



Research report

Oscillatory brain mechanisms of the hypnotically-induced out-of-body experience

Maor Zeev-Wolf^{a,1,2}, Yair Dor-Ziderman^{a,*1}, Abraham Goldstein^{a,b},
Omer Bonne^c and Eitan G. Abramowitz^c

^a Gonda Brain Research Center, Bar Ilan University, Ramat-Gan, Israel

^b Department of Psychology, Bar Ilan University, Ramat-Gan, Israel

^c Hadassah Medical Center and Hebrew University, Jerusalem, Israel

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ABSTRACT

One of the most challenging questions regarding the nature and neural basis of consciousness is the embodied dimension of the phenomenon, that is, feeling located within the body and viewing the world from that spatial perspective. Current theories in neurophysiology highlight the active role of multisensory and sensorimotor integration in supporting self-location and self-perspective, and propose the right temporal-parietal-junction (rTPJ) as a key area for such function. These theories are based mainly on findings from two experimental paradigms: manipulation of bottom-up multisensory information integration regarding one's body location (full-body illusion), or direct and invasive manipulation disrupting brain activity at the rTPJ. In this study we take a different approach by using hypnotic suggestion – a non-invasive top-down technique – to manipulate the subjective experience of self-location. The brain activity of 18 right-handed participants was recorded using magnetoencephalography (MEG) while their subjective experience of self-location was hypnotically manipulated. Spectral analyses were conducted on the spontaneous MEG data before and during an induction of an out-of-body experience (OBE) by a trained psychiatrist. The results indicate high correlations between power at alpha and high-gamma frequency-bands and the degree of perceived change in self-location. Regions exhibiting such correlations include temporal-occipital regions, the rTPJ, as well as frontal and midline regions. These findings are in line with an oscillatory-based predictive coding framework.

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1. Introduction

Current neurobiological theories highlight the active role of multisensory and sensorimotor integration in inducing

fundamental states of consciousness, such as the experience of being a self, localized within the space of a physical body (Aspell, Lenggenhager, & Blanke, 2012; Ehrsson, 2007). Much of the data regarding the mediating neural mechanisms involved in consciousness comes from neurological patients (Blanke &

* Corresponding author. Gonda Brain Research Center, Bar-Ilan University, Ramat-Gan, 52900, Israel.

E-mail address: yairem@gmail.com (Y. Dor-Ziderman).

¹ These authors contributed equally to this work.

² Present address: Department of Education, Ben Gurion University of the Negev, Beer-Sheva, Israel.

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Mohr, 2005) suffering from out-of body experience (OBE) and similar types of experiences, and highlights the role of the right temporo-parietal-junction (rTPJ) (Blanke, Ortigue, Landis, & Seeck, 2002; Ionta et al., 2011; Ridder, Laere, Dupont, Menovsky, & Heyning, 2007). The development of the ‘full body illusion’ paradigm (Blanke & Metzinger, 2009; Ehrsson, 2007; Lenggenhager, Tadi, Metzinger, & Blanke, 2007), where virtual reality and robotics technology are used to provide ambiguous multisensory information about the location of one’s own body, has made it possible to manipulate self-location and -perspective in healthy participants under rigorous experimental settings, including neuroimaging settings such as functional Magnetic Resonance Imaging (fMRI) (i.e., Ionta et al., 2011) and electroencephalogram (EEG) (Lenggenhager, Halje, & Blanke, 2011). fMRI results confirm the privileged role of multisensory mechanisms in the TPJ in supporting self-location and -perspective (Blanke, 2005, 2012; Ionta et al., 2011), but have suggested the involvement of other regions, including the precuneus (Guterstam, Björnsdotter, Gentile, & Ehrsson, 2015), extrastriate cortex (including the extrastriate body area), the insula and ventral premotor areas (Arzy, Thut, Mohr, Michel, & Blanke, 2006; Gentile, Björnsdotter, Petkova, Abdulkarim, & Ehrsson, 2015; Heydrich & Blanke, 2013; Petkova et al., 2011; Urgesi, Candidi, Ionta, & Aglioti, 2007). In terms of neurophysiology, the only EEG study examining oscillatory-based modulation of self-location implicates alpha band power in sensorimotor and premotor regions, and has shown that the strength of induced-self-location-change correlates positively with frontal alpha and negatively with right parietal gamma (Lenggenhager et al., 2011).

The neurocognitive mechanism underlying the ‘full body illusion’ involves the mismatching of low-level sensory processing of visual and tactile representations. This mismatch in the bottom-up processing of different sensory modalities ‘surprises’ the brain, leading it to change its habitual top-down predictive tendency (Carhart-Harris & Friston, 2010; Limanowski & Blankenburg, 2013; Seth, 2013) of placing the self within the confines of the physical body, giving precedence to visual representations over tactile representations, and aligning self-location with the former. Our understanding regarding the neural coding of such feedback and feedforward, top-down and bottom-up processes has been greatly advanced in recent years. A number of influential intracranial EEG and magnetoencephalography (MEG) studies in humans have shown that alpha and beta oscillations encode top-down modulations of predictions, while gamma oscillations encode bottom-up ‘surprise’ due to prediction violation (Bauer, Stenner, Friston, & Dolan, 2014; Brodski, Paasch, Helbling, & Wibral, 2015; Friston, 2012; Michalareas et al., 2016; Sedley et al., 2016). Thus, the alpha-gamma oscillatory results mentioned above (Lenggenhager et al., 2011) are very much in line with an oscillatory-based predictive coding account (Arnal & Giraud, 2012; Arnal, Wyart, & Giraud, 2011; Clark, 2013; Friston, 2009). Specifically regarding the alpha band, there is substantial evidence that supports the role of alpha as a top-down control mechanism for inhibiting conflicting information (Jensen & Mazaheri, 2010; Klimesch, 2012). An increase in alpha power may reflect inhibitory processes affecting sensory and vestibular regions which anchor the self to its habitual body-based location.

