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The Induction of Religious Experiences and Temporal-Lobe Activation: neuronal source localization using EEG inverse solutions

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Corresponding Author:	Yoshija Walter Bern, SWITZERLAND
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	
Corresponding Author's Secondary Institution:	
First Author:	Yoshija Walter
First Author Secondary Information:	
Order of Authors:	Yoshija Walter
	Thomas Koenig
Order of Authors Secondary Information:	
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Dear editor of cognitive science

The interest in the study of special states of mind is growing, which becomes evident in the increasing numbers of publications in the domain of neurological meditation research. However, knowledge about another spiritual phenomenon – religious experiences – is still surprisingly scarce. Previous studies dealing with these kinds of experiences often do not have a strong basis in psychocognitive theory concerning religiosity and to our knowledge, they have not set an analytic emphasis on the dimension of experience (rather, it was implicitly analyzed by taking religious practice not as an induction mechanism but as an implicit proxy for religious experience itself). In the present study, we have tried to remedy this by specifically focus on experience in the domain of religiosity and using inverse solutions stemming from EEG experiments, we found that there was an activation pattern in the right temporal lobe. This coincides well with the literature and fills a respective void since it validates previous findings that have mostly focused on practice.

As such, we believe that this study is worth publishing in this journal and we hope that you agree with us. Please feel free to contact us in case there are any open questions.

Best regards
Dr. Josh Walter
Prof. Dr. Thomas Koenig

The Induction of Religious Experiences and Temporal-Lobe Activation: neuronal source localization using EEG inverse solutions

Yoshija Walter [a, b] *

Thomas Koenig[b]

[a]Laboratory for Cognitive Neurosciences, University of Fribourg, Switzerland
[b]University Hospital of Psychiatry and Psychotherapy, Translational Research Center, University of Bern, Switzerland

*Yoshija Walter

Brunnmattstrasse 73A

3007 Bern

Switzerland

yoshija.walter@kalaidos-fh.ch

+41 44 200 19 11

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Abstract

So far, knowledge about brain source localizations for religious states of mind is limited. Previous studies have not set a direct emphasis on experience. The present study investigated the phenomenon of religious experience using inverse solution calculations, and it was one of the first to measure the dimension of experience directly. A total of 60 evangelical Christians participated in an experiment where they were asked to engage in worship and try to connect with God. Using a bar slider, the participants continuously rated how strongly they sensed God's presence at any given moment. A selection of songs helped to induce the desired experience. Measurements were made using EEG with 64 electrodes and inverse solutions were calculated with sLORETA. We appropriated two mutually compatible hypotheses from the literature pertaining to religious experiences: the executive inhibition hypothesis (reformulated as the frontal relaxation hypothesis) and the temporal involvement hypothesis. Our results did not yield any information about the frontal areas; however, they indicated that the right temporal cortex appeared to be involved during the experience.

Keywords: EEG, inverse solutions, source localization, religious experience, worship

Introduction

Religious experience

A research project on religion and experience must first specify the definitions and conceptual approaches used by the researchers (cf. Clarke, 2011), which are often held as salient interpretative frameworks (Oman, 2013a, 2013b). There is no consensus on the "right" definition of religion and associated phenomena (Droogers, 2011) but there has been a strong call for a pragmatic take on defining the terms so that it becomes tangible for study in respect to a given research field (Byrne, 1999; Molendijk, 1999; Platvoet, 1999; Saler, 2000). Therefore, we follow a useful definition that is often employed in the cognitive sciences, which conceives of *religion* as cognitive and emotional representations with beliefs in supernatural powers, often perceived as sacred or inviolable (Bulbulia & Sosis, 2011). When it comes to its conceptual application to the notion of *religious experience*, we largely follow a Tavesian approach, which is often used in empirical research and has been devised specifically to this end (Paloutzian & Park, 2013, 2021). This is based on foundational work in the field of religious studies by Ann Taves (2005, 2009, 2009, 2011, 2020). It is basically a building-block approach to the phenomenon of religious experiences, which states that through a cognitive mechanism referred to as "singularization", special experiences are mentally set apart from more ordinary ones and are being connected to theological constructs. At the core of the theory lies the idea that an occurrence is *deemed* religious by the experiencer. The implication is that there is a subjective valuation of the experience, and we incorporated this in our study by asking the participants to subjectively rate their own experiences and indicate them on a bar slider.

