



# Alterations in the sense of time, space, and body in the mindfulness-trained brain: a neurophenomenologically-guided MEG study

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Meditation practice can lead to what have been referred to as “altered states of consciousness.” One of the phenomenological characteristics of these states is a joint alteration in the sense of time, space, and body. Here, we set out to study the unique experiences of alteration in the sense of time and space by collaborating with a select group of 12 long-term mindfulness meditation (MM) practitioners in a neurophenomenological setup, utilizing first-person data to guide the neural analyses. We hypothesized that the underlying neural activity accompanying alterations in the sense of time and space would be related to alterations in bodily processing. The participants were asked to volitionally bring about distinct states of “Timelessness” (outside time) and “Spacelessness” (outside space) while their brain activity was recorded by MEG. In order to rule out the involvement of attention, memory, or imagination, we used control states of “Then” (past) and “There” (another place). MEG sensors evidencing alterations in power values were identified, and the brain regions underlying these changes were estimated via spatial filtering (beamforming). Particularly, we searched for similar neural activity hypothesized to underlie both the state of “Timelessness” and “Spacelessness.” The results were mostly confined to the theta band, and showed that: (1) the “Then”/“There” overlap yielded activity in regions related to autobiographic memory and imagery (right posterior parietal lobule (PPL), right precentral/middle frontal gyrus (MFG), bilateral precuneus); (2) “Timelessness”/“Spacelessness” conditions overlapped in a different network, related to alterations in the sense of the body (posterior cingulate, right temporoparietal junction (TPJ), cerebellum); and (3) phenomenologically-guided neural analyses enabled us to dissociate different levels of alterations in the sense of the body. This study illustrates the utility of employing experienced contemplative practitioners within a neurophenomenological setup for scientifically characterizing a self-induced altered sense of time, space and body, as well as the importance of theta activity in relation with these altered states.

**Keywords:** space perception, time perception, body perception, magnetoencephalography (MEG), theta rhythm, neurophenomenology, mindfulness meditation

## INTRODUCTION

Long-term contemplative practitioners offer an exclusive opportunity to study unique mental states, due both to their heightened introspective abilities, as well as their ability to intentionally alter subtle aspects of consciousness (Lutz et al., 2007). Here, we employ long-term Mindfulness meditators to study unique states of alteration in the sense of time and space, which have not yet been neuroscientifically investigated.

One of the characteristics of altered states of consciousness is a *joint* alteration in the experience of time and space (Tart, 1972; Glicksohn, 1993; Baruss, 2003; Glicksohn and Berkovich-Ohana, 2011), which has been called by Fingelkurts and Fingelkurts (2006) “a sense of timelessness, spacelessness.” The incidence of mutual alteration in the experience of time and space is so

common that it led Walter Stace, the well-known scholar of mysticism, to include one characteristic named “non-spatial and non-temporal” (1960, p. 110) in his definition of the universal core of mystical experience. According to Suzuki, *sunyata*, the Buddhist concept of emptiness, means: “absolute emptiness transcending all forms of mutual relationship... There is no time, no space, no becoming, nothingness... when the mind is devoid of all its possible content” (in Stace, 1960, p. 109). Similarly, in Vedic psychology, transcendental consciousness, which is a state achieved through the practice of Transcendental Meditation in which the individual’s mind transcends all mental activity to experience the simplest form of awareness, is characterized by being unbounded in space and time (Alexander et al., 1987).

Cognitively, an altered sense of time can be viewed as the limit for the functioning of the cognitive timer, the breakdown of apparent duration (Glicksohn, 2001). Apparent duration, in turn, is closely related to spatial perception (Boroditsky and Ramscar, 2002; Glicksohn and Myslobodsky, 2006; Srinivasan and Carey, 2010; reviewed by Walsh, 2003). Neuroscientific evidence suggests common underlying mechanisms for spatio-temporal processing (Basso et al., 1996; Walsh, 2003; Danckert et al., 2007; Oliveri et al., 2009a), as do linguistic (Boroditsky and Ramscar, 2002; Núñez and Sweetser, 2006; Casasanto, 2008, 2010) and psychophysical studies (e.g., Sarrazin et al., 2004; Oliveri et al., 2009a,b; Srinivasan and Carey, 2010). An altered experience of space has been called by Stanley (1898) “space annihilation,” again in relation to the time dimension. An altered sense of time and space has hardly been studied scientifically, the major obstacle being the production of these experiences in the lab (but see the hypnosis experiment of Aaronson, 1970).

Phenomenologically, altered states of consciousness are frequently accompanied by a joint alteration in both the experience of time and space, as noted above, but also in bodily perception (Tart, 1972; Travis and Pearson, 2000; Shanon, 2003; Vaitl et al., 2005; Hunt, 2007; Ataria and Neria, 2013). Hence, we hypothesized that an altered sense of time and space would be related to an altered sense of body. An altered sense of body is conceptualized as a disrupted sense of spatial unity between self and body, where the self is not experienced as being confined within the boundaries of the body. A possible candidate mediating this connection is the insula, related to both proprioception and the sense of time (Craig, 2002, 2009a,b).

Mindfulness meditation (MM) practice focuses on cultivating a non-judgmental awareness of momentary experience (Kabat-Zinn, 2003) with the aim of liberation from human suffering (Olendzki, 2003; Dreyfus and Thompson, 2007). While not being the goal of training, long-term practice is often accompanied by altered states of consciousness (Stace, 1960; Goleman, 1988; Shapiro, 2008). This makes MM practitioners potentially familiar with alteration in the experience of both time and space. In addition, advanced practitioners have been documented as not only being able to produce voluntary alterations of subtle consciousness-related experiences within laboratory settings, but also to provide refined first-person descriptions of these experiences (Lutz et al., 2007). This renders MM practitioners ideal candidates for the study of such unique states, which have hitherto been quite unexplored.

Here, we study the experience of alteration in the sense of time and space by collaborating with a select group of 12 long-term MM practitioners in a neurophenomenological setup. All of the participants have experienced these states in the past (see Methods), and thus possess a frame of experiential reference. The participants were asked to volitionally produce two distinct states, which we *a priori* named “Timelessness” and “Spacelessness” (outside time and space, respectively). In order to rule out the involvement of attention, autobiographic memory or imaginative processes (Szpunar et al., 2007), participants were also asked to produce control states of “Then” and “There” (be in the past and in another place, respectively). The data were analyzed in terms of “Timelessness” vs. “Now” and “Spacelessness”

vs. “Here,” and contrasted with “Then” vs. “Now” and “There” vs. “Here” (two target and two control contrasts, respectively). In particular, we investigated whether there would be similar neural activity underlying both these states of “Timelessness” and “Spacelessness.” Specifically, we hypothesized that: (1) the control conditions, “Then” and “There,” would yield overlapping activity in an autobiographic memory network; (2) “Timelessness” and “Spacelessness” conditions would overlap in a different network, related to alterations in the sense of body, including the insular cortex; and (3) phenomenologically-guided neural analyses would yield further insight into the underlying physiology of the alteration in the sense of time and space.

## METHODS

### PARTICIPANTS

Sixteen practitioners participated in this study, of whom two were excluded due to self-reported severe tiredness and back pain, respectively, during the data recordings. Two others were excluded as they practiced different forms of meditation (not MM), in an attempt to homogenize the group. The remaining participants practiced within the Theravada tradition. Participants were right-handed (3 females, age  $44.9 \pm 10.9$  years, range: 31–64) and healthy, with no history of mental or neurological diseases. All participants were long-term practitioners with an average of 16.5 ( $SD = 7.9$ , range: 9–34) years, and 11,225 ( $SD = 9909$ , range: 1290–29,290) total hours, of meditation practice. The study was approved by the Research Ethics Board of Bar-Ilan University. The participants gave their written consent and were financially compensated.

### PRE-RECORDING PROCEDURES

The participants were introduced to the lab, then filled out forms (research consent, personal details, formal practice estimate) and Hood’s (1975) Mysticism scale, to test for previous experiences of alteration in the sense of time and space. The experimenters explained to the participants each part of the experiment, and it was made certain that the participants understood the tasks. Altogether, this part took 45–60 min.

### Hood’s (1975) MYSTICISM SCALE (MSCALE)

Hood’s (1975) Mscale is a general measure of self-transcendent experience, based on Stace’s (1960) conceptualization of eight dimensions of transcendence. This is a 32-item scale, where the items are grouped into eight components of experience: *Positive affect*, *Religious quality*, *Noetic quality*, *Ineffability*, *Unifying quality*, *Inner subjective quality*, *Ego quality*, and *Temporal and spatial quality*, the last being an experience of “timelessness” and “spacelessness.” The results of the last item were used to assess whether participants had previous experiences of altered sense of time and space, of interest for this report. The four statements pertaining to this item were: (1) I have had an experience which was both timelessness and spacelessness; (2) I have had an experience in which I had no sense of time or space; (3) I have never had an experience in which time, place, and distance were meaningless; and (4) I have never had an experience in which time and space were non-existent. Participants were requested to indicate on a five-point scale from  $-2$  (*definitely not true*) to  $+2$  (*definitely true*), the extent to which each of 32 statements is true of their own

experiences. After reversing appropriate items, these responses are converted to a five-point Likert scale, from 1 (*low*) to 5 (*high*), where indecision is scored as 3.

