5–12.5 Hz), beta1 (13–20 Hz), beta2 (20.5–30 Hz), beta3 (30.5–40 Hz), and gamma (40–50 Hz).

2.5. Statistical analyses

Regression analysis tested the strength and direction of relationship between years of Transcendental Meditation practice (predictor variable) and self-reported transcendental experiences during the practice (criterion variable).

The eLORETA software contains statistical routines to conduct randomized statistical parameter mapping of 3-D areas of grey matter activation (Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002). Reported p-values were corrected for multiple comparisons.

Three comparisons were conducted: (1) eLORETA patterns during eyes-closed rest versus the choice reaction-time task, (2) eLORETA patterns during Transcendental Meditation practice versus the choice reaction-time task, and (3) eLORETA patterns during eyes-closed rest versus Transcendental Meditation practice. The eyes-closed rest/choice task comparison is a standard protocol to identify areas involved in the default mode network (Gusnard et al., 2001; Raichle & Snyder, 2007). This comparison defined eLORETA cortical patterns in these subjects during a protocol known to result in DMN deactivation. These eLORETA patterns were the benchmark to compare patterns during Transcendental Meditation practice.

3. Results

3.1. Regression analysis

Regression analysis of self-reported experiences of transcendental experiences and years of Transcendental Meditation practice was conducted with SPSS 13. This analysis did not reveal significant relations between these two variables ($F(1,86) < 1.0$, ns). Fig. 1 presents a scatter plot of the raw data. Years Transcendental Meditation practice is on the x-axis and frequency of transcendental experiences during the meditation session is on the y-axis. The regression line is positive but very flat (r = 0.07). It crosses the y-axis at "7" which on the survey corresponds to "more than once per week." For comparison, a "6" on this scale means "once or more per month," and an "8" means "once per day." Supporting these subjective reports, eLORETA comparison of cortical activation patterns of individuals practicing TM for less than one year (N = 47) and those practicing TM for more than one year (N = 40) yielded no differences in cortical activation during their TM practice.

3.2. eLORETA analysis: Eyes-closed rest compared to the choice reaction-time task

3.2.1. Eyes-closed rest > task

Higher cortical activation was seen in the theta and alpha bands in the posterior subsystem of the default mode network during eyes-closed rest. Fig. 2 shows statistical parameter maps of higher cortical activation during eyes-closed rest (white areas surrounded by black) compared to the task in the posterior cingulate gyrus (BA 31) in the theta band, and in the posterior cingulate gyrus (BA 31), precuneus (BA 7, 31), medial temporal cortex (BA 39) and inferior temporal cortex (BA 37) in the alpha1 and alpha2 bands. The differences were most wide-spread in the alpha bands.

3.2.2. Task > eyes-closed rest

Higher cortical activation was seen in the beta bands in the ventral lateral and dorsolateral prefrontal cortices, which are part of the central executive network. Fig. 3 shows statistical parameter maps of higher cortical activation during the choice reaction time task (black areas surrounded by white) in the beta2 and beta3 bands in anterior cingulate gyrus (BA 32), ventral lateral prefrontal gyrus (BA 9), and the dorsolateral prefrontal cortex (BA 11).

3.3. eLORETA analysis: Transcendental Meditation compared to the choice reaction-time task

3.3.1. Transcendental Meditation > task

The cortical activation areas in this analysis were strikingly similar to those in the eyes-closed rest/task comparison. Fig. 4 shows higher cortical activation during Transcendental Meditation (white areas surrounded by black) in the posterior cingulate gyrus (BA 31) in the theta band and in the posterior cingulate gyrus (BA 31), precuneus (BA 7, 31), medial temporal cortex (BA 39) and inferior temporal cortex (BA 37) in the alpha bands. The differences were again most wide-spread in the alpha bands.

3.3.2. Task > Transcendental Meditation

Again, the eLORETA activation patterns were very similar to the task/rest comparison. Fig. 5 shows higher cortical activation during the task (black areas surrounded by white) in the beta2 and beta3 bands in anterior cingulate gyrus (BA 32), ventral lateral prefrontal gyrus (BA 9), and the dorsolateral prefrontal cortex (BA 11). These are key areas in the central executive network.