While an oscillatory-based predictive coding account of self-location is plausible, it lacks support from the literature in two important respects: First, there is no information regarding the prospects, and neural mechanisms, of producing altered self-location states using top-down strategies rather than by manipulating bottom-up sensory information. From a predictive coding account this should be possible. Second, there is very little evidence to show that the mediating neural mechanisms underlying the production of altered self-location states (regardless of induction method) are in line with the oscillatory predictive-coding framework. The present study addresses both of these issues by (i) inducing altered self-location states using hypnotic suggestion, in which incoming tactile-visual (or other sensory) information is not manipulated, thus necessarily involving top-down mechanisms; and (ii) doing so while recording brain activity using MEG, a direct measure of the brain’s neurophysiology ideally suited to mapping fast brain rhythms.

In recent years there has been a growing interest in hypnosis from a cognitive neuroscience perspective (Kihlstrom, 2013; Oakley & Halligan, 2009, 2013). This ‘instrumental’ approach utilizes hypnotic suggestion to study a range of normal and abnormal psychological processes. Hypnotic suggestion has been used to study a range of cognitive processes such as limb anesthesia, vision, volition, control, pain and attention (Deeley et al., 2013; Derbyshire, Whalley, Stenger, & Oakley, 2004; Kosslyn, Thompson, Costantini-Ferrando, Alpert, & Spiegel, 2000; Lifshitz, Aubert Bonn, Fischer, Kashem, & Raz, 2013; Ludwig et al., 2013; Magalhães De Saldanha da Gama, Slama, Caspar, Gevers, & Cleeremans, 2013; Zeev-Wolf, Goldstein, Bonne, & Abramowitz, 2016). The idea of studying OBEs by way of hypnotic suggestion is not a new one (Alvarado, 1992; Blackmore, 1982). Manipulating subjective awareness via hypnotic suggestion in conjunction with neuroimaging allows probing some of the deeper and more challenging questions relating to the nature and neural basis of consciousness, and in particular its attribute of being an embodied phenomenon: localized within the body and viewing the world from that spatial perspective (Bertossa, Besa, Ferrari, & Ferri, 2008).

For a hypnotic suggestion of an alternate self-location to succeed two processes are hypothesized to occur. First, the brain would need to adopt the suggested top-down world-model regarding the self’s altered location; and second, error signals indicating the incompatibility of the suggested world-model with the self’s embodiment would need to attenuate. Thus, we hypothesized that the strength of perceived change in self-location would (i) correlate positively with alpha/beta band power, and (ii) correlate negatively with gamma band power. In addition, in line with the fMRI full-body-illusion literature, (iii) we hypothesized these processes would involve, among other regions, the TPJ.

2. Method

2.1. Participants

Twenty five right-handed participants with no prior OBEs were recruited for the experiment. Exclusion criteria included current or past neurological, physical and mental disorders

(including dissociative symptoms), medication or substance abuse, and low hypnotizability assessed using the Hebrew version of the Stanford Hypnotic Susceptibility Scale form C (SHSS-C; Lichtenberg, Shapira, Kalish, & Abramowitz, 2009; Weitzenhoffer & Ernest, 1962). The SHSS-C score is the sum of 12 dichotomy tasks (1 point for each successful task), thus, the final score ranges between 0 and 12 with scores between 4 and 8 considered moderate, and 8 or above considered high. The Kuder-Richardson reliability correlation of the Israeli SHSS-C version is .79.

Two participants were excluded from participation due to substance abuse, one due to mental disorder and one due to low hypnotizability. Thus, 21 individuals participated in the experiment. However, three participants were excluded from data analysis due to excessive artifacts (heart beat and muscle artifacts). As a result, a total of 18 individuals (seven females and 11 males with an average age of 33.66, $SD = 8.96$) with moderate to high hypnotizability were included in the analysis (average score of 9, $SD = 1.03$). Participants were recruited from the community and received monetary compensation.

The research was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans, and was approved by the Hadassah Hospital ethics committee. In addition, and according to the Israeli law on hypnosis, a special permission for hypnosis protocol, used in the research, was obtained from the Hypnotic Committee of the Israeli Ministry of Health. Written informed consent was obtained from all participants.

2.2. Procedure

Prior to scanning, participants completed a demographic questionnaire followed by the Hebrew version of the Dissociative Experiences Scale (DES; Bernstein & Putnam, 1986) for the purpose of excluding participants with dissociative symptoms, which evidence suggests may be counter-indicative for hypnosis (West, 1965). Participants were then scanned in a supine position. Before the scan, head-shape was digitized using a Polhemus Fastrack digitizer. Scanning commenced with a digital registration of head position. Explanations were then given, emphasizing the need for participants to remain with closed eyes and to refrain from moving the head during the entire experiment.

After participants confirmed that they understood the experimental procedure the hypnotic state was induced and deepened by a trained specialist (last author in this paper, EGA) sitting beside the participant inside the shielded room. The hypnotic induction commenced with simple progressive muscle relaxation, which was deepened by the application of hypnotic pacing to the here-and-now experience of the participant. This was followed by the application of counting, in order to further deepen the hypnotic state. The entire hypnotic induction stage took around 6 min (mean = 5.97, $SD = 1.11$).

Once hypnotic induction was achieved (as judged by the hypnotherapist according to changes in participants' breathing pace and facial color), OBE suggestion was initiated according to an OBE protocol developed by the last author in this paper (Abramowitz, 2005, 2014). It was suggested to the

participants to visualize their reflection in a large mirror placed above them, and to then switch places with their reflection and look down at their body lying on the bed in the MEG room from the perspective of the mirror. This experience was deepened, and was followed by the suggestion to experience themselves floating in the MEG room while gradually loosening the connection to their body. The suggestion of moving away from one's own body, free floating in the MEG room and even further out was accompanied by suggestions of pleasure, pleasant surprise, and movement in the air. This stage lasted around four and a half minutes (mean = 4.64, $SD = .76$). The participants were then given detailed instructions to float back to the MEG room and reunite with their bodies. The reunion experience was reinforced while emphasizing in detail the bodily sensations and mental psychological experience of reuniting with one's own body. Finally, de-hypnotization and de-induction of all suggestions took place. Participants were then asked to open their eyes and communicate with the hypnotherapist in order to confirm that they were completely de-hypnotized.