The mean score for the Mscale was  $4.30 \pm 0.40$ , indicating that participants experienced mystical states high above the indecision point. Importantly, mean score for the sub-scale of *Temporal and spatial quality* was high,  $4.47 \pm 0.67$ . Thus, participants had previous acquaintance with the concurrent experience of alteration in the sense of time and space. For comparison, the mean Mscale score in a population of 191 religious participants was 3.58, and the *Temporal and spatial quality* was 3.42 (Lazar and Kravetz, 2005). This indicates that meditation practice increases the occurrence of alteration in the sense of time and space experiences high above mere religious tendency.

### EXPERIMENTAL TASKS

The experiment comprised seven MEG recording sessions. Each session was followed by an interview conducted via the intercom system, during which brain activity was not recorded. The participants were encouraged to stretch their limbs and relax during the interviews, but were requested not to move and to keep their eyes closed while performing the tasks. To correct for head and body movements during the interviews, head-shapes were re-registered at the beginning of each session. A 20-min break was suggested to the participants after completing the 5th session of the experiment, during which refreshments were offered. Total time in the MEG was around 2 h.

The two sessions reported here are the “Time” and “Space” sessions (3rd and 4th, respectively), which were preceded by a resting state and a time production session, and followed by a “Self” session, reported elsewhere (Dor-Ziderman et al., 2013). The participants were asked to volitionally bring about alterations in their experience of time and space, in a manner which had been previously explained. Each of the two sessions comprised 3 conditions, each repeated 3 times in succession for 30 s (Figure 1). A recording with instructions for each condition was sounded (<2 s), after which the participant performed the requested task for 30 s. At the end of the 30 s, a short sound was heard indicating the participant to stop, and then the next instruction was delivered. The session was followed by a structured interview conducted via the intercom system.

The specific instructions for the three conditions in the “Time” session were:

“Now”—“Try to be in the present moment”

“Then”—“Try to be in the near past (in the same place—the lab)”

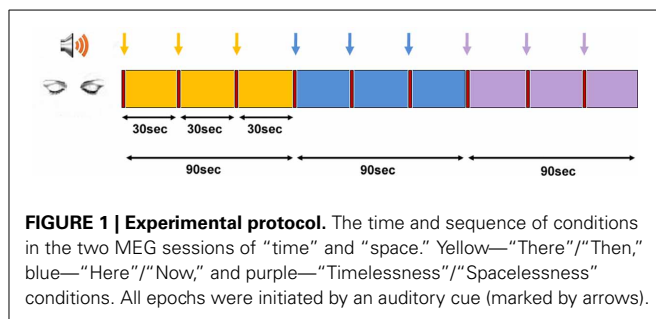
“Timelessness”—“Try to be outside time”

The specific instructions for the three conditions in the “Space” session were:

“Here”—“Try to be here”

“There”—“Try to be elsewhere (at the moment, with the experimenters outside the shielded MEG room)”

“Spacelessness”—“Try not to be in the center of space”



### SUBJECTIVE REPORTS

#### Phenomenological analyses

Participants were asked, immediately after each session, to describe their experiences during the session, following a semi-structured interview. The reports of the “Timelessness” and “Spacelessness” conditions were carefully analyzed by the first author. Two broad themes emerged: “sense of time and space,” and “bodily boundaries,” each including several categories of experience. Subsequently, participants were allocated into one of three categories for the “sense of time and space” theme, and into one of four categories for the “bodily boundaries” theme. The reports were then given to four other judges for anonymous rating. A classification of any report to one of the categories was accepted based on the majority (minimum three out of five) (Table 1).

For the “sense of time and space” theme, three categories emerged, all along a continuum of increasing alteration in the sense of time and space:

- (i) Regular sense of time and space (regular TS)—regular experience of time and space.
- (ii) Change in the sense of either time or space (Change either TS)—an alteration in the usual sense of time or of space.
- (iii) Change in the sense of both time and space (Change both TS)—an alteration in the usual sense of both time and space.

For the “bodily boundaries” theme, four categories emerged, the first three along a continuum of alteration in bodily boundaries and egocentric frame of reference:

- (i) Regular bodily boundaries (regular BB)—regular experience of bodily boundaries, fully egocentric experience.
- (ii) Lower bodily boundaries (lower BB)—weaker than usual experience of bodily boundaries, bodily expansion, a reduction in the egocentric experience.
- (iii) Substantial loss of bodily boundaries (Substantial loss BB)—very weak, and occasionally a total loss of experience of bodily boundaries, strong bodily expansiveness, a strong reduction in the egocentric frame of reference.
- (iv) Out-of-body experience (OBE)—an extracorporeal egocentric perspective (floating outside one’s body and perceiving one’s physical body from a place outside one’s body), with normal or distorted bodily boundaries.

**Table 1 | Classification of participants to phenomenological categories and groups.**

ID no.	Timelessness description	Category		Spacelessness description	Category		Group
		Body boundary	Sense of time/space		Body boundary	Sense of time/space	
11	The fact that I tried to reach this state obstructed it. The moment there was intention there was a narrowing of the space. But there were moments where I felt outside time and space. There was a vanishing of bodily sensations, although there was awareness to awareness itself. The purest form of the sensation was there, but un-restricted. There was relaxation and widening. The body was not present. There were no body sensations in the Timelessness moments. In the pure awareness moments there was no awareness to bodily boundaries. There was spatial expansion.	Substantial loss BB	Change both TS	The bodily dimension expanded but there was no sense of boundless space, rather that body dimensions have changed. The body was wider and wider. The body as physical image was absent. There was a sense of open space without the bodily dimension. The mechanism that senses time was absent. There was a sense of immediateness, without a center aware of temporality.	Substantial loss BB	Change both TS	BTS
12	It was a sense of un-knowing. It was actually close to the present moment. I had to let go of the present moment, and it was subtle. Entering this experience was through the present moment, and then I had to leave the world of experience in order to let go of the present moment. I focused in not knowing the moment. Like letting-go, falling. The bodily sensation disturbed and I had to let go of it again and again, as it returned automatically.	Lower BB	Change both TS	It was a sense of spaciousness, boundlessness, the center was not so interesting, there was no clarity where the center is and where is the periphery. There was no quality of border. Sensations were minimal compared to the "Here" condition; the sense of space occupied 90% of awareness. Maybe there was a slight increase in a visual sense of blackness, maybe because associating space. I was not aware of my self - boundaries. There was a sense of timelessness in the background.	Substantial loss BB	Change both TS	BTS
5	There was relaxation and letting-go, emptiness, experience of bliss. Quiet, wide, something wider than the body. Like a long line crossed me and continued beyond me. More open, something relaxed in the muscles. A wide experience with un-defined boundaries. A sense of dissolving, that I am dissolving, my body dissolving.	Substantial loss BB	Change either TS	The metaphor is an amoeba, everything spreads. A sense of nothingness, emptiness. A sense of expansion. There's quiet, the hearing sharpens. A part of the time I was outside myself, in another world. There was no time.	Substantial loss BB	Change both TS	BTS
13	It was hard not to think of time, to be outside time. After a while I started worrying about the time. It was most similar to being in the present moment, not being occupied with time. There was no alteration in sensation, it was more mental, but everything felt wider, and there was no awareness to bodily and self boundaries.	Substantial loss BB	Change either TS	When I was outside the center of space the mind became more spacious and exploring. There was no self-reference. A state of wide and spacious mind. There was less emphasis on the body, more on the mental space. Time seemed less important, not well defined.	Lower BB	Change both TS	BTS

(Continued)

Table 1 | Continued

ID no.	Timelessness description	Category		Spacelessness description	Category		Group
		Body boundary	Sense of time/space		Body boundary	Sense of time/space	
14	There was an expansion of the chest. I lost discrimination between different body parts. It felt pleasant, like a huge hammock. A sense of expansion. There was a spatial change, I was aware both of the bodily boundaries as well as a pleasant dissolution, something liquid-like.	Substantial loss BB	Change either TS	It was like being in the tub hole where all the water drains. Self-forgetfulness. A sense that everything drains to me. Like wood barks, the space outside, and suddenly a collapse into my body. Like nylon that you stretch and let go of repeatedly. ... Bodily sensations were wider. Bodily space was larger. Much less awareness to my self boundaries. There was no change in the sense of time.	Lower BB	Change either TS	BTS
4	The mind was in the present moment, as this is the gate to timelessness. I felt pressure to succeed, and that time was too short to enter a "blackout," which is for me a Timelessness dimension. There was awareness to body and breath, I was aware of the subject-object duality.	Regular BB	Regular TS	I released the subject-object contrast, and then the center of space became endless, without a reference point in the middle. There was a sense of floating in a sea of being. Experiences arise, but no emotions, no sounds. Everything was a part of one conscious experience. The dichotomy between subject and object dissolved. There was no reflective awareness of "this is a sound." Everything was a part of a singular event. The experience of the body faded. There was a sense of body in the background, not in front of consciousness. There were no self boundaries, only fusion with everything that exists. There was a change in the sense of time, time lost its linearity.	Substantial loss BB	Change both TS	NTS
9	All the time I focused on visualizing black, as if I see darkness, not considering anything related with time. There was no sensory alteration, but I was less aware of how much time passed. There was awareness to space, but lower than usual. Fifty percent of the time I was not aware of my bodily boundaries.	Substantial loss BB	Change both TS	I was imagining that the body is un-real, fragmented all over the place, breaking apart. I used perception—the mind is not mine, it's only processes in time. It's not I who is thinking, thoughts exist, simply energy. It's not me who is in the space. There was no alteration in bodily sensations. I was not aware of the mental side, and less aware of the physical side. There was an alteration in the sense of time. When I related to the body as non-existent it became abstract and time was less relevant.	Regular BB	Change either TS	NTS
1	I wasn't outside time. I tried not to localize myself, not knowing where I am in time, not to control my thoughts, not even to here. There was an alteration in bodily sensation in the direction of less, I cannot define it.	Lower BB	Regular TS	I let myself be very big, expand. There was little awareness to different body parts, more something like not exactly I. Mainly a sense of expansion, something open and wide. Little bodily boundaries compared to the usual feeling. Little instances of awareness to my boundaries. There was no change in the sense of time.	Lower BB	Change either TS	NTS