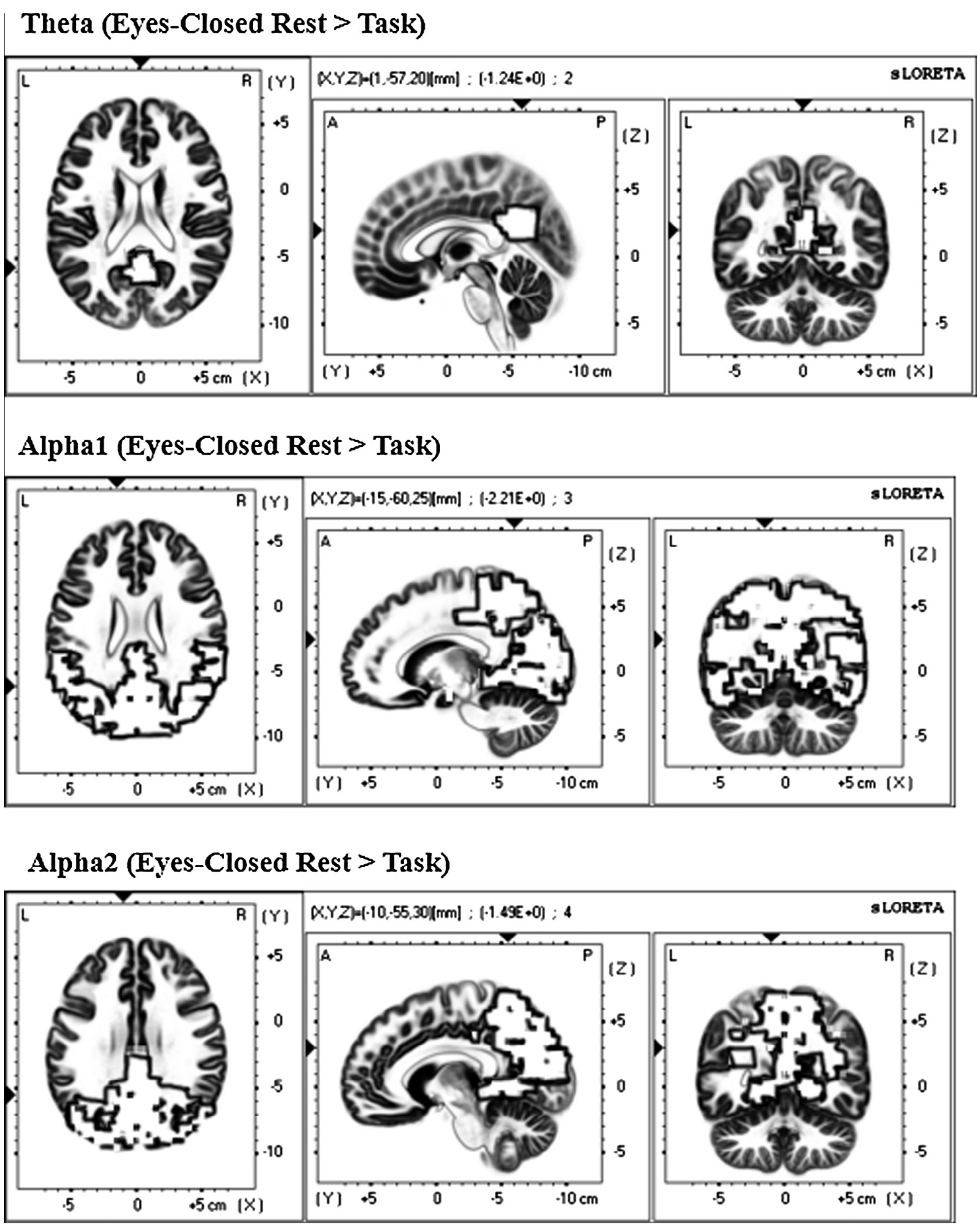

Fig. 2. eLORETA statistical maps: Eyes-closed rest > task. Cortical activation during eyes closed rest (white areas surrounded by black) was higher in the posterior cingulate gyrus in the theta band and in the posterior cingulate gyrus, precuneus, and the medial and inferior temporal cortex in the alpha bands. These are key areas in the default mode network. The differences were most wide-spread in the alpha bands.