Previous studies have usually taken religious *practice* (e.g. praying, singing, meditating) as a proxy for the religious *experience* itself (cf. Azari et al., 2001, 2005; Demmrich, 2018; Newberg et al., 2006). Investigations on the construct system of religion, however, showed that there are five dimensions of religiosity – namely intellect, ideology, private practice, public practice and experience – hence showing that religious practice and religious experience are *distinct* dimensions (Huber & Huber, 2012). As such, the present study sets an emphasis on experience, and we provide one of the first attempts to measure it directly while studying its neural correlates.

Religious experience and the brain

The neural underpinnings of religious cognition and emotion are an emerging field of research (Rim et al., 2019). Some evidence suggests religious experiences may have a positive impact on mental health and wellbeing (Fabricatore et al., 2000; Fry, 2000; Koenig & Larson, 2001; Kok et al., 2013; Krause, 2011, 2015; Lambert et al., 2009; Mueller et al., 2001; Park, 2005; Rizvi & Hossain, 2017), so better understanding the psychobiological mechanisms may be useful for practitioners. Additionally, discussions on the state of the literature demonstrate that research on experiential aspects of religiosity needs to be further strengthened (for current in-depth reviews, see: Grafman et al., 2020; van Elk & Aleman, 2017).

The investigation of religious experiences is no longer restricted to the humanities and the social sciences but has become a topic of interest within the empirical and experimental sciences as well. Andrew Newberg (2010) has famously coined the term *Neurotheology* and applied it to the neuroscientific study of religious occurrences. Shortly after, Cunningham (2011) has issued a publication with the titled question “Are Religious Experiences Really Localized Within the Brain?”. The article highlights some methodological challenges but also acknowledges the progress that has been made in trying to find the neural correlates of such phenomena. EEG and brain imaging techniques have been applied to study a broad range of religious rituals, such as contemplative prayer (Newberg et al., 2003), praying in tongues (Newberg et al., 2006; Walter et al., 2020), meditation with concentration tasks (Austin, 1998; Lehmann et al., 2001; Newberg et al., 2002), reading scriptures (Azari et al., 2001, 2005), religious recollections (Beauregard & O'Leary, 2008; Beauregard & Paquette, 2008), or meditations using mantras (Stigsby et al., 1981).

A review by Grafman et al. (2020) highlighted several key brain regions associated with religious cognitive processes:

- ***Cognitive control:*** the dorsolateral Prefrontal Cortex (dlPFC) is related to the downregulation of supernatural interpretations with unusual experiences.
- ***Theory of mind:*** the Inferior Frontal Gyrus (IFG), the Temporoparietal Junction (TPJ), the Medial Prefrontal Cortex (MPFC) and the precuneus are involved with rationalizing God's intent and emotions.
- ***Semantic processing:*** the ventrolateral Prefrontal Cortex (vlPFC), the Superior Temporal Gyrus (STG) and the temporopolar region are associated with retrieving religious beliefs stored in semantic and episodic memory.
- ***Reward and evaluation:*** the dorsomedial Prefrontal Cortex (dmPFC), the ventromedial Prefrontal Cortex (vmPFC) and the Nucleus Accumbens (NAcc) are connected to evaluating religious beliefs.
- ***Conflict detection:*** the Anterior Cingulate Cortex (ACC) is involved in detecting conflicts between religious beliefs and task stimuli or demands.

Drawing from neurological research on religious states of mind, two hypotheses have become particularly famous: (i) the Temporal Involvement Hypothesis (Beauregard, 2011; Beauregard & Paquette, 2008; Granqvist et al., 2005; Tinoca & Ortiz, 2014), and (ii) the Executive Inhibition Hypothesis (Andersen et al., 2014; Deeley et al., 2014; Kapogiannis et al., 2009; Lindeman et al., 2013; Schjoedt, 2009; Schjoedt et al., 2013). The former claims that religious experiences are triggered by an activation of the temporal lobes and the latter holds that an inhibition of frontal executive regions is key.

The temporal involvement hypothesis is based on the idea that temporal lobe excitations may be at least partly responsible for religious experiences (Tinoca & Ortiz, 2014). It was supplemented by studies showing that spiritual states of mind may sometimes be induced through phenomena like temporal lobe epilepsy (Devinsky & Lai, 2008; Garcia-Santibanez & Sarva, 2015; Johnstone et al., 2016; McCrae & Elliott, 2012). The temporal lobes are believed to be associated with auditory processing, memory and emotion. There are also some visual processes involved, such as object recognition. Their connections to the limbic system further implies some motivational functions including automatic states of the vegetative nervous system (Gloor, 1997; Joseph, 2011).