(Continued)



Table 1 | Continued

ID no.	Timelessness description	Category		Spacelessness description	Category		Group
		Body boundary	Sense of time/space		Body boundary	Sense of time/space	
6	The mind could not produce this condition. There was a sense of the body, many bodily sensations.	Regular BB	Regular TS	It was hard to differentiate space from time. It was a little more successful than the Timelessness condition, but didn't put me outside space. I let myself rest within the sensations, than the sense of time and space becomes vague, there was just presence.	Regular BB	Change either TS	TS
2	It started with momentary experience, as I usually enter timelessness through momentary experience. I tried to dim concrete signs of momentary experience, like body and breath. I tried to be less focused on what is happening now, like sensory experience.	Regular BB	Regular TS	It was like before with Timelessness. I started with momentary sensation of my body lying down, and then I tried to expand the experience. Meaning, to dim bodily boundaries and to see if I can experience myself wider, extended, less physically bounded. The focus was trying to dim bodily boundaries; I gave less attention to what is happening in the time domain.	Lower BB	Regular TS	NTS
16	It was like floating, trying to remain in a letting go state. The bodily boundaries did not change, there was no sensory change, it was more mental.	Regular BB	Regular TS	I tried to be in a state of rest where it's as if I lose my center, my thought, and it alternated. A pleasant bodily sensation. A regular sense of self. Much less sense of time.	Regular BB	Change either TS	NTS
8	It was very hard to maintain, every sound disturbed it, it was about being very quiet and concentrated, a very visual experience. It jumped to my mind "I'm floating outside the earth and atmosphere." I saw the time-line from a bird view. There was no awareness of momentary physical sensations, only awareness to bodily boundaries. I took myself to a different space, I wasn't here. But I was with my body, just floating in outer space. The body was identical, I wasn't floating as consciousness, but as a body.	OBE	Change both TS	The body stayed in bed but I saw myself from the corner of the room. The first time (first 30 s) it was continuous. The second time it was hard to maintain and I kept entering and leaving my body. In the third time I came back to the corner and it was more successful. Outside the body I felt short and small, like a little child, I shrank. I went in and out of bodily borders. It's hard to say if there was any temporal change. The third time seemed too short.	OBE	Change both TS	Excluded

Yellow and cyan, sentences pertaining to body or to time/space, respectively. BB, bodily boundaries; OBE, Out of body experience; TS, time and space; BTS, Both time and space; NTS, Not both Time and Space.

In line with this analysis, 11 participants could be placed along a continuum of alteration in bodily boundaries and egocentric frame of reference. As the OBE could not be placed along the continuum of reduction in egocentric frame of reference, the sole participant having this experience was excluded from all subsequent analyses (see Table 1). The remaining 11 participants were included in the subsequent analyses, and were regarded as being placed along one continuum: at one end were those who experienced a weak and gentle shift, while at the other end were those who experienced a profound shift. This is in line with

Shapiro (2008) who states that unique meditative states "need to be seen along a continuum. On one hand of the continuum are "full blown" mystical experiences, at the other, more common alterations of perception" (p. 25). Next, we set out to differentiate between participants along the higher and lower ends of the above continuum, by creating two groups (Table 1):

- (1) Both Time and Space (BTS) group—during the two conditions of "Timelessness" and "Spacelessness," participants experienced a change in both themes of phenomenal

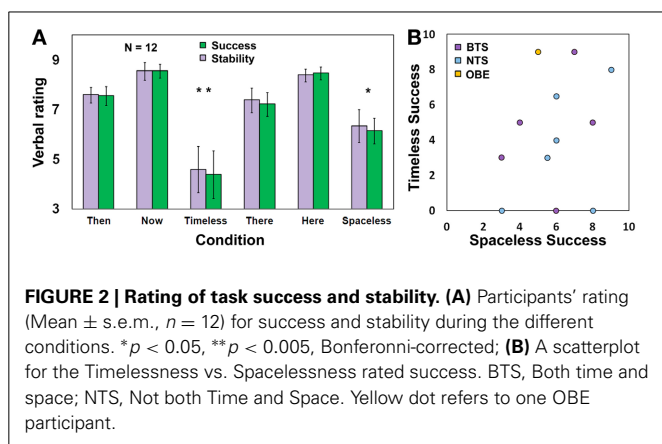
experience (i.e., do not belong to “Regular BB” or “Regular TS”).

- (2) Not both Time and Space (NTS) group—during the two conditions of “Timelessness” and “Spacelessness,” participants did not experience a change in both themes of phenomenal experience (i.e., belong to “Regular BB” or “Regular TS”).

Testing for differences between the BTS and NTS groups, there were no significant differences in age or practice experience, as well as mean score for the Mscale or the sub-scale of *Temporal and spatial quality*.

### Success and stability ratings

Participants were asked to verbally rate, on a 1–10 scale (1—“very low,” 10—“very high”), their success (defined here as: how strong was the experience, on average, across the 90 s allocated for each condition) and stability (defined here as: how stable was the experience during the 90 s allocated for each condition) in performing each of the tasks. Subsequently, a Three-Way ANOVA was conducted, with Session (Time/Space)  $\times$  Condition (Then/There, Here/Now, Timelessness/Spacelessness)  $\times$  Measure (success, stability) on these ratings. There was no difference between success and stability (Figure 2A), hence we will focus subsequently on success. We found only a main effect for Condition [ $F_{(2, 20)} = 18.5$ ,  $MSE = 5.07$ ,  $p < 0.0001$ ]. The “Timelessness” and “Spacelessness” conditions were rated as significantly less successful compared to “Here” and “Now” [ $t = 3.80$ ,  $p = 0.011$  and  $t = 3.99$ ,  $p = 0.0045$ , respectively, Bonferroni-corrected *post-hoc* paired *t*-tests], but showed no significant difference between them. When comparing scores for the “Timelessness” and “Spacelessness” conditions between the BTS and NTS groups, no significant difference was found. Figure 2B depicts the rating for the “Timelessness” vs. “Spacelessness” conditions, showing the BTS and NTS groups to be similarly distributed. This is in contrast to the phenomenological difference found between the groups. We suggest that the discrepancy stems from different levels of self-criticism, as well as different personal expectations. In fact, some of the most-experienced practitioners scored their success as being lower compared to the less-experienced practitioners. Altogether, our results emphasize the need to collect verbal reports in addition to self ratings when conducting neurophenomenological analyses.



An additional observation is that the “Timelessness” scores were more variable compared to the “Spacelessness” scores. The reason for this is that two of the three participants reporting zero success in the “Timelessness” condition belong to the Burmese Mahasi school, which adheres strictly to the “Progress of insight” which is an inner “map” of how insights unfold through 16 developmental stages of insight knowledge. This tradition encourages an experience of “cuts” in consciousness, which are considered the culmination of these stages, and are called fruition (*phala*). Nanarama (1983) describes this state: “consciousness...transcends the continuous occurrence of formations and aligns upon non-occurrence” (p. 117). The fruition is mentioned here in some length, as it turned out that these two participants attempted to reach this acquainted state unsuccessfully during the short time allocated to the “Timelessness” condition, which affected their rating of success. However, after the Time session, it was emphasized that the experimenters did not expect these unique fruition states during the short lab procedure, thus their scores for the “Spacelessness” condition increased markedly, to 6 and 8.

### MAGNETOENCEPHALOGRAPHY (MEG)

#### MEG data acquisition

MEG recordings were conducted with a whole-head, 248-channel magnetometer array (4-D Neuroimaging, Magnes 3600 WH) in a magnetically-shielded room. Reference coils located  $\sim 30$  cm above the head oriented by the  $x$ ,  $y$ , and  $z$  axes were used to remove environmental noise. Head position was indicated by attaching 5 coils to the scalp and determining, to a 1 mm resolution, their position relative to the sensor array before and after measurement. Head localization was performed before and after each set of tasks to determine degree of head movement. Head shape and coil position were digitized using a Pollhemus FASTTRAK digitizer. Brain signals were recorded with a sampling rate of 1017.25 Hz and an analog online 0.1–400 Hz band-pass filter. The instructions for each condition were presented using E-prime 1.0 and delivered via a STAX SRS-005 amplifier and SR-003 push-pull electrostatic ear speakers coupled by a vinyl tube to silicon earpieces to prevent magnetic noise within the shielded room. Task performance ratings were collected using a LUMItouch photon control response box.