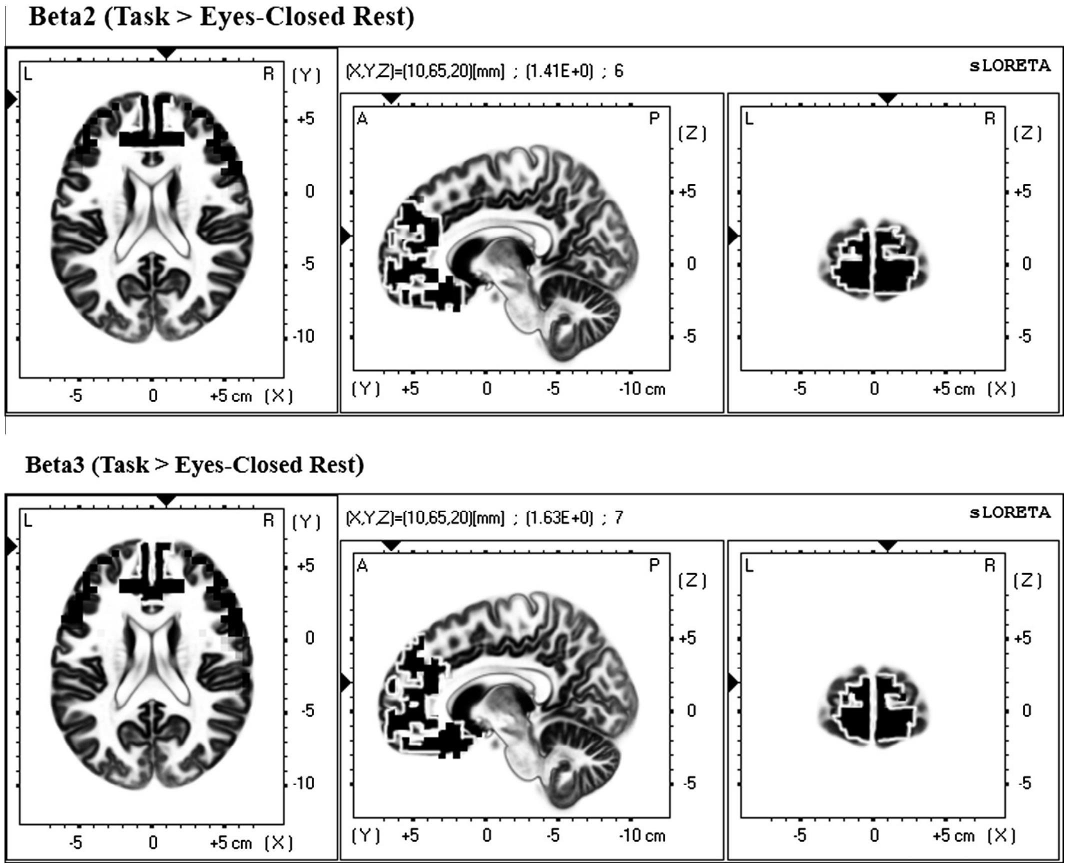

Fig. 3. eLORETA statistical maps: Task > Eyes-closed rest. Cortical activation during the task (black areas surrounded by white). Cortical activation during the task was higher in the beta2 and beta3 bands in the anterior cingulate gyrus, ventral lateral prefrontal cortex, and the dorsolateral prefrontal cortex. These are key areas in the central executive network.

3.4. eLORETA analysis: Transcendental Meditation compared to eyes-closed rest

As presented in Fig. 6, cortical activation was higher in the theta band during Transcendental Meditation (white area surrounded by black) in the orbitofrontal cortex (BA 25, 47), and was higher during eyes-closed rest (black areas surrounded by white) in beta1 band in the right inferior temporal cortices (BA 20, 21).

4. Discussion

Three results stand out in this analysis. First, subjective reports of transcendence during Transcendental Meditation practice were similar in frequency after one month TM practice as after five years TM practice. Second, the eLORETA activation patterns during Transcendental Meditation practice compared to the task were strikingly similar to activation patterns of eyes-closed rest compared to the task. Third, eLORETA activation patterns also differentiated eyes-closed rest and TM practice.

4.1. Why did the frequency of transcendental experiences not increase over time during Transcendental Meditation practice?