After completing the experiment, participants were briefed on the possible effects of the hypnosis and were asked to answer a short questionnaire regarding their subjective experience during the experiment. In order to avoid response bias, the hypnotherapist was not present during this stage. The questionnaire consisted of three open questions and two Likert questions. The open questions asked participants: a) to describe their subjective experience during the experiment, b) to recall the stages of the experiment in a chronological sequence and c) to express their thoughts regarding the experiment.

The Likert questions included two questions aimed at validating the hypnotic induction stage and the suggestion stage. In the first question, participants were asked to quantify the extent to which they felt their attention was focused during the hypnotic induction stage on a scale from 1 to 7 (1 – “I could not focus my attention at all”; 7 – “My attention was extremely focused and I was not disturbed at any point”). The average result was 5.78 ($SD = 1.17$).

The second Likert question asked participants to quantify the extent to which they succeeded in experiencing an OBE on a scale from 1 to 7 (1 – “I could not see myself from outside”; 7 – “I easily saw and experienced myself from outside and the intensity of the experience was very strong”). Average OBE self-report experience was 4.5 ($SD = 1.34$), ranging from 2 to 6. Thus none of the participants completely failed to experience an altered self-location state.

Pearson correlations between OBE success and hypnotizability, and OBE success and the self-report measure of hypnotic induction depth were not significant ($p = .2902$ and $p = .2243$, respectively). Thus, participants' trait propensities for hypnosis or state hypnotic depth did not act as mediating factors for OBE success.

2.3. MEG recording and analysis

Throughout the experiment, ongoing brain activity was recorded (sampling rate, 1017.23 Hz, online .1–400 Hz band-pass filter) using a whole-head 248-channel magnetometer array (4-D Neuroimaging, Magnes 3600 WH) in supine position inside a magnetically shielded room. Reference coils

located approximately 30 cm above the head oriented by the x, y, and z axes were used to remove environmental noise. Five coils were attached to the participant's scalp for recording the head position relative to the 248 sensor-array. External noise (e.g., power-line, mechanical vibrations) and heartbeat artifacts were removed from the data using a pre-designed algorithm for that purpose (Tal & Abeles, 2013). Spectral analysis was performed using MATLAB R2012b (MathWorks, Natick, MA, USA) and the FieldTrip toolbox (Oostenveld, Fries, Maris, & Schoffelen, 2011).

Two 90 s periods corresponding to the OBE condition and a baseline (BL) condition were extracted from the data. The OBE condition was constrained to the phase where it was suggested to the participants to switch places with their reflection and look at their body from the perspective of the mirror, as this stage was uniform among all participants. The BL condition was defined as the final 90 s of the hypnotic induction phase, where subjects were under deep hypnosis. Such a BL period is appropriate (rather than a pre-hypnosis BL) for limiting the differences between the conditions to self-location (and not hypnotic level).

Data were segmented into 1000 ms epochs (with 250 ms overlap between neighboring epochs). Four bad channels were detected and excluded from further analysis. Epochs containing muscle artifacts and signal jumps were rejected by visual inspection. Data were then band-pass filtered in the 1–90 Hz range. Finally, spatial component analysis was applied in order to clean eye-blinks, eye movements, and residual heart-beat contamination.

A frequency analysis for 1–90 Hz frequencies at 1 Hz resolution was performed for each 1-sec epoch in each sensor in each condition (OBE and BL) using the Multitaper Method Fast Fourier Transform and a Hanning taper with 1 Hz smoothing. Power values were then collapsed across the delta (1–4 Hz), theta (5–7 Hz), alpha (8–13 Hz), beta (14–30 Hz), low gamma (31–60 Hz), and high-gamma (61–90 Hz) frequency bands.

Frequency bands exhibiting differences between the defined conditions (OBE and BL) were identified by analyzing the correlation between band-power fluctuations and the self-reported degree of success in experiencing the OBE (see Section 2.2) in the following way: For each frequency band, within-subject t-scores were computed for each sensor by applying an independent samples t-test for the OBE-BL comparison. Second level between-subjects regression statistics were then assessed and corrected for multiple comparisons by applying nonparametric cluster-based permutations (NCBP) on pooled t-values analyses (Maris & Oostenveld, 2007) using the FieldTrip toolbox. The NCBP approach was chosen as it does not make any assumptions on the underlying distribution, and is unaffected by partial dependence between neighboring sensors/voxels. In addition, this approach has been shown to yield nominal (non-inflated) false-positive rates for spatial extent (Eklund, Nichols, & Knutsson, 2016). The same approach was implemented at the sensor and source level for neighboring sensors (in a 4 cm radius) or voxels, respectively. In both cases 2000 permutations were applied, with a clustering threshold of $p < .05$. Once the significant clusters were identified, power values of the sensors within the clusters were collapsed for each condition and subject and a percent-in-signal-change (PSC) measure

between the OBE and BL conditions was computed ($[(\text{OBE-BL})/\text{BL}]$). These were in turn used for further post-hoc t-test and Pearson correlation analyses, implemented using MATLAB.