#### MEG data cleaning and preprocessing

Data processing and analysis was performed using Matlab® R2009b and FieldTrip toolbox for MEG analysis (Open source software for advanced analysis of MEG) (Oostenveld et al., 2011). Data were cleaned for line frequency (by recording on an additional channel the 50 Hz from the power outlet, and subtracting the average power-line response from every MEG sensor), and 24 Hz building vibration (measured in  $x$ ,  $y$ , and  $z$  directions using 3 Bruel and Kjaer accelerometers) artifacts (Tal and Abeles, 2013). The data from the 3 “Time” and 3 “Space” conditions were then segmented into non-overlapping 2-s epochs. Each epoch was visually examined for muscle and jump artifacts (in the MEG sensors). Contaminated epochs were discarded. No malfunctioning MEG sensors were identified. To ensure the removal of all heartbeat, eye and muscle artifact, an independent component analysis (ICA) was performed on the data (Jung et al., 2000).

Segmented data were down-sampled to 339 (1017/3) Hz to speed up data decomposition. The data were then decomposed into a set of independent components (248, equal to the number of sensors) ordered by degree of their explained variance. Components indicating heartbeats or eye movements were determined from a visual inspection of the 2D scalp maps and time course of each component. The remaining components were then used to reconstruct the pre down-sampled data.

### Sensor-level analyses

The first 4 s of each task (3 tasks of 30-s in each condition) were omitted so as to allow the participants sufficient time to enter the states. This decision was made after consulting an expert meditator as to the study design, and following two self-pilot runs (with Aviva Berkovich-Ohana and Yair Dor-Ziderman, also long-term practitioners). From the remaining data in each condition, the first 32 epochs were used for further sensor-level analyses. These 2-s epochs were multiplied by a Hanning taper, and subjected to a Fast Fourier Transformation (FFT) for the frequencies ranging from 4 to 45 Hz. This resulted in a power spectrum with a frequency resolution of 0.5 Hz for each epoch. The power spectra were then averaged across the epochs of each condition and across the theta (4–8 Hz), alpha (8–13 Hz), beta (13–25 Hz), and gamma (25–45 Hz) frequency bands, thus obtaining mean power for each condition, participant and frequency band.

Sensor-level cluster-based statistics were assessed, and corrected for multiple comparisons, using a Monte-Carlo non-parametric permutations approach (Maris and Oostenveld, 2007). This approach was chosen as it does not make any assumptions on the underlying distribution. Finally, 2D *t*-value scalp topographies marking the significant clusters were created.

### Source-space projection

Localization was performed for all frequency bands. Sources were estimated using Synthetic Aperture Magnetometry (SAM, Robinson and Vrba, 1999). SAM is an adaptive non-linear minimum-variance beamformer algorithm. It calculates the signal covariance from the MEG sensor data and uses it in conjunction with a forward solution for the dipoles at each 3D brain voxel (of a specified size) to construct optimum spatial filters. The spatial filtering suppresses interference of unwanted signals from other locations.

For source estimation, the pre-ICA data were used. Data were band filtered (using the SAM default IIR filter) for each participant and condition and frequency band. Covariance matrices, and subsequently SAM weights, were computed for each 5 mm cubic voxel using the data from the two conditions participating in each signal change calculation, for each frequency-band-filtered time-series data. For each voxel, the data were multiplied by the weights, thus creating “virtual sensor” time-series, which were then transformed via FFT to the frequency domain, thus deriving power values. The next step involved calculating, for each frequency of each sensor of each participant, a power signal (SC) metric, for estimating activity differences between contrasted conditions. For normalization, SC was computed using a log ratio. More specifically, for sensor *S*, frequency *f*, and power values of conditions *A* and *B*,  $SC[S(f)] = \log(A/B)$ . Each participant's SC values for each of the comparisons were then collapsed across

all sensors, and averaged across the frequency bands specified above in the sensor-level analysis.

To facilitate group analysis, head models were constructed by co-registering each participant's SAM volume to a previously obtained MRI scan (T1-weighted anatomical images acquired with high-resolution 1-mm slice thickness, obtained by Aviva Berkovich-Ohana, by means of a 3T Trio Magnetom Siemens scanner located at the Weizmann Institute of Science, Rehovot, Israel), based on the position of the fiducial markers established during the digitization phase. Each participant's MRI and its co-registered SAM volume were then transposed into a common Talairach anatomical space (Talairach and Tournoux, 1988). Voxel-level group statistics, for each comparison and frequency band, were conducted using one-sample *t*-tests against the null hypothesis that the SC measures came from a continuous, normal distribution with a zero mean, and corrected for multiple comparisons based on a Monte Carlo simulation of random noise distribution (using AFNI's 3dClustSim module) (Forman et al., 1995).

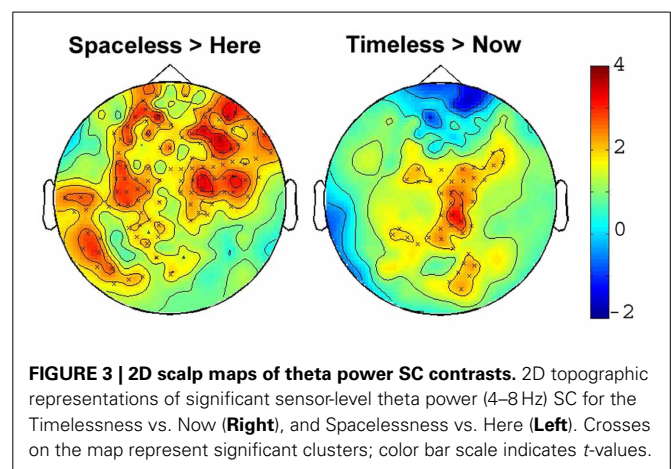
## RESULTS

### MEG SENSOR-LEVEL RESULTS

We first tested for significant differences in power between the “Here” and “Now” conditions, which were considered to be the baseline states for the other conditions. Importantly, there were no significant differences between them in any of the four frequency bands tested. Testing the “Spacelessness” vs. “Here” and the “Timelessness” vs. “Now” contrasts, we found clusters of significant differences only within the theta band ( $p = 0.014$ , and  $p = 0.049$ , respectively). **Figure 3** provides 2D topographic representations of the sensor-level *t*-values for these two significant contrasts. As could be expected, the two contrasts evidence a different topography. The significant clusters for “Spacelessness” vs. “Here” occur predominantly over bilateral central-frontal electrodes, while “Timelessness” vs. “Now” shows central and right lateralized theta activity. However, there is an overlapping region (right central), which is further explored at the source level.

### MEG SOURCE LOCALIZATION ESTIMATES

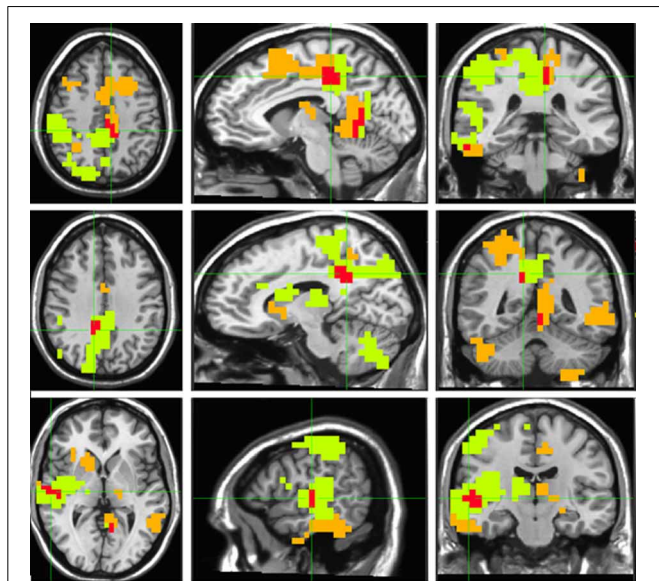
To examine the neural activity underlying the conditions of “Timelessness” and “Spacelessness,” “Timelessness” was compared





to “Now,” and “Spacelessness” was compared to “Here.” Although the sensor-level analyses guided our source localization toward the theta frequency, we validated these results by searching for an overlap between the time and space comparisons over all frequency bands. Overlapping clusters were found only within the theta band, indicating increased activity. While not being the main goal of this study, we nevertheless report the “Timelessness” and “Spacelessness” activity patterns, before focusing on their overlapping activity.

“Timelessness” vs. “Now” (Figure 4, Table 2) showed mostly right-lateralized (88%) theta activity spanning several regions, including right motor areas [postcentral gyrus and middle frontal gyrus (MFG)], parietal lobe, thalamus, basal ganglia, bilateral cerebellum, right temporal gyrus, right insula, right somatosensory and bilateral medial posterior cingulate cortices (PCC, including precuneus and cuneus). Spacelessness vs. Here showed theta activity which was bilaterally distributed (54% right hemisphere), over several regions (Figure 4, Table 2). It included bilateral PCC (with precuneus), bilateral cerebellum, bilateral parahippocampus, right basal ganglia, bilateral temporal gyrus, left thalamus, right postcentral gyrus, MFG right parietal lobe, and a small portion of the right insula. The “Timelessness” and “Spacelessness” conditions overlapped at the posterior part of the right superior temporal gyrus (STG), left cerebellum, and bilateral posterior cingulate cortex and adjacent precuneus (PCC/Prc) (Figure 4, Table 3).