A novice/expert dichotomy is reported in many meditation traditions including compassion meditation in the Tibetan Buddhist tradition (Brefczynski-Lewis et al., 2007) and focused attention and open monitoring meditations in the Theravada Buddhist tradition (Manna et al., 2011). As discussed earlier in this paper, novice/expert differences were not seen in brain functioning during Transcendental Meditation practice as reported in cross sectional and longitudinal studies. The subjective reports in the current study of similar frequencies of transcendental experiences in subjects with a range of ages (18–49 years) and range of TM practice (one month to 5 years) fit these brain findings.

If a meditation procedure involves cognitive control, then practice might be expected to meld those processes together leading to greater automaticity in practice, and so deeper experiences over time (Travis & Shear, 2010). The Transcendental Meditation practice was described earlier in this paper as not involving cognitive control—neither focusing the mind nor directing of attention. Rather, Transcendental Meditation practice was described as using the *natural tendency of the mind* to transcend (Maharishi Mahesh Yogi, 1963).

The *natural tendency* of the mind is more than mind wandering. Mind wandering has been investigated using iphone technology in 2250 people. They were randomly texted throughout the day, and asked to answer a happiness-question, an activity-question and a mind wandering-question. Mind wandering with positive emotions was rated at the same level of positive emotional tone as the average of all other tasks, and mind wandering with neutral and negative emotions was rated progressively more negative. This led to the conclusion that a "wandering mind is an unhappy mind" ((Killingsworth & Gilbert, 2010), pg 932). However, follow up research reported that when the object of mind-wandering was rated as being *highly interesting*, it was associated with *greater* positive emotional tone than when the person was on-task (Franklin et al., 2013). The movement of the mind to more interesting experiences is what is intended by the phrase the *natural tendency of the mind*. The mind takes that direction due to the inherent pleasure in