Sources were estimated by computing the cross-spectral density matrix (together for all conditions) between all MEG sensor pairs from the Fourier transforms of the tapered data epochs. Spatial filters were constructed for each grid location, based on the identified frequency bin, and the Fourier transforms of the tapered data epochs were projected through the spatial filters. To facilitate analysis at the source level, for each participant, a single shell brain model was built based on a template brain (Montreal Neurological Institute), which was modified to fit each participant's digitized head shape using SPM8 (Wellcome Department of Imaging Neuroscience University College London, www.fil.ion.ucl.ac.uk). The head shape was manually digitized (Polhemus Fastrak digitizer), and the participant's brain volume was then divided into a regular grid. The grid positions were obtained by a linear transformation of the grid positions in a canonical 1 cm grid. This procedure facilitates the group analysis because no spatial interpolation of the volumes of reconstructed activity is required. For each grid position, spatial filters (Gross et al., 2001) were reconstructed with the aim of optimally passing activity from the location of interest, while suppressing activity that was not of interest. Statistics were assessed similarly to the sensor-level data.

3. Results

The frequency-based whole-head regression NCBP analyses indicated that only the alpha and high-gamma bands exhibited significant OBE versus BL power changes which correlated with self-reported OBE success. Two significant clusters were detected, one in the alpha band and one in the high-gamma band. The alpha band cluster indicated a positive correlation ($p < .031$) over right and central electrodes (see Fig. 1A); while the high-gamma cluster indicated a negative correlation ($p < .002$) over left electrodes (see Fig. 1B).

The correlations were not only significant (as indicated by the cluster analysis) but also substantial. Pearson correlations between each subject's averaged (over all significant cluster sensors) PSC ($[(\text{OBE-BL})/\text{BL}]$) values and reported OBE success indicated a high positive correlation for the alpha band ($r = .6033$, $p < .008$, see Fig. 1C) and a high negative correlation for the high-gamma band ($r = -.7063$, $p < .0011$, see Fig. 1D). An additional Pearson correlation analysis between participants' alpha and high-gamma cluster-averaged power PSC values revealed a high negative correlation ($r = -.5.839$, $p < .011$, see Fig. 1E), confirming the functional synchrony between the two carrier frequency bands.

In order to highlight differences between participants with high versus low success in experiencing the OBE, participants were divided into low-OBE (scores of 1–4 on OBE success; $n = 8$) and high-OBE (scores of 5–7, $n = 10$) groups according to the mean value of the self-report scores ($M = 4.5$). This division is further supported by the participants' oscillatory power profiles. The correlation Figs. 1C and D indicate OBE effects in different directions (synchronization or de-synchronization relative to BL). In the alpha band, 7 out of 8 low-OBE

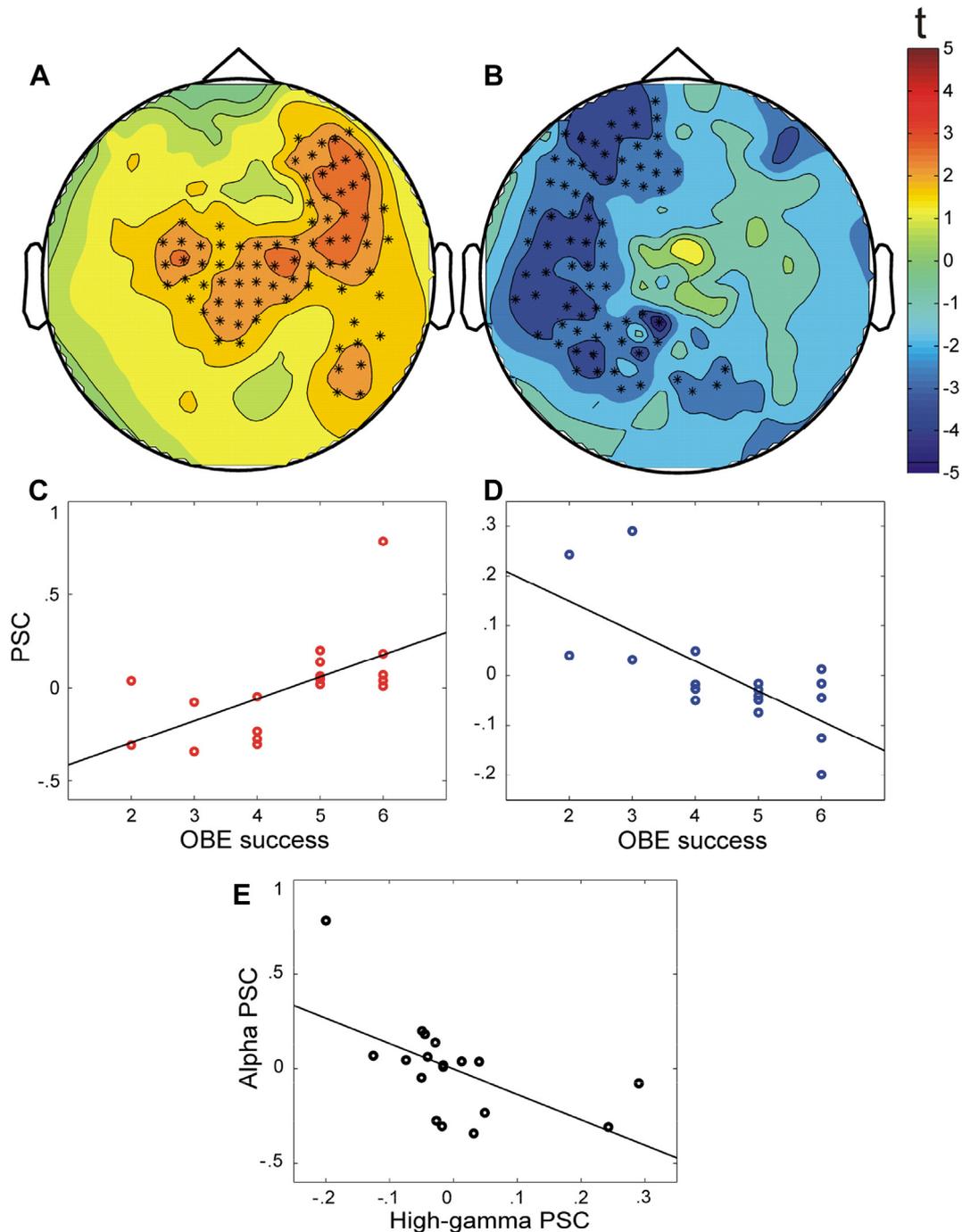


Fig. 1 – Significant OBE versus BL power change correlated with self-reported OBE success in the alpha band (A) and high-gamma band (B). Scatter plots of the correlation between averaged significant sensors and OBE success in the alpha band (C) and high-gamma band (D). Warm colors represent positive regression t coefficient values and cold colors represent negative regression t coefficient values. Significant sensors are marked by asterisks. PSC – Percent signal change; OBE – Out of body experience.