**FIGURE 4 | Beamforming source estimates for the overlap between Timelessness vs. Now and Spacelessness vs. Here contrasts in the theta (4–8 Hz) frequency.** Axial, sagittal and coronal views (left to right) of group ( $n = 11$ ) SAM pseudo- $F$  source estimates overlaid on the Colin template. Note that in all images right and left sides are crossed. Green, orange, and red indicate Timelessness, Spacelessness and overlap between conditions, respectively. **Top:** left cingulate/precuneus and culmen (clusters 2 and 4, respectively, Table 3); **Center:** right cingulate/precuneus (cluster 1, Table 3); **Bottom:** right superior temporal gyrus (cluster 3, Table 3).

In order to control for attention, memory or imagination processes, we contrasted, in source space, the “Then” vs. “Now” and “There” vs. “Here” conditions, and then looked for an overlap between them. As before, while focusing on the theta rhythm, we checked for overlapping regions over all frequency bands. Overlapping clusters were found mostly within the theta band, with the only exception being one alpha band cluster localized exactly (same 10 voxels) over theta cluster no. 1, on the right superior parietal lobule (Figure 5, Table 3). The two contrasts overlapped in three clusters, which included four main regions: Right posterior parietal lobule (PPL), right precentral and MFG, and bilateral precuneus (Figure 5, Table 3). Yet, there were regions which did not overlap between the two contrasts (Table 4). These included the right superior temporal gyrus (STG), which although activated in both contrasts, did not overlap. Additionally, only “Then” vs. “Now” activated the right insula, and only “There” vs. “Here” activated the right anterior cingulate and right lateral cerebellum.

#### NEUROPHENOMENOLOGICALLY-GUIDED MEG ANALYSIS

To study possible differences between the BTS and NTS groups, we derived for each participant the mean theta activity value within each of the four clusters of overlap between the “Timelessness” and “Spacelessness” conditions. On these values, we ran a Three-Way ANOVA with one grouping factor (BTS, NTS) and repeated measures on Condition (Timelessness, Spacelessness)  $\times$  Cluster (R-PCC, L-PCC, R-STG, cerebellum). There was no main effect for Condition, Cluster or Group. However, we found a significant Group  $\times$  Cluster interaction [ $F_{(3, 27)} = 2.85$ ,  $MSE = 0.001$ ,  $p < 0.05$ ]. As can be seen in Figure 6, the BTS group exhibited lower R-STG and higher L-cerebellum theta activity compared to the NTS group.

While the insula showed theta activity during both “Timelessness” and “Spacelessness,” the activity pattern was not overlapping. As a result, this region does not appear as an overlapping cluster. However, in order to test the hypothesis that group differences in bodily boundaries are related to insula activity, as the insula is a major interoceptive regions (Craig, 2002), we defined the insula anatomically as an ROI, and then calculated the theta activity value within the bilateral insula for the overlap between the “Timelessness” and “Spacelessness” conditions. On these values, we ran a Three-Way ANOVA on Group (BTS, NTS)  $\times$  Condition (Timelessness, Spacelessness)  $\times$  Hemisphere (L, R). Two outliers with very high values (above two standard deviations from the group mean) for the “Spacelessness” condition, one from each group, were excluded. We found a Condition  $\times$  Hemisphere interaction [ $F_{(1, 7)} = 5.52$ ,  $MSE = 0.002$ ,  $p < 0.05$ ], with “Spacelessness” being left-lateralized, and “Timelessness” being right-lateralized (the latter being significant [ $p < 0.05$ , Bonferroni-corrected, *post-hoc t-test*]) (Figure 7A). Importantly, we found a main effect for Group [ $F_{(1, 7)} = 6.12$ ,  $MSE = 0.006$ ,  $p < 0.05$ ], with the BTS group showing lower overall insula theta activity compared to NTS (Figures 7B,C).

For comparison purposes, we show the mean theta activity value within each of the four clusters of overlap between the “Timelessness” and “Spacelessness” conditions for the one participant who reported an OBE (Figure 8). In comparison with

**Table 2 | Beamforming solutions for the contrasts Timelessness vs. Now and Spacelessness vs. Here in the theta (4–8 Hz) frequency band (n = 11).**

Overlapped conditions	Cluster (no. voxels)	TLRC coordinates (mm, RAI)			Hemisphere overlap		Regions included in cluster (atlas TT_Daemon)	
		x	Y	z	L (%)	R (%)	Name	Voxels
Timelessness vs. Now	1 (529)	-47.5	37.5	47.5	18	72	Precuneus	104
							Cingulate gyrus	63
							R. Postcentral gyrus	60
							R. Inferior parietal lobule	41
							R. Precentral gyrus	40
							Paracentral lobule	35
							R. Middle frontal gyrus	19
							Culmen	19
							Cuneus	15
						R. Superior parietal lobule	13	
						Uvula	12	
	2 (253)	-67.5	22.5	-7.5	0	97	R. Superior temporal gyrus	63
							R. Insula	61
							R. Middle temporal gyrus	38
							R. Thalamus	23
							R. Lentiform nucleus	12
							R. Transverse temporal gyrus	8
							R. Claustrum	6
	3 (22)	-17.5	-7.5	17.5	0	96.7	R. Caudate	9
							R. Anterior cingulate	4
Spacelessness vs. Here	1 (204)	17.5	-12.5	47.5	89	7	Superior frontal gyrus	45
							Medial frontal gyrus	42
							Cingulate gyrus	40
							Middle frontal gyrus	24
							Paracentral lobule	18
							Precuneus	3
	2 (149)	-37.5	-12.5	-22.5	0	99	R. Inferior frontal gyrus	24
							R. Superior temporal gyrus	23
							R. Uncus	19
							R. Lentiform nucleus	15
						R. Parahippocampal gyrus	13	
						R. Subcallosal gyrus	4	
						R. Caudate	3	
						R. Insula	3	
3 (73)	-67.5	22.5	-12.5	0	97	R. Inferior temporal gyrus	21	
						R. Fusiform gyrus	12	
						R. Culmen	9	
						R. Cerebellar tonsil	6	
						R. Middle temporal gyrus	3	

(Continued)

Table 2 | Continued

Overlapped conditions	Cluster (no. voxels)	TLRC coordinates (mm, RAI)			Hemisphere overlap		Regions included in cluster (atlas TT_Daemon)	
		x	Y	z	L (%)	R (%)	Name	Voxels
		4 (72)	-37.5	37.5	57.5	0	89	R. Postcentral gyrus R. Inferior parietal lobule R. Superior parietal lobule R. Precuneus
5 (52)	2.5	42.5	-2.5	94	0	L. Posterior cingulate L. Culmen L. Cerebellar lingual	24 13 3	
6 (44)	52.5	47.5	-2.5	100	0	L. Middle temporal gyrus L. Inferior temporal gyrus	28 3	
7 (33)	32.5	42.5	-42.5	100	0	L. Cerebellar tonsil	5	
8 (33)	-42.5	-12.5	47.5	0	78	R. Middle frontal gyrus R. Superior frontal gyrus	22 8	
9 (22)	2.5	12.5	17.5	98	2	L. Thalamus L. Parahippocampal gyrus	10 3	
10 (15)	-67.5	7.5	2.5	0	88	R. Superior temporal gyrus	13	
11 (13)	-12.5	37.5	32.5	0	100	R. Cingulate gyrus	11	

Information supplied includes number of voxels in each cluster, center of cluster characteristics, hemispheric overlap, brain regions, and number of voxels in the region. Only clusters > 2 voxels are presented. The Afni-supplied TT Daemon atlas was used. Due to poor resolution and signal leakage to non-brain regions, overlap percentages do not always add up to 100%.

the BTS and NTS groups, the OBE participant exhibited much lower bilateral PCC and left cerebellar values. Right MTG and total insula values were slightly higher than the NTS group.

## DISCUSSION

### MEG SENSOR-LEVEL RESULTS

Significant differences in power between the “Spacelessness” vs. “Here” as well as the “Timelessness” vs. “Now” contrasts were found only within the theta frequency. Both contrasts showed maximal theta power over the right hemisphere. This result is in line with accumulating evidence from animal and human studies, showing that theta activity is tightly related to space and time processing, i.e., encoding and retrieval (recently reviewed by Hasselmo and Stern, 2013). This is also in agreement with the notion that there is a right-hemisphere specialization for space and time processing (Rao et al., 2001; Ellison et al., 2004; Oliveri et al., 2009a,b; reviewed by Walsh, 2003).

The production of theta with eyes closed is a well-known accompaniment of states of deep relaxation such as stage 1 sleep, meditation and hypnosis (Vaitl et al., 2005). Gruzelier (2009) reviews EEG-neurofeedback (NF) training studies for increasing theta activity, showing wide behavioral effects, including increased creativity, heightening psychological integration, relief from anxiety and depression and resolved post traumatic stress syndrome. Phenomenologically, participants in this EEG-NF

protocol reported increased theta “to be associated with a deeply internalized state and with a quieting of the body, emotions, and thought” (Gruzelier, 2009, p. 102). Based on the findings that theta oscillations play a critical role in the coupling and integration of widely distributed neural circuits (Von Stein and Sarnthein, 2000), as well as the EEG-NF results, Gruzelier (2009) proposed that the wide ranging behavioral correlates of theta result from theta’s role in mediating distributed circuitry in the brain, relating the concepts of psychological integration (integrative experiences leading to feelings of psychological well-being) and neural integration.