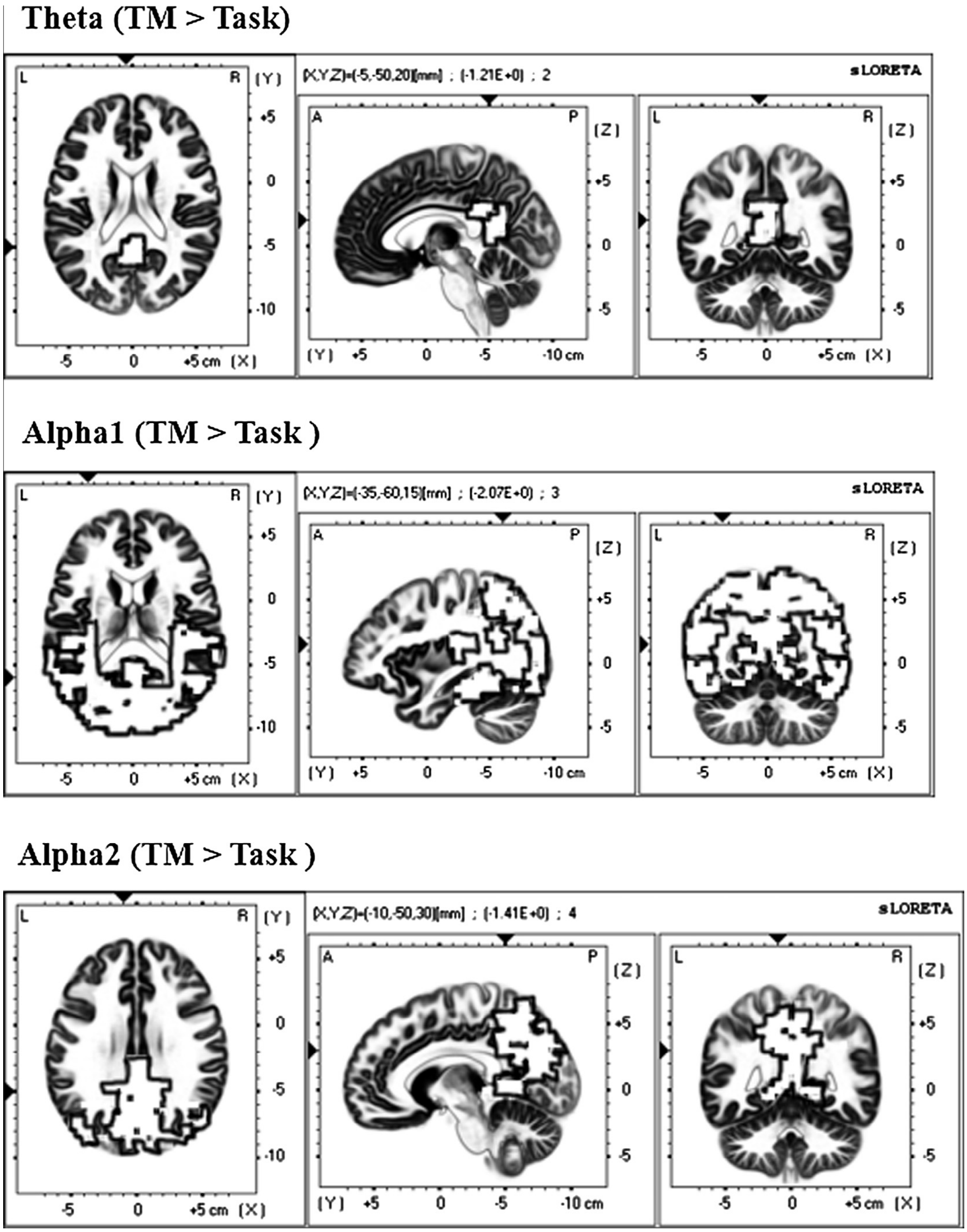

Fig. 4. eLORETA statistical maps: Transcendental Meditation > Task. Cortical activation during Transcendental (white areas surrounded by black) was higher in the posterior cingulate gyrus in the theta band and in the posterior cingulate gyrus, pre-cuneus, and the medial and inferior temporal cortex in the alpha bands. The differences were most wide-spread in the alpha bands. This pattern was very similar to the rest/task comparison.

the experience, rather than through cognitive control. Thus, meditation practices that provide an experience that is pleasurable to the individual could be readily learned and mastered without extensive practice.

4.2. Do eLORETA activation patterns accurately capture DMN activation levels?

Research has not established a relation between default mode network activity levels and eLORETA activation patterns. However, the eyes-closed rest/task comparison in this study is a standard protocol used to elicit deactivation in the default mode network—eyes-closed rest being an inward experience and the task being a goal-oriented, externally directed experience leading to DMN deactivation. Thus, the eLORETA patterns seen in the eyes-closed rest/task comparison should provide a benchmark of DMN deactivation in these subjects when they are involved in a goal-oriented task. Also, there is frequency information in the eLORETA analysis. EEG/fMRI research reports that theta (Fomina, Hohmann, Scholkop, & Grosse-Wentrup, 2015) and alpha spatial patterns overlap with the default mode network (Jann et al., 2009; Mantini, Perrucci, Del Gratta, Romani, & Corbetta, 2007). Thus, theta and alpha eLORETA activation patterns could accurately reflect DMN activation levels.