participants exhibited negative PSC values, while all of the high-OBE participants exhibited positive PSC values. This trend was reversed in the high-gamma band where 9 out of 10 high-OBE participants exhibited negative PSC values, while 5 out of 8 exhibited positive PSC values. These differences between high- and low-OBE participants were also statistically significant for both the alpha and high-gamma bands

[$t(16) = -3.7236, p = .0018$ and $t(16) = 2.8125, p = .0125$; see Fig. 2], with higher alpha PSC values and lower high-gamma PSC values for high-OBE participants relative to low-OBE participants. In order to rule out BL effects we compared the BL alpha and gamma power values between the high- and low-OBE success groups. Results were not significant for both alpha [$t(16) = -1.35, n.s.$] and gamma [$t(16) = -1.3, n.s.$].

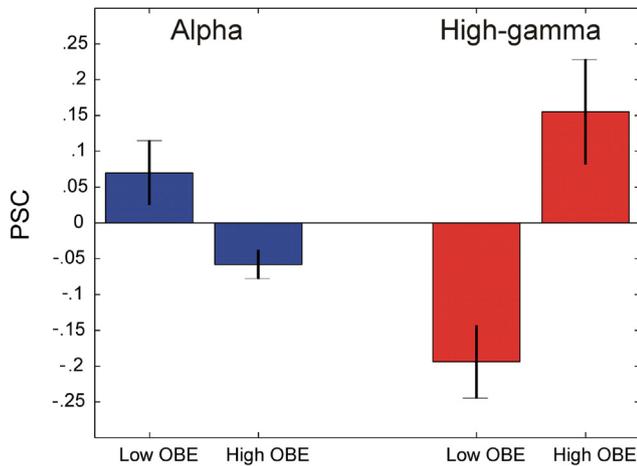


Fig. 2 – Differences in percent signal change between high- and low-OBE participants in the alpha band and high-gamma band. PSC – Percent signal change; OBE – Out of body experience.

Following the distinction between low- and high-OBE participants, we ran between-subject sensor- and source-level NCBP analyses for the alpha and high-gamma bands. The results, shown in Fig. 3, indicate a complex picture of neural processing related to OBE. The alpha band power difference images reveal higher alpha power ($p < .02$) for high-OBE participants than for low-OBE participants (see Fig. 3A). The regions involved include bilateral occipital and occipital-temporal regions, the rTPJ and insula, and in addition, medial parietal regions (for a full list of locations see Table 1), with a clear tendency toward the right hemisphere (66% of clusters' voxels were located in the right hemisphere).

The high-gamma images indicate left-lateralized decrease in power for high-OBE participants compared to low-OBE participants (see Fig. 3B). The highlighted regions include the left temporal-occipital junction, the left premotor (including the ventral premotor), as well as frontal and prefrontal regions (for a full list of locations see Table 2). It is important to note that the high-gamma source images did not survive the correction for multiple comparisons. However, as the source level images correspond to the sensor-level results, which did