The “Timelessness” and “Spacelessness” conditions represent alterations in the sense of time and space, akin to those reported in various meditative practices, and can be compared to previously reported theta topography in studies of meditative states. The increased frontal-central theta power (Figure 3) is in accord with ample meditation studies, reporting increased theta activity, mostly over frontal-central sites (Hebert and Lehmann, 1977; Aftanas and Golosheikine, 2001; Kubota et al., 2001; Faber et al., 2004; Cahn and Polich, 2006; Slagter et al., 2009; Bajjal and Srinivasan, 2010). Increased theta in meditation studies has been interpreted as reflecting internalized attention (Cahn and Polich, 2006), space and time processing (Bajjal and Srinivasan, 2010), as well as being related, especially when manifesting as theta bursts, to deep meditative states, feelings of blissfulness and low

**Table 3 | Beamforming solutions for the overlapping contrasts between Timelessness/Spacelessness and Then/There in the theta (4–8 Hz) frequency band ( $n = 11$ ).**

Overlapped conditions	Cluster (no. voxels)	TLRC coordinates (mm, RAI)			Hemisphere overlap		Regions included in cluster (atlas TT_Daemon)	
		x	Y	z	L (%)	R (%)	Name	Voxels
Timelessness vs. Now and Spacelessness vs. Here	1 (13)	-10.2	41.7	31.3	0	100	R. Cingulate gyrus R. Precuneus R. Posterior cingulate	11 1 1
	2 (13)	7.1	31.3	42.1	100	0	L. Cingulate gyrus L. Paracentral lobule L. Precuneus	7 3 1
	3 (11)	-54.3	16.1	3.0	0	100	R. Superior temporal gyrus	11
	4 (9)	5.8	51.9	0.3	100	0	L. Culmen I. Posterior cingulate L. Lingual gyrus	6 1 1
Then vs. Now and There vs. Here	1 (30)	-33.3	57.3	47.2	0	94	R. Superior parietal lobule R. Inferior parietal lobule R. Precuneus	10 8 5
	2 (14)	-43.9	7.5	49.6	0	86	R. Precentral gyrus R. Middle frontal gyrus	12 2
	3 (7)	7.5	42.5	56.1	100	0	L. Paracentral lobule L. Precuneus	4 2

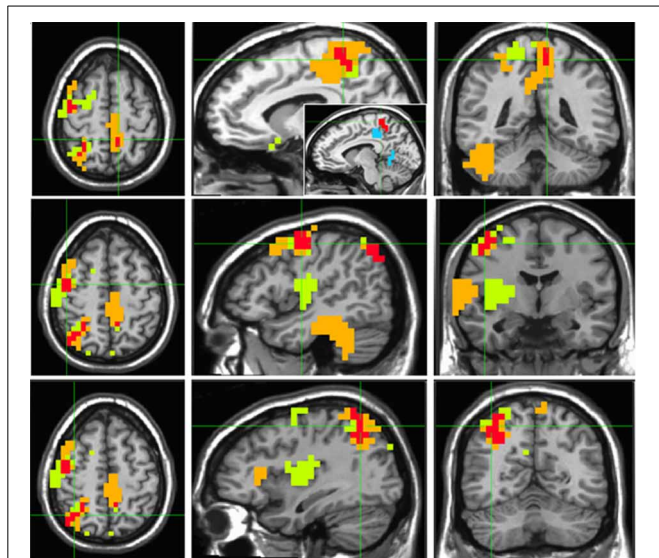
Information supplied includes number of voxels in each overlapping cluster, center of cluster characteristics, hemispheric overlap, brain regions, and number of voxels in the region. Only clusters > 1 voxels are presented. The Afni-supplied TT Daemon atlas was used. Due to poor resolution and signal leakage to non-brain regions, overlap percentages do not always add up to 100%.

thought content, and a sense of integration (Kasamatsu and Hirai, 1966; Hebert and Lehmann, 1977; Aftanas and Golocheikine, 2001).

The results are also in agreement with the junction-point-model hypothesis proposed by Travis (1994). Briefly, Travis proposes that bursts in the 7–9 Hz band underlie the state of transcendental consciousness (Travis, 1994), which is “the least excited state of mental activity,” unbounded by a sense of time and space (Alexander et al., 1987). Travis suggests that transcendental consciousness underlies other forms of consciousness, and can be seen especially during transitions between different states of consciousness. He then provides support for his hypothesis by showing increased 7–9 Hz activity during the transition between waking, NREM-sleep, and REM-dreaming. Similar theta activity has also been reported during Transcendental Meditation (TM); and in TM practitioners, it also unusually accompanies sleep, a state called witnessing sleep (Travis, 1994). This state differs from lucid dreaming by increased “separateness” and reduced dream control (Alexander, 1988). The junction-point model ties all these states as windows to an underlying field of transcendental consciousness, related to alterations in the sense of time and space, and a sense of boundlessness.

Taken together, the literature on theta in neurofeedback and meditation suggests that this is the optimal bandwidth for integration and synthesis across neural regions. As Hunt (2007, p. 226) argues, “widespread EEG theta would appear to be the level of activation which affords a maximized coherence across the widest possible neural areas...” This interpretation aptly fits the phenomenology of the “Timelessness” and “Spacelessness” states, which include many descriptions of integration (Table 1): “The purest form of the sensation was there, but un-restricted. There was relaxation and widening” and “There was a sense of open space without the bodily dimension” (participant no. 11); “It was a sense of spaciousness, boundlessness... there was no clarity where the center is and where is the periphery. There was no quality of border” (participant no. 12); “There was relaxation and letting-go, emptiness, experience of bliss, quiet, wide” and “The metaphor is an amoeba, everything spreads. A sense of nothingness, emptiness. A sense of expansion” (participant no. 5); “I lost discrimination between different body parts. It felt pleasant, like a huge hammock. A sense of expansion” (participant no. 14); “The center of space became endless, without a reference point in the middle. There was a sense of floating in a sea of being... Everything was a part of one conscious experience. The dichotomy between subject and object dissolved... Everything





**FIGURE 5 | Beamforming source estimates for the overlap between Then vs. Now and There vs. Here contrasts in the theta (4–8 Hz) frequency.** Axial, sagittal, and coronal views (left to right) of group ( $n = 11$ ) SAM pseudo- $F$  source estimates overlaid on the Colin template. Note that in all images right and left sides are crossed. Green, orange and red indicate Then, There and overlap between conditions, respectively. **Top:** left paracentral lobule and precuneus (cluster 3, **Table 3**). In the sagittal view, the same cluster (red) is compared with left cingulate/precuneus activity (cyan) for the Timelessness/Spacelessness overlap (cluster 2, **Table 3**). Note the clear separation between the superior cluster found in the Then/There overlap, and the inferior cluster found for the Timelessness/Spacelessness overlap; **Center:** right precentral and middle frontal gyrus (cluster 2, **Table 3**); **Bottom:** posterior parietal lobule (cluster 1, **Table 3**).

was a part of a singular event. The experience of the body faded” (participant no. 4). Indeed, Faber et al. (2012) discuss the question, “Why are there so few systematic reports on subjective experience during meditation,” and emphasize that “it could be very useful in sorting out brain states of different cogitations” (p. 262). In this study, we have shown how such reports can be utilized in a productive way, both to aid in interpreting brain activity during these unique states, but also to learn more about these states, from the systematic self observations of our meditators. One does not have to rely on the ingestion of a hallucinogen such as *ayahuasca*, to uncover what Bresnick and Levin (2006) term “profound alterations of temporal-spatial experiences including expansive space and slowed time.” These experiences can be found in long-term meditators. Whether the meditators in this study are more aware of what Travis (1994) terms “an underlying, undifferentiated field,” wherein presumably there is an alteration in the experience of both space and time, is a metaphysical issue—and not one that we can resolve using the present experimental protocol. Nevertheless, as Hunt (2007, p. 226) has suggested, “advanced meditation involves an attunement to a background field of consciousness, whose increased meditative access seems to be correlated with an unusually coherent EEG in the theta bandwidth.” What might be considered to be the *psychedelic* effects invoked by systematically observing (or, becoming sensitized to) one’s experience of both space and time—sometimes resulting in

spacelessness and/or timelessness—might, in turn, be actually the externalization of this background field of consciousness (Hunt and Chefurka, 1976). We cannot make a conclusive case here for this; we can, however, provide a portal for future research, building on the protocol explored here.

### MEG SOURCE LOCALIZATION ESTIMATES

#### “Then” and “There” (control) conditions, and their overlap

The “Then” vs. “Now” and “There” vs. “Here” contrasts served as control conditions for ruling out autobiographic memory and imagination processes, respectively, as well as attentional processes, which might have taken place during the “Timelessness” and “Spacelessness” target conditions. In both contrasts, only increased theta activity was detected, mostly right-lateralized (**Tables 3, 4**). Within the context of the hypothesis that time can be represented along a left-to-right oriented mental time-line, and based on psychophysical and neuroimaging studies, it has been suggested that the right hemisphere entails the representation of the past and the left hemisphere the representation of the future (Szpunar et al., 2007; Oliveri et al., 2009a). The right hemisphere dominance in the “Then” vs. “Now” contrast is in line with this, as participants were recalling past events.