The executive inhibition hypothesis draws from the fact that certain religious prayer forms and associated experiences exhibit a decrease in function of frontal regions, most notably the dorsolateral prefrontal cortex (DLPFC; Newberg et al., 2002, 2006). It was said that the DLPFC and the right inferior frontal gyrus (rIFG), which are both believed to play a role in executive control, are activated more strongly in skeptics when compared to believers while watching emotional pictures (Lindeman et al., 2013). Such an executive inhibition was also discussed in the context of cognitive *dis*inhibition, thereby fostering religious creative thought and emotion (Deeley, 2003; Kapogiannis et al., 2009; Schjoedt et al., 2013). These studies appear to suggest that there may be a frontal relaxation characterized through a downregulation of frontal areas at play during religious states of mind, which prompted us to reformulate the idea into the *frontal relaxation hypothesis.*

Using EEG data from the scalp, it would be possible to test these two influential hypotheses through source localization analyses with inverse solution methods in combination with spectral analysis (cf. Hämäläinen & Ilmoniemi, 1994; Pascual-Marqui, 1999, 2002; Pascual-Marqui et al., 2011). Source localization through Low Resolution Electromagnetic Tomography (LORETA) was already applied to meditative states (Lehmann et al., 2001).

Research goal and hypotheses

To our knowledge, there has neither been an EEG study measuring the dimension of religious experience directly, nor an attempt to determine the possible source localizations of these experiences using inverse solutions. With the present research, we aimed to address this lack in the literature.

Based on the above-mentioned studies, we used the following two hypotheses:

Frontal relaxation hypothesis:	Religious worship experiences are associated with a partial downregulation of the frontal lobes.
Temporal involvement hypothesis:	Religious worship experiences are associated with an activation of the temporal lobes.

On an exploratory note, we also wanted to figure out whether these regions behaved similarly on the left and right hemispheres.

If the research sample is selected accordingly, religious experiences can be induced via worship practices with the help of music (Walter, 2021). To that end, it was shown that a mix of self-selected songs and pre-selected songs may help to both instantiate subjective states of mind as well as standardizing them for further analysis (Cheung et al., 2018, 2019; Koelsch, 2005, 2018; Koelsch, Bashevkin, et al., 2019; Koelsch et al., 2018; Koelsch, Vuust, et al., 2019; Koelsch & Siebel, 2005; Martin et al., 2018). Our study design therefore included worship for every condition, consisting of self-selected as well as pre-selected songs by the researchers, both from the secular and from the religious musical domain (for more on this type of design, see Walter & Altorfer, 2022). It was shown that evangelical Christians appear to be particularly adept in the induction process and that experiences under worship with music can be frequently observed (Bielo, 2011; Ingalls, 2018; Luhrmann, 2012; Walter, 2021). As such, all our participants were evangelicals and had to state that they were able to easily sense the presence of God when engaging in worship through music (cf. Walter, 2021)[1]. Overall, there were four reasons why we used an evangelical sample: (i) they have a strong focus on religious experience, (ii) they often use worship as an induction for the

[1] This is a study about the neurological correlates of a special state of mind where people believe to be sensing the presence of God. As the present investigation makes no claim about the ontological reality of any deity, all references to God correspond to the emic perspectives of the believers that are participating in this research.

experience, (iii) they have a shared theological background for the mental concepts that are associated with it, (iv) and we already had access to this cohort, which made the recruitment process more effective (for more on evangelicals and worship experiences, see Boyce-Tillman, 2007; Cassaniti & Luhrmann, 2014; Ingalls, 2018; Luhrmann, 2012).

Materials and Methods

Participants

A total of 60 evangelical participants have agreed to take part in the study, although three subjects had to be discarded due to recording errors during experiments. The participants' age ranged from 19 to 40 years (mean: 27y; SD: 4.2y); the gender ratio was roughly equal (male: 45%; female 55%); 87% of them were right-handed; and 70% stated that they played an instrument once or more per week. The highest education was spread out in the following fashion: 22% had a master's; 23% a bachelor's; 22% a high school diploma; and 33% finished an apprenticeship. Auditory tests confirmed adequate hearing, written informed consent was provided and the study was approved by the local ethics committee.[2]

When asked how they usually experienced God during worship, 23% of the participants held that they experienced something emotional (whereas 22% said that they sensed a divine presence and 21% felt close to God), 12% believed to sense something physical, and 9% professed to receive a message from God. 11% claimed that they get happy during the experience and three respondents (1.5%) reported to get melancholic or sad during the experience.