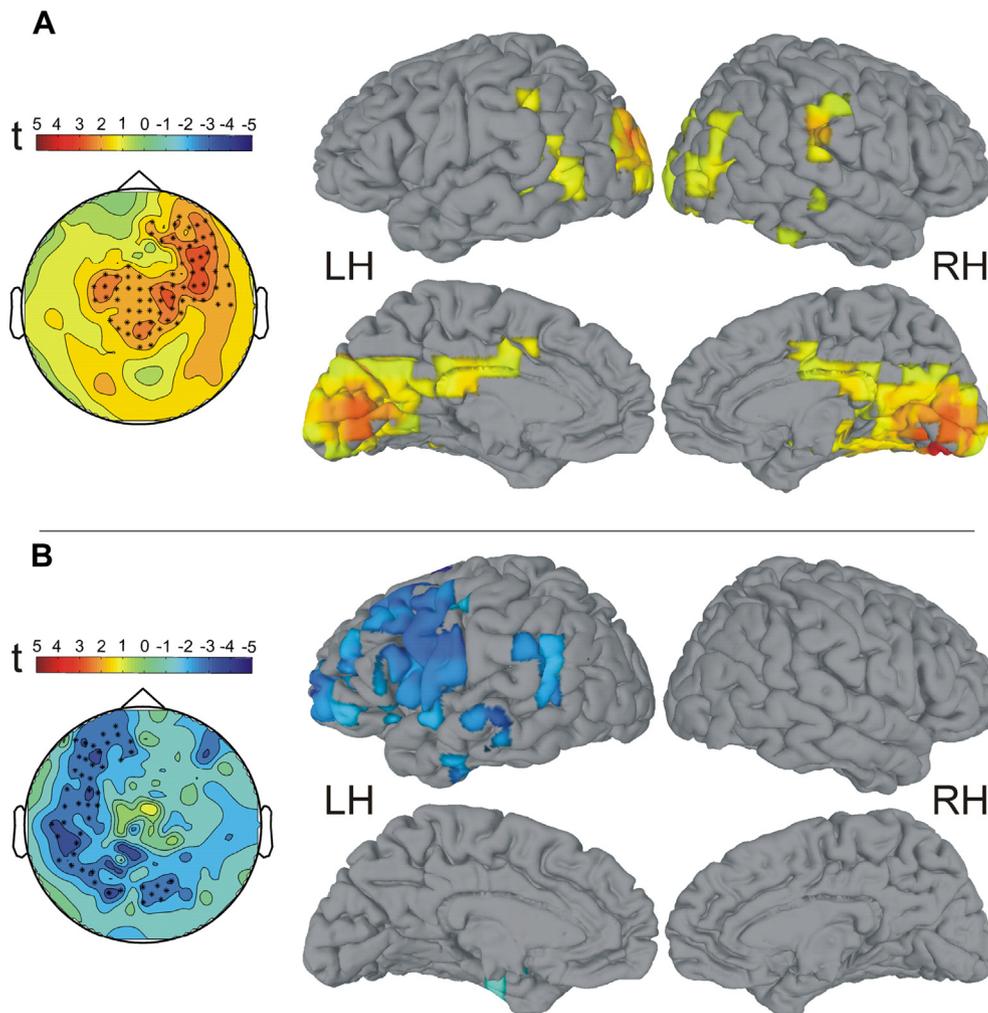


Fig. 3 – Cluster analysis differences between high- and low-OBE participants in the alpha band (A) and high-gamma band (B) in the sensor and source levels. Warm colors represent positive t values and cold colors represent negative t values. Significant sensors are marked by asterisks. LH – Left hemisphere; RH – Right hemisphere.

Table 1 – Cluster sizes and locations.

Alpha band						
Cluster no.	Cluster size	MNI coordinates (cm)			Anatomic area	% From cluster
		L	P	I		
1	215	1	-7.5	-1	R lingual gyrus	7.1
					L cuneus	9.6
					R cuneus	6.9
					L lingual	4.2
					R middle occipital gyrus	4
					R cingulate gyrus	3.7
					R posterior cingulate	3.6
					R culmen	3.3
					R parahippocampal gyrus	3.2
					L middle occipital gyrus	2.9
					R precuneus	2.7
					L precuneus	2.7
					R fusiform gyrus	2.5
					L posterior cingulate	2.3
					R inferior parietal lobule	2.2
					R middle temporal gyrus	2.2
					R declive	1.7
					L cingulate gyrus	1.6
					R insula	1
					R superior temporal gyrus	.9
					R inferior occipital gyrus	.9
					R thalamus	.8
					L culmen	.6
R postcentral gyrus	.5					
2	18	-4	-4.5	1	L superior temporal gyrus	25.4
					L middle temporal gyrus	30.2
					L parahippocampal gyrus	4.1
					L inferior temporal gyrus	2.9
					L middle occipital gyrus	2.7
					L fusiform gyrus	2.4
					L supramarginal gyrus	1.4
					L inferior parietal lobule	1.4

Information supplied includes total number of voxels, peak voxel location, brain regions involved and their overlap with the significant voxels. Due to poor resolution and signal leakage to non-brain regions, percentages do not add up to 100%. R – Right hemisphere; L – Left hemisphere.

Table 2 – Cluster sizes and locations.

High-gamma band											
Cluster no.	Cluster size	MNI coordinates (cm)			Anatomic area	% From cluster					
		L	P	I							
1	107	-5	5	6	L middle frontal gyrus	28.4					
					L precentral gyrus	14.4					
					L inferior frontal gyrus	9.5					
					L superior frontal gyrus	5.1					
					L parahippocampal gyrus	2.6					
					L postcentral gyrus	2.6					
					L superior temporal gyrus	2.5					
					L inferior temporal gyrus	1.8					
					L fusiform gyrus	1.4					
					L uncus	.5					
					L middle temporal gyrus	.5					
					2	16	-6	-4.5	4	L inferior parietal lobule	2
										L superior temporal gyrus	27.8
L supramarginal gyrus	23.5										
L middle temporal gyrus	19.3										

Information supplied includes total number of voxels, peak voxel location, brain regions involved and their overlap with the significant voxels. Due to poor resolution and signal leakage to non-brain regions, percentages do not add up to 100%. R – Right hemisphere; L – Left hemisphere.

pass the multiple comparisons threshold, it is permissible to present these as well (Gross et al., 2013), yet they should be treated with caution.

In order to complement the different images shown above, a within-subjects comparison between the OBE and BL conditions was conducted for alpha and high-gamma bands in each group (low- and high-OBE success) separately (see Fig. 4). These images reveal the oscillatory-based neural patterns mediating the successful production of an OBE relative to a BL state, as well as the neural activity of less successful attempts to achieve an OBE state relative to BL.

High-OBE participants show a right-lateralized increase in alpha power ($p = .001$) over a continual cortical strip running

from occipital regions through parietal and sensorimotor regions to frontal regions (see Fig. 4B), with a parallel medial route. Left hemisphere alpha increases are limited to occipital and posterior temporal regions, with a decrease in alpha power over the left temporal pole. Low-OBE participants, on the other hand, show impressive decreases in right-hemisphere-dominated alpha power ($p = .001$) over occipital and temporal regions, as well as posterior insula and TPJ and medial regions (see Fig. 4A). In addition, left hemisphere decreases are evident over lateral frontal regions, and a small right lateral prefrontal increase in alpha.

In the high-gamma band, both high- and low-OBE participants evidence notable increases in power in most of the right