The two contrasts overlapped in three clusters, which included four main regions: Right PPL, right precentral and MFG, and bilateral precuneus (**Figure 5, Table 3**). These results are in line with fMRI studies of mental traveling to the past, reporting bilateral PPL activation (Arzy et al., 2009) and left precuneus and MFG activation (Szpunar et al., 2007). Moreover, the results support our hypothesis of episodic memory network activation in the control conditions, as the right PPL and MPG were shown to be involved in episodic memory performance (Rajah et al., 2011). Similarly, the precuneus is a region involved with autobiographic memory (Cabeza and Nyberg, 2000; Rugg et al., 2003), as well as mental imagery (Lundstrom et al., 2003). Altogether, the overlapping pattern of the “Then” vs. “Now” and “There” vs. “Here” conditions reveals a largely right-lateralized network specialized in episodic memory, as well as mental imagery of one’s body.

#### Alteration in the experience of time

The “Timelessness” vs. “Now” (**Figure 4, Table 2**) contrast revealed theta activity in a right-lateralized network of parietal, temporal and insular cortical regions, as well as the basal ganglia, thalamus and cerebellum. Specifically, these regions included the motor areas (postcentral gyrus) spreading into supplementary motor area—SMA (MFG), parietal lobule, thalamus, and basal ganglia. This is consistent with previous prospective timing studies suggesting that fronto-striatal circuits consisting of recurrent loops between SMA, basal ganglia and thalamus are critical for the processing of duration (Coull and Nobre, 1998; Ferrandez et al., 2003; Coull, 2004; Wittmann, 2009), as well as with neuroimaging of temporal task performance documenting recruitment of the right posterior parietal cortex (Coull and Nobre, 1998; Walsh, 2003; Oliveri et al., 2009a). Theta activity was also found in the bilateral cerebellum, in accord with TMS (Tomlinson et al., 2013) and PET (Coull and Nobre, 1998) studies showing a cerebellar role in time perception and representation (Salman, 2002), as well as over the right temporal gyrus, a region shown previously



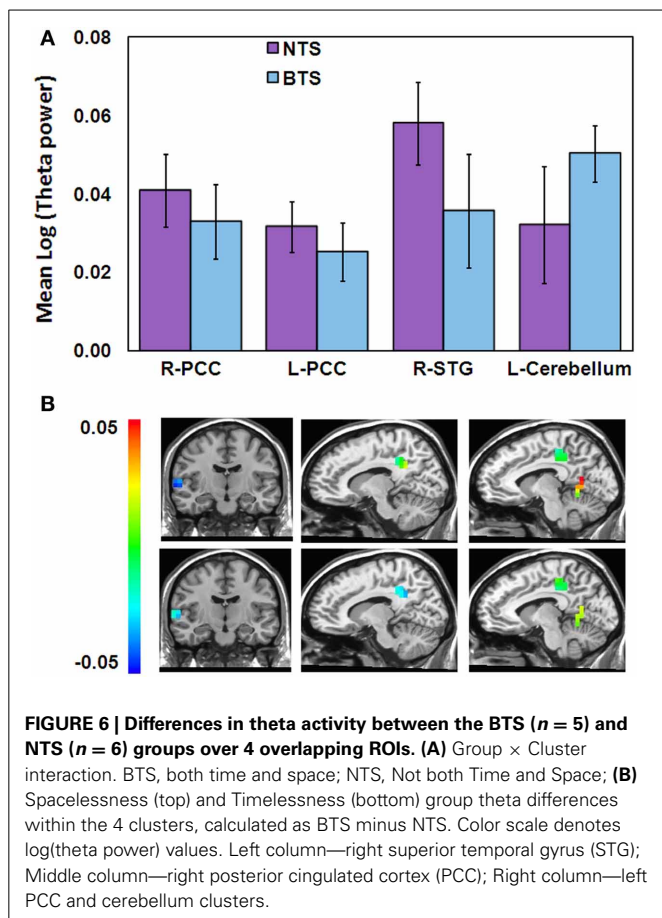
**Table 4 | Beamforming solutions for contrasts Then vs. Now and There vs. Here in the theta (4–8 Hz) frequency band.**

Overlapped conditions	Cluster (no. voxels)	TLRC coordinates (mm, RAI)			Hemisphere overlap		Regions included in cluster (atlas TT_Daemon)	
		x	y	z	L (%)	R (%)	Name	Voxels
Then vs. Now	1 (87)	−27.5	52.5	57.5	0	93	R. Superior parietal lobule R. Postcentral gyrus R. Inferior parietal lobule	22 13 7
	2 (78)	−42.5	7.5	52.5	0	70	R. Precentral gyrus R. Postcentral gyrus R. Middle frontal gyrus	26 26 11
	3 (66)	−32.5	17.5	17.5	0	100	R. Insula R. Lentiform nucleus	34 11
	4 (53)	−12.5	67.5	32.5	1	92	R. Precuneus R. Cuneus	36 14
	5 (15)	7.5	42.5	62.5	94	0	L. Precuneus L. Paracentral lobule	6 4
	6 (14)	−67.5	32.5	7.5	0	55	R. Superior temporal gyrus R. Middle temporal gyrus	10 2
There vs. Here	1 (201)	−62.5	7.5	12.5	0	90	R. Middle temporal gyrus R. Superior temporal gyrus R. Inferior temporal gyrus R. Fusiform gyrus R. Culmen R. Postcentral gyrus R. Cerebellar tonsil R. Precentral gyrus R. Parahippocampal gyrus	36 27 20 18 16 9 6 5 3
	2 (129)	2.5	47.5	57.5	74	23	Cingulate gyrus Paracentral lobule Precuneus Postcentral gyrus Medial frontal gyrus	39 34 29 7 5
	3 (66)	−32.5	42.5	57.5	0	92	R. Superior parietal lobule R. Precuneus	21 14
	4 (38)	−37.5	12.5	52.5	0	74	R. Inferior parietal lobule R. Precentral gyrus R. Middle frontal gyrus	11 21 15
	5 (36)	−12.5	−32.5	7.5	0	100	R. Anterior cingulate R. Caudate	20 8

Information supplied includes number of voxels in each cluster, center of cluster characteristics, hemispheric overlap, brain regions, and number of voxels in the region. Only clusters >2 voxels are presented. The Afni-supplied TT Daemon atlas was used. Due to poor resolution and signal leakage to non-brain regions, overlap percentages do not always add up to 100%.

to be involved in time production in lesion (Noulhiane et al., 2007) and TMS (Bueti et al., 2008) studies. Finally, theta activity was seen in the right insula, right somatosensory and bilateral medial posterior cingulate cortices, a network involved in somatic

information processing. The interoceptive insula has been previously suggested to be responsible for the perception of duration (Craig, 2009a,b; Wittmann, 2009; Wittmann et al., 2010). Indeed, an fMRI study of MM practitioners showed that attending to

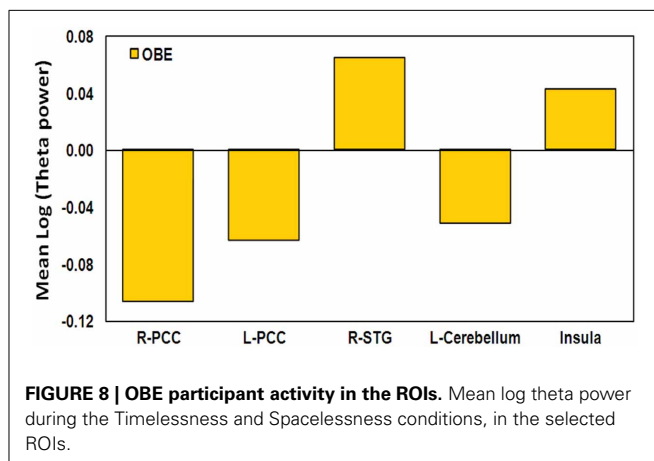
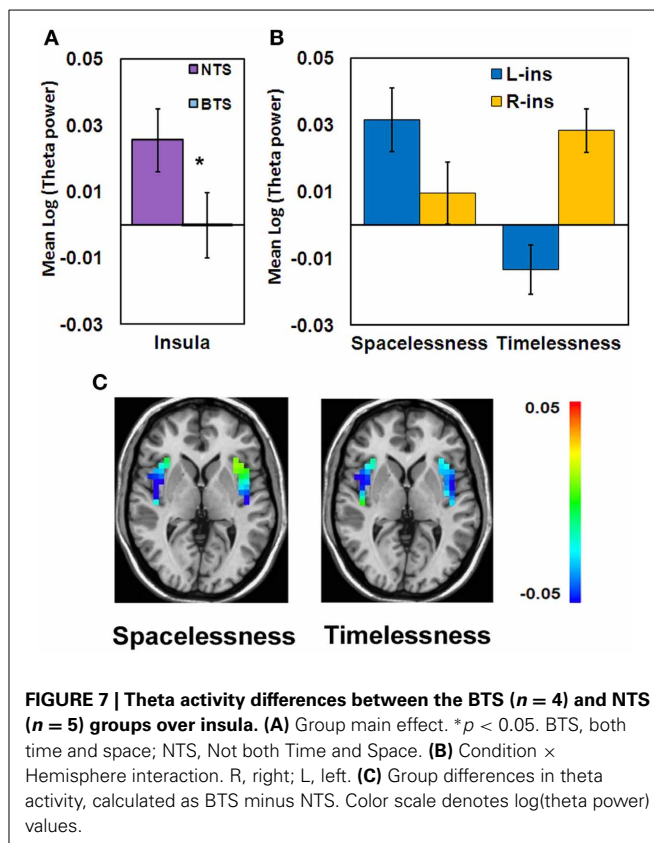


the present moment was accompanied by activation in the right insula as well as the somatosensory cortex (Farb et al., 2007).