[2] Here we inserted the details provided by the ethics committee – for blind review, this information is presently omitted.

Assessment and Experimental Design

At the beginning, informed consent was declared, and a questionnaire was completed. It provided an adequate understanding of the participants' experiential dimensions, faith and prayer lives as well as demographic variables.

Then the EEG was applied and before the experiment started, a pre-experimental EEG recording was conducted. This was made with open eyes, closed eyes, blinking as well as horizontal eye movement, which was later used for the preprocessing of the EEG data.

Each experiment lasted for about one hour with six experimental conditions plus two resting state conditions at the very beginning and the end. Every condition's duration was around 4.5mins, separated by a time-free distraction task where the subjects had to concentrate on a series of flashing letters and answer questions about them. The goal of the distraction task was to clearly separate the mental states of the conditions so that the spillover effects would be minimized and hence the conditions could be viewed as independent observations. Both the letters in the distraction task as well as the turn of the experimental conditions (except for the resting states) were randomized as to avoid any systematic halo effect. The *Feedback Loop Model of Religious Worship Experiences* reported that environmental factors including the music can help govern and induce the religious experience by helping or distracting a person to focus on God (Walter, 2021). Hence, the different conditions were carefully selected based on how strongly they are thought to help or distract their focus. The six experimental conditions are portrayed in Table 1:

Table 1. Experimental conditions used to induce and guide the religious experience.

Name	Acronym	Description
Religious subjective	Rs	Participants brought along a religious worship song they liked, which had a personal track-record of helping them to sense God's presence in worship. This song was different for all individuals.
Religious given	Rg	Based on aforegoing interviews, the researchers selected a religious worship song that appeared to work well for the induction of the experience for the denominations of the present sample. This song was the same for all individuals.[3]
Secular subjective	Ss	Participants brought along a secular song they liked, which was similar in style and feel to the Rs song they selected. This song was different for all individuals.
Secular given	Sg	Based on aforegoing interviews, the researchers selected a secular song that appeared to work well for the induction of the experience in the denominations of the present sample. This song was the same for all individuals and it was selected to evoke similar feelings to the Rg condition.[4]
Empty (*blank*)	B	This was a 4.5mins session where no music was played so that the participants had the opportunity to engage in worship and the experience with no musical guidance or distraction.
Twelve-tone song	S12	Since the religious experience was our phenomenological variable of interest, we wanted to increase the variability by introducing a dissonant song that made it hard for participants to focus on God, therefore dampening the experience. The S12 song was a disharmonic twelve-tone piece selected to make it difficult for the people to focus. This one was the same for all individuals.[5]

The task instruction was the same for every condition and was read before each condition started anew. It requested the participants to engage in worship and to try to connect with God to sense his presence, regardless of whether there was a religious song, a secular one or no music played at all. The participants were not aware of the purpose of the individual

[3] For the Rg condition, the song *Reckless Love* by Cory Asbury (2017, Bethel Music) was selected.
[4] For the Sg condition, the song *Lose You To Love Me* by Selena Gomez (2019, Interscope Records) was selected.
[5] For the S12 condition, the song *Pierrot Lunaire* by Arnold Schönberg (1874-1951, Op.21: No. 1-4, Mondestrunken, Columbine, Der Dandy, eine blasse Wäscherin) was selected.

conditions and have not been informed that one condition was deliberately selected to distract them with dissonant melodies. The conditions all started and ended with a beep tone.

Using a sound engineering software (Audacity 2.4.2.), all songs were cut at natural breaks to last no longer than 4.5mins. Songs that were shorter were made longer (e.g. a verse or a chorus being duplicated) but only in a way as it sounded natural to the song, so that eventually all conditions took about 4.5mins.

Subjects had to close their eyes during the songs, the empty condition, and the resting states. Hence, after the beep tone the eyes were closed and after the second beep tone, 4.5mins later, the eyes were reopened. The reasons for closing the eyes were twofold: on the one hand, closing one's eyes reduced the input stimuli to maximize the guidance of the experimental conditions and on the other hand, recording the EEG with eyes closed made it more comparable to similar research in the literature. To feel comfortable and to navigate the bar slider with closed eyes at ease, every participant had some time to familiarize oneself with the instruments, the surroundings, the screen, the speakers, and the bar slider before the experiment started.