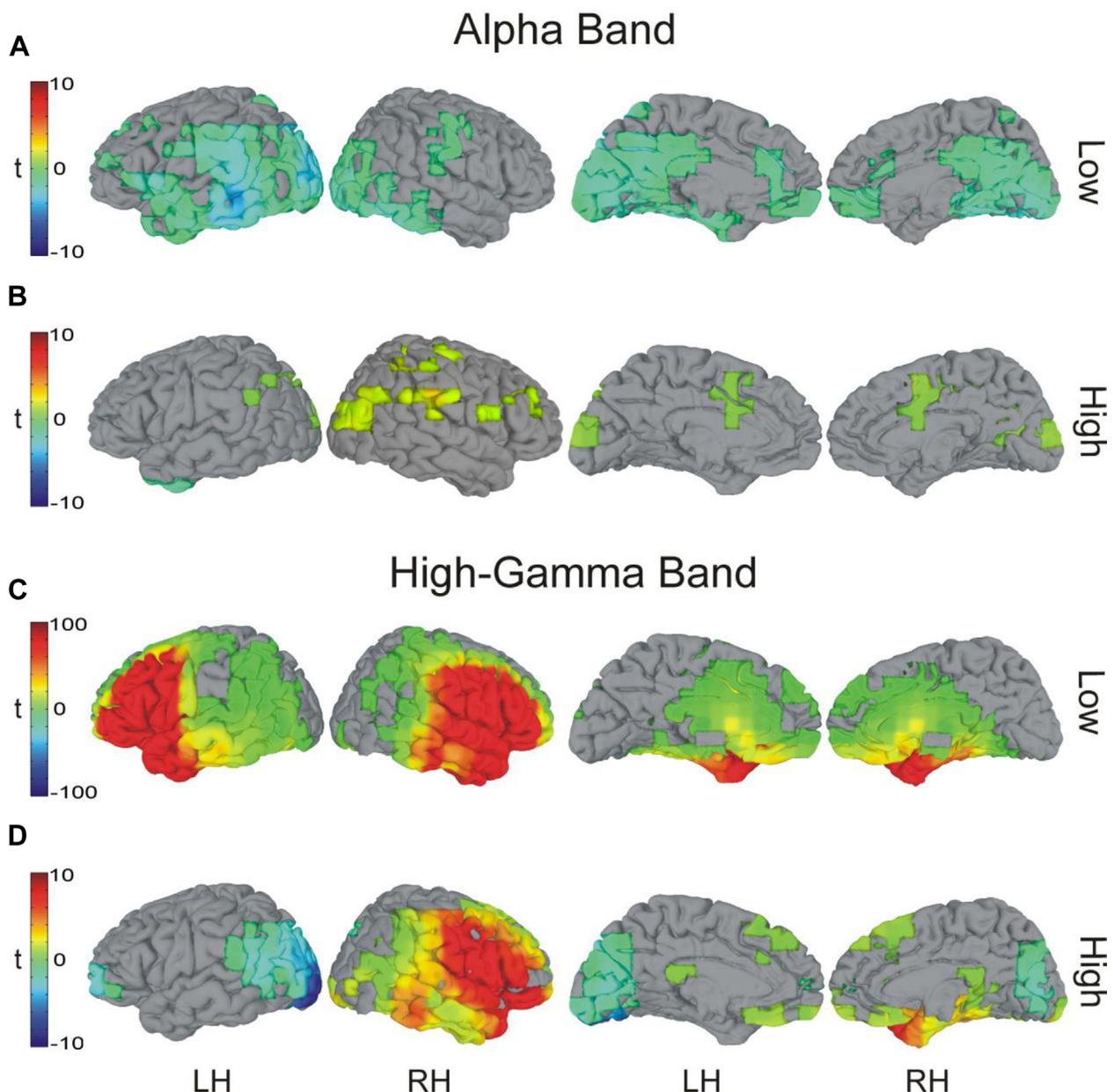


Fig. 4 – Cluster analysis differences between OBE and BL in the alpha band for low-OBE participants (A) and high-OBE participants (B); and in the high-gamma band for low-OBE participants (C) and high-OBE participants (D). LH – Left hemisphere; RH – Right hemisphere; Low – Low-OBE participants; High – High-OBE participants.

hemisphere ($p = .001$). The locus of activity is above and below the lateral sulcus (perisylvian cortex), in particular over lateral secondary sensorimotor and auditory areas (see Fig. 4D), as well as the inferior frontal gyrus. In the left hemisphere, low-OBE participants evidence a parallel left-hemisphere enhancement of high-gamma power (see Fig. 4C), while high-OBE participants show decreases in gamma power ($p = .001$) over occipital and posterior temporal, as well as lateral prefrontal regions.

4. Discussion

The objective of the study was to investigate the frequency-based neural mechanisms underlying altered self-location states by inducing OBEs via hypnotic suggestion. Contrary to previous studies of self-location, we utilized a top-down technique of hypnotic suggestion to manipulate the subjective experience of self-location. As indicated by the participants' OBE success reports, this method proved effective in producing OBEs. This means that the subjective experience of being a self localized within the spatial bounds of the physical body can be manipulated in laboratory settings not only by bottom-up tactile-visual mismatch manipulations or direct interventions in brain function, but also by well-controlled top-down techniques (e.g., hypnotic induction).

The present paradigm differs from the full-body illusion paradigm in a number of respects. Besides the difference in the direction of the manipulation (top-down vs bottom-up), different sensory modalities were engaged (auditory rather than visual-tactile) and the disembodied experience was suggested rather than emergent. Still, the present findings are largely in line with Lenggenhager et al. (2011), which is, to our knowledge, the only published work involving spontaneous data regarding the neurophysiological frequency-based correlates of altered self-location states. In both studies alpha and gamma frequency bands were found to be positively and negatively correlated, respectively, with degree of perceived change in self-location. It is important to emphasize that the experience of having an OBE induced by hypnotic suggestion may not be the same experience as that of a whole-body illusion. The latter has to do with illusory bodily sensations and is comparable to other perceptual illusions, such as optical illusions, while the former intervenes with more high-level cognitive and attentive processes. We are also not aware of any studies which directly examine the experiential overlap between the two experiences. The scope of the present study is limited to the perceived location of the self – which is altered in both cases. The similar pattern of neural results in both studies suggests that the reported carrier frequencies of alpha and gamma reflect the experiential state of a disembodied self, rather than processes relating to the methods by which the state is induced. However, future studies are needed in order to clarify the similarities and differences between these two types of experiences.