Altogether, the regions recruited during the “Timelessness” condition were previously related to either momentary processing of time, or interoception. This is in accord with our hypothesis that alteration in the experience of time is related to an altered sense of body.

### Alteration in the experience of space

“Spacelessness” vs. “Here” showed theta activity which was largely bilaterally distributed, over several regions (Figure 4, Table 2). Activated regions included bilateral cerebellum—known to regulate balance via processing of vestibular information (Timmann et al., 2010); bilateral parahippocampus, known to subservise spatial computation and learning (Aguirre et al., 1996); and right basal ganglia, sensitive to spatially-related behavioral conditions (Lavoie and Mizumori, 1994). Additionally, bilateral temporal gyrus, left thalamus, right postcentral gyrus, MFG, bilateral frontal cortices and right parietal lobule (IPL) were activated, all related to space processing (Halligan et al., 2003; Hagler and Sereno, 2006; Silver and Kastner, 2009). Additionally, the bilateral PCC and a small portion of the right insula, both related to interoception (Damasio and Meyer, 2009), were activated. Moreover, the PCC is involved in processing vestibular information (Wiest et al., 2004) supporting its major role in navigation of the body in space (Vogele et al., 2004; Vogt and Laureys, 2005).



Altogether, the regions showing theta activity during the “Spacelessness” condition were previously related with some form of spatial processing (summarized by Iacoboni et al., 1997), or with interoceptive processing. This, again, is in line with our hypothesis that the alteration in the experience of space is related to an altered sense of body.

### Shared alterations in the experience of time, space, and body

The “Timelessness” and “Spacelessness” conditions overlapped in four clusters (Figure 4, Table 3): bilateral cingulate cortex/precuneus (PCC/Prc), right temporoparietal junction (TPJ) and left cerebellum. In line with our hypothesis, this pattern of theta activity was different from the overlap pattern between the

control conditions of “There” and “Then,” which showed activity in regions related to mental imagery and episodic memory. We argue that this overlap pattern is predominantly related to alterations in the experience of the body. Subsequently, we provide support for this argument, relating the overlapping regions with bodily processing.

The PCC/Prc plays a central role in consciousness (Cavanna and Trimble, 2006) as these regions differentiate patients in minimally conscious states from those in vegetative states (Laureys, 2005; Vogt and Laureys, 2005; Vanhaudenhuyse et al., 2010), and are deactivated during REM sleep, when participants experience vivid dreams (Alkire et al., 2008). In addition, these are key regions for bodily representation (Damasio, 1998, 1999; Damasio and Meyer, 2009) and vestibular processing (Wiest et al., 2004). Importantly, the PCC/Prc overlap for the “Timelessness” and “Spacelessness” conditions clearly differs from the left precuneus cluster found in the “There” and “Then” overlap (see relative activity in **Figure 5**), by being relatively inferior, anatomically. A recent fMRI study of emotional processing (Immordino-Yang et al., 2009) proposes a different role for inferior and superior parietal medial cortex, suggesting the first to be related to interoceptive processing, and the second to musculoskeletal processing. Consistent with that emotional processing study, our data suggest a functional subdivision in the parietal medial cortex regarding spatio-temporal processing. While the “There” and “Then” conditions overlapped in a more superior position, strongly related anatomically with the lateral parietal cortex (Parvizi et al., 2006), which is activated in episodic memory and imagination, the “Timelessness” and “Spacelessness” conditions overlapped at an inferior position, strongly related with interoception (Damasio and Meyer, 2009).

The caudate part of the STG is encompassed within the temporo-parietal junction (TPJ). The TPJ is a multimodal association cortex, integrating thalamic, visual, auditory, somatic, and limbic areas (Decety and Lamm, 2007). It is also a key region for multisensory body-related self-processing, related to a first-person perspective; damage to this area can produce a variety of disorders associated with bodily awareness (Blanke and Arzy, 2005). Recent findings emphasize the role of the right TPJ in abnormal vestibular processing, as during OBEs (Blanke et al., 2004), and Near-Death Experience (NDE) characterized by an altered sense of time, and sensations of lightness and void (Blanke and Dieguez, 2009).

The observed cerebellar activity is within the midline culmen. This area is the vestibulo-cerebellum (Barmack, 2003). Several studies point to the role of the cerebellum in altered sense of body. In a PET study where OBEs were repeatedly elicited during stimulation of the right TPJ in a patient in whom electrodes had been implanted to suppress tinnitus (De Ridder et al., 2007), a strikingly similar pattern of activity to our overlapping pattern was found. Activity during OBE was seen at the right TPJ, right precuneus and superior vermis of the cerebellum. In another single-subject study (Schutter et al., 2006), the participant reported that after cerebellum rTMS, but not after sham and occipital stimulations, she experienced her body falling/drifting sideways and even out of the chair.

To summarize, we show that an altered experience of time and space involves theta activity in regions related to a sense of the body. These findings support the phenomenologically reported spaciousness, a sense of alteration in the regular bodily boundaries. The type of altered sense of body found in this study include states where the sense of self becomes diffused and “spills out” of the body boundaries (participants no. 1, 2, 4, and 5), or simply disappears (participants no. 12, 13, and 14), and not just cases where the self simply changes its location, as in an OBE (participant no. 8).

### **Neurophenomenologically-guided analyses**

The participants were split into two groups based on the phenomenology of their reported experience of time and space. Interestingly, the both-time-and-space (BTS) group showed lower right TPJ and insula theta activity, accompanied by higher cerebellar theta activity, compared to the not-both-time-and-space (NTS) group. As all these regions are related to bodily processing and body schema, this shows that the BTS group activates regions involved in bodily processing differently than the NTS group. This might lead to their heightened alteration in sense of bodily boundaries, which is in turn related to their heightened alterations in the experience of time and space.

In comparison, the OBE participant manifested a markedly different pattern of theta activity compared to both the NTS and BTS groups (**Figure 8**). This might explain the preserved sense of body (though perceived as floating in space), “I was with my body, just floating in outer space. The body was identical, I wasn’t floating as consciousness, but as a body” (**Table 1**). Here we see a different form of an altered sense of body—without loss of boundaries (not along the body—boundary continuum). This was expressed in this participant’s very different bilateral PCC theta power values, which evidenced a reduction in theta activation, rather than an increase (as with the other participants). These distinctions highlight the utility of phenomenology in guiding neuroscientific analyses.

### **Summary of the MEG source localization estimates**

The results obtained from the MEG source localization estimates provide evidence that alterations in the sense of time and space: (1) do not rely on memory and mental imagery; and (2) are related to an altered sense of body.

In relation to the sensor level results (section MEG Sensor-Level Results) pointing to the critical role of the theta band in such experiences, we suggest that theta activity in cortical regions related to bodily processing results in experiences of an altered sense of the body, of time and of space, where the different sensory modalities integrate, and sensorial boundaries decrease. The neurophenomenologically-guided analyses (section Neurophenomenologically-Guided Analyses) provide further evidence that different phenomenological experiences result in significantly different levels of theta activity within these cortical regions, which are related to bodily processing.

### **LIMITATIONS OF THE STUDY**

This study has a number of limitations that should be taken into consideration. First, sample size was rather small after exclusion

of five of the participants. The 11 remaining participants were further divided into two sub-groups, resulting in very small group sizes. Second, the study design was fixed, as opposed to counter-balanced, between the Time and Space sessions. The verbal ratings of success of the participants were lower for “Timelessness” compared to “Spacelessness.” This might be due to the study design, as the two conditions were studied in that order, which makes it impossible to dissociate perceived task difficulty from increasing depth of state due to the previous session, or due to increasing acquaintance with the experimental setup. Thus, all results reported here should be considered preliminary, and warrant replication.

## CONCLUSIONS

This study illustrates the utility of employing experienced contemplative practitioners within a neurophenomenological setup for scientifically characterizing self-induced altered spatio-temporal experiences. The results reported here support our hypotheses that an altered experience of time and space is related to an altered sense of body, by showing that: (1) “Timelessness” and “Spacelessness” conditions overlap in a neural network related to alterations in bodily processing. This was shown to be distinct from mere memory and imagination processes; and (2) phenomenologically-guided neural analyses yielded further insight, by enabling us to dissociate different levels of an altered sense of the body. Additionally, our results underscored the specificity of theta activity, and emphasize theta’s unique role in altered experience of time, space and the body. Taken together, the results reported here support previous suggestions of the psychological integrative role of the theta band (Hunt, 2007; Gruzelier, 2009), and provide further understanding of deep meditative states, reported frequently to invoke enhanced theta activity.

## AUTHOR CONTRIBUTION

Joseph Glicksohn, Aviva Berkovich-Ohana, and Abraham Goldstein sponsored the study; Abraham Goldstein provided research facilities; Aviva Berkovich-Ohana and Joseph Glicksohn designed, while Yair Dor-Ziderman and Aviva Berkovich-Ohana ran the experiment; Yair Dor-Ziderman analyzed MEG data; Aviva Berkovich-Ohana analyzed phenomenological data and Aviva Berkovich-Ohana, Joseph Glicksohn, and Yair Dor-Ziderman wrote the paper.

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