During the experiment, the EEG signal was continuously recorded and eventually the data from the distraction tasks were discarded. The religious experience was measured through a right-hand bar slider that participants were asked to move up and down depending on how strongly they sensed God's presence at any given moment during the experiment (except for in the resting state and during the distraction tasks).

EEG recording and processing

The electrophysiological potential on the scalp was measured using the Brain Products actiCap™ system with 64 active electrodes and recorded with Brain Vision Recorder 2.2™. The sampling rate occurred with 500 Hz and an elastic cap was applied to place the active electrodes according to the international 10-20 montage system with Ag/AgCl gel. The impedance level was fixed at 20 kOhm and the EEG was amplified and digitized using two Brain Amps. The beep tones providing the timestamps for the onset and offset of the conditions were recorded with a marker channel together with the EEG data.

The EEG raw data was exported to Brain Vision Analyzer 2.2™ for preprocessing, which occurred in two steps (cf. C. Mikutta et al., 2012; C. A. Mikutta et al., 2014): (i) we set out to create clean data, meaning that it was corrected for artifacts created by eye movement and ECG remnants; (ii) and we created segmented data, which were saved as separate files for the different experimental conditions per person. Both steps are further elucidated below.

First, the pre-experimental EEG recordings of each person was inspected to see if there were malfunctioning channels. Deficient channels were topographically interpolated. The channels were then used to create an individual spatial filter for eye movement artifact correction, and in rare cases it also included heartbeat artifact correction. To build these individual spatial filters, the data was filtered using an infinite impulse response (IIR) band-pass filter between 1.5 Hz to 20 Hz and an independent component analysis (ICA) was applied to the pre-experimental data. The resulting factors were visually inspected and depending on their explained variance as well as contribution to the perceived artifacts, the respective factors were excluded. Through an ICA inverse method, a corrected EEG was recalculated. The reconstructed data was visually inspected one more time to make sure that the artifact correction worked. Then, based on the exclusion of the respective ICA factors, the individual spatial correction filter was created.

Next, the filters from the pre-experimental recordings were applied to the data from the experimental recordings, after deficient channels were topographically interpolated. On each participant, another visual inspection was performed to mark places for exclusion where the muscle and movement artifacts distorted the experimental signals. Re-referencing was performed by recalculating the data to average reference.

Second, in a further segmentation process, each session was split into pieces of 2.048 seconds with no overlaps. From these epochs, cross-spectral matrices were computed and averaged within each condition and subject. Based on these averaged cross-spectral matrices sLORETA inverse solutions were computed. Inverse solutions were calculated with sLORETA (Pascual-Marqui, 2002), which has been validated independently (Greenblatt et al., 2005; Sekihara et al., 2005). The method implements the lead field by Fuchs et al. (2002) and the electrode coordinates by Jurcak, Tsuzuki and Ippeita (2007). Through allocating the respective Brodmann areas, four regions of interest (ROIs) were produced, corresponding to the frontal and temporal regions bilaterally (see Table 2).

Table 2. Allocation of Brodmann areas to regions of interest (ROIs) for the source localization analysis.

Region of Interest (ROI)	Brodmann areas
Left frontal cortex	Left: 4, 6, 8, 9, 10, 11, 24, 25, 32, 33, 44, 45, 46, 47
Left temporal cortex	Left: 20, 21, 22, 27, 28, 34, 35, 36, 37, 38, 41, 42, 43, 52
Right frontal cortex	Right: 4, 6, 8, 9, 10, 11,24, 25, 32, 33, 44, 45, 46, 47
Right temporal cortex	Right: 20, 21, 22, 27, 28, 34, 35, 36, 37, 38, 41, 42, 43, 52

Inverse Solutions analysis

Our hypotheses motivated us to expect a significant association of the frontal and temporal lobes in the statistical models, either on one or on both hemispheres, with a negative correlation of the frontal cortex (frontal relaxation hypothesis) and a positive one of the temporal cortex (temporal involvement hypothesis).

The inverse solutions generated by sLORETA were exported and analyzed with SPSS 27. Our statistical outline followed a four-step program: (i) first, a mixed model with the overall effects was calculated to see if there were any interaction effects of the experience, the frequency bands and the regions of interest (