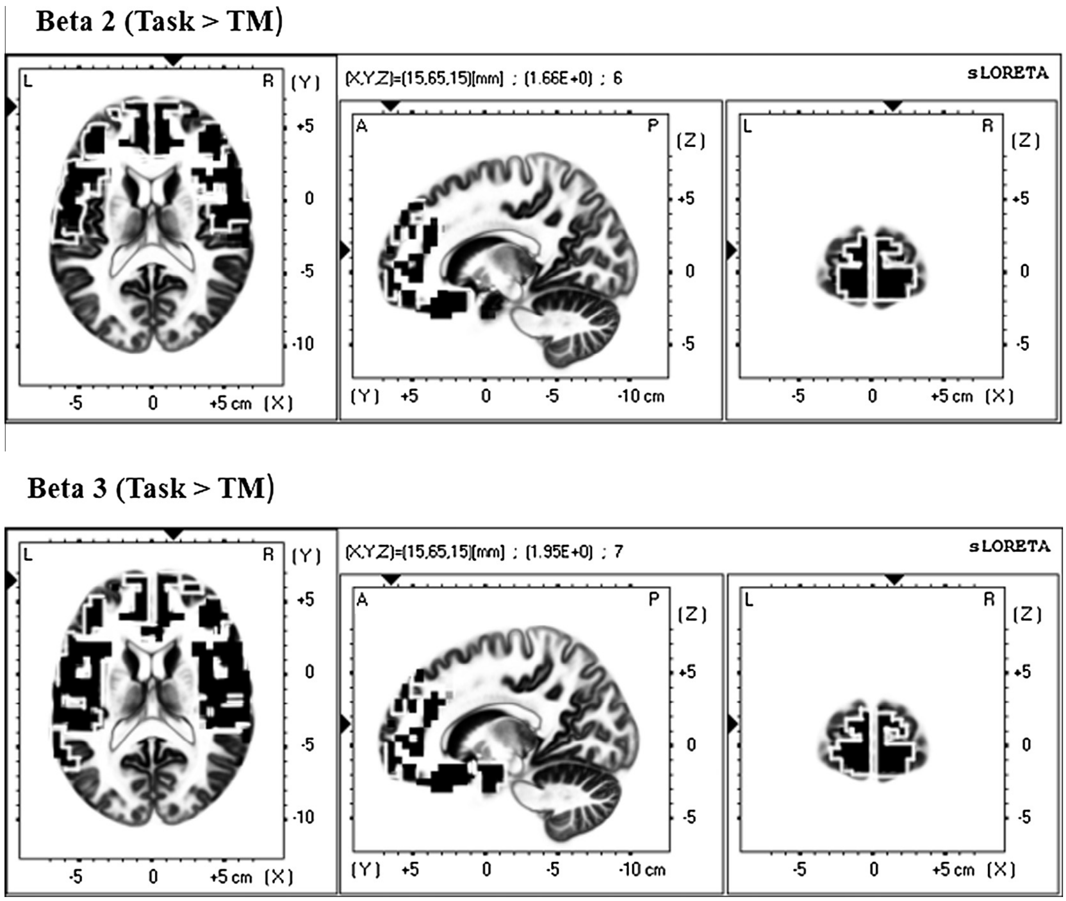

Fig. 5. eLORETA statistical maps: Task > Transcendental Meditation. Cortical activation during the task (black areas surrounded by white) was higher in the beta2 and beta3 bands in anterior cingulate gyrus, ventral lateral prefrontal gyrus, and the dorsolateral prefrontal cortex. These are key areas in the central executive network.

4.3. Consideration of eLORETA patterns during the eyes-closed rest and Transcendental Meditation comparison

The comparisons of eyes-closed rest and Transcendental Meditation to the task condition yielded similar patterns of activation and deactivation. However, there were also differences in eLORETA patterns during eyes-closed rest and Transcendental Meditation practice. During eyes-closed rest, right temporal activation was higher in the beta1 band, and during Transcendental Meditation practice, activation in the orbitofrontal cortex was higher in the theta band.

Beta activity in right temporal areas is associated with memory and motor aspects of speech production (Piai, Roelofs, Rommers, & Maris, 2015). The observed higher beta activation during eyes closed rest could suggest that internal speech was more prevalent during eyes-closed rest compared to TM practice, which could also be phrased as internal mental dialog was reduced during TM.

Theta activation in orbitofrontal cortices is reported in tasks requiring impulse control, such as in go/nogo tasks (Aron, Robbins, & Poldrack, 2004), reward anticipation (Yan et al., 2015), and risk aversion—turning away from negative consequences (Christopoulos, Tobler, Bossaerts, Dolan, & Schultz, 2009). Orbitofrontal theta activation, which appears to reflect movement of attention away from negative and towards more positive experiences, could support the process of transcending—awareness moving to increasingly more abstract, more charming, levels of inner experience. High DMN activation strongly suggests that the process of transcending is not conducted by cognitive control, but by an automatic process that does not require control—such as the *natural tendency of the mind* (see above).

4.4. To what extent might Transcendental Meditation involve focused attention?

Focused attention is characterized by gamma EEG (Singer, 1999). Transcendental Meditation practice is characterized by alpha1 EEG (Travis et al., 2010). Focused attention—any goal-directed activity—is characterized by DMN deactivation (Mantini et al., 2007), and all other meditations have been characterized by DMN deactivation (Brewer et al., 2011). Transcendental Meditation practice was characterized by high levels of DMN activation. The eLORETA patterns seen in the eyes-closed rest/task comparison—the benchmark of DMN activation in this study—were the same patterns seen in the Transcendental Meditation/task comparison. These findings support the claim that TM practice does not involve focused attention.