As mentioned in the introduction, we adopt an oscillatory-based predictive coding framework. Thus, increases in alpha band power are interpreted as indicating the brain's interaction with the suggested top-down world-

model regarding the self's altered location; and decreases in gamma band power are interpreted as a marker of decreased bottom-up error signaling regarding the incompatibility of the suggested self-location with the embodiment processes. In support of this, there is mounting evidence from human and primate studies regarding the role of the lower frequencies (alpha and beta) in top-down processing, and the role of higher frequencies (gamma) in bottom-up processing (Bastos et al., 2012; Bauer et al., 2014; Buschman & Miller, 2007; van Kerkoerle et al., 2014; Pelt et al., 2016; Sedley et al., 2016; Stein, Chiang, & Ko, 2000). The functionality of alpha oscillations is a complex matter. It has been suggested that task-related increases in alpha power reflect top-down, inhibitory control of task irrelevant processing (Klimesch, 2012; Klimesch, Sauseng, & Hanslmayr, 2007). Thus, increased alpha acts as an “inhibitory filter”, inhibiting processes from competing, task-irrelevant regions for the purpose of routing information to task-relevant regions and thereby increasing SNR (Jensen & Mazaheri, 2010). For the hypnotized participants to have a disembodied experience, habitual processing of regions anchoring the self to the body need to be inhibited. Body-centered perception is based on the integration of proprioceptive, vestibular, and visual body inputs (Blanke, Slater, & Serino, 2015). In line with this, our results (Fig. 3A) show that top-down hypnotic suggestion serves to inhibit habitual processing in self-anchoring brain regions including cortical vestibular regions such as posterior parietal regions (Pfeiffer, Serino, & Blanke, 2014), areas relating to vision, the rTPJ (Blanke, 2005, 2012; Ionta et al., 2011), which serves to integrate multisensory and bodily signals, and the PCC, which has been shown to reflect the integration of self location and body ownership (Guterstam et al., 2015).

While we find the oscillatory predictive coding framework attractive, other interpretations cannot be ruled out. In particular, the alpha band results can be interpreted in terms of attention modulation *per se*. Alpha oscillations have been shown to modulate attention (Klimesch, 2012), and internal attention in particular (Benedek, Schickel, Jauk, Fink, & Neubauer, 2014; Fink & Benedek, 2014). Benedek et al. (2014) show that right parietal increases in alpha correspond to focused internal attention, and interpret the results as reflecting an inhibition of the ventral attentional network (Corbetta & Shulman, 2002). When attention is focused, the ventral network is suppressed to prevent reorienting toward distracting events (Corbetta, Patel, & Shulman, 2008). Thus, the increased propensity for attentional focus while undergoing hypnotic suggestion may be part of the explanation for increased success in OBE production.

Our results indicate laterality effects in both the alpha and high-gamma bands. These coincide with the literature, which highlights the privileged role of the right hemisphere, parietal regions in particular, both in populations suffering from autoscopical disorders (Blanke & Mohr, 2005; Ionta et al., 2011), as well in healthy subjects (Arzy et al., 2006; Blanke, 2005). It is interesting to note that laterality was implemented differently by participants with high versus low OBE success. Increases in alpha in the right hemisphere (high OBE success) as well as decreases in left alpha (low OBE success) (Fig. 4A and B) both result in a shift in the balance of alpha power towards the

right hemisphere. Thus it appears that the mean by which the brain implements the right lateralization effect is related to the subjective experience of self-location.

The high-gamma results show similar increases in power in frontal and anterior temporal regions for both high and low OBE success participants (Fig. 4C and D respectively), but opposite trends in the left hemisphere. Low OBE success participants evidence a parallel increase in left homologous regions, while high OBE success participants evidence a decrease in power in left premotor, prefrontal and occipital regions, resulting in a sharp rightward shift in the balance of high-gamma power. We interpret the decrease in left premotor, prefrontal, occipital and occipital-temporal-parietal regions, including the TPJ, as indexing decreases in error signaling in task-related visual (seeing oneself from above), as well as bodily and sensory integration regions. In particular, the left ventral premotor region has been shown to reflect a whole-body multisensory precept, thus a decrease in error signaling in this region facilitates an alteration of the sense of body ownership (Gentile et al., 2015; Petkova et al., 2011). The medial prefrontal decrease in error signaling might indicate a decrease of higher-order processes relating to the self network, which holds the habitual conceptual knowledge regarding the unity of one's self and body (Northoff et al., 2006; Peer, Salomon, Goldberg, Blanke, & Arzy, 2015).

One concern regarding the study may be that the findings reflect general processes related to hypnosis, rather than OBE processes. While the comparison of high and low OBE-success groups suggests a specific OBE effect, it does not fully resolve this issue. However, there are a number of indications suggesting that such general hypnosis processes cannot fully explain our results. First, as reported in the methods (see Section 2.2), there was no correlation between OBE success rates and both the participants' hypnotizability levels and their self-report hypnotic depth measures. Second, our BL state was the final period of the hypnosis induction process (see Section 2.3), when participants were already in a deep state of hypnosis. Thus any differences found between the OBE state and the BL state cannot be attributed to hypnosis processes *per se* as in both conditions participants are under hypnosis. Finally, as reported in the Results section we ruled out the alpha and gamma effects being due to BL effects. Nevertheless, future studies could resolve this concern more definitively by adding a control condition in which participants also undergo a hypnotically suggested unusual bodily experience which does not involve a change in self-location.

One of the most challenging questions regarding the nature and neural basis of consciousness is the embodied dimension of the phenomenon, that is, feeling located within the body and viewing the world from that spatial perspective. The present study joins other recent studies which attempt to explain fundamental aspects of selfhood within an oscillatory-based predictive coding framework (Limanowski & Blankenburg, 2013; Seth, 2013; Seth, Suzuki, & Critchley, 2011). In addition, the present study highlights the utility of using hypnosis induction and suggestion for studying such processes. It is our hope that the novel methodology and conceptual framework presented here will spark new interest in exploring the neural basis of the more fundamental aspects of self-awareness. These processes are notoriously difficult to

manipulate and study in controlled laboratory settings, but are essential for any advancement in our understanding of the nature and meaning of being embodied, conscious and self-aware beings.

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