5. Conclusion

The analyses of eLORETA brain activation and the regression of subjective experience and years Transcendental Meditation practice strongly suggest that the TM technique involves minimal, if any, focused attention. Alpha DMN activation patterns during Transcendental Meditation were similar to those during eyes-closed rest, and individuals with one month through five years TM practice reported similar frequencies of transcendental experiences. Thus, it is not accurate to include Transcendental Meditation practice with other meditations that involve focused attention or open monitoring, since meditations in these categories are reported to lead to DMN deactivation (Brewer et al., 2011), and

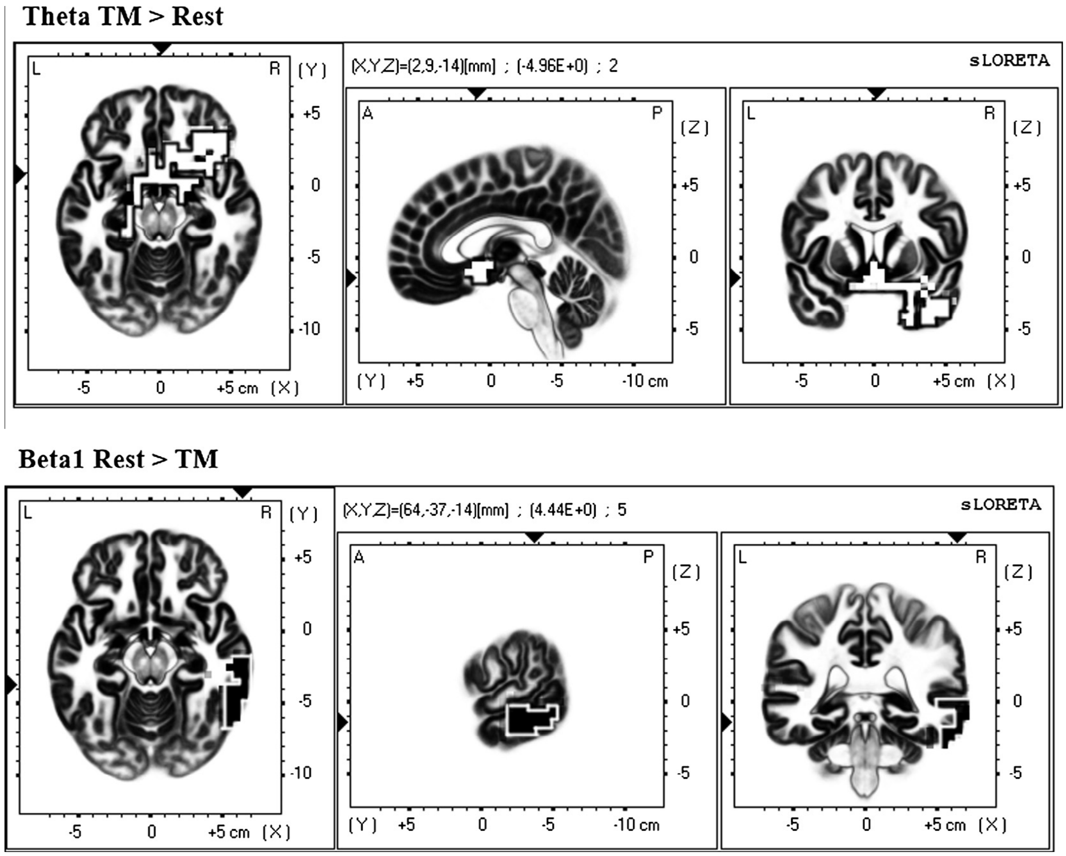

Fig. 6. eLORETA Analysis: Transcendental Meditation Compared to Eyes-closed Rest. Cortical activation was higher in theta band during Transcendental Meditation (white area surrounded by black) in the orbitofrontal cortex, and was higher during eyes closed rest in beta1 band in the right inferior temporal cortices (black area surrounded by white).

they are characterized by different EEG patterns than Transcendental Meditation practice (Travis & Shear, 2010). Mixing meditations with different procedures and brain patterns into a single group only adds noise to the exploration of effects of meditation practice on psychological and physiological measures and distorts assessment of the application of meditation to different subject populations.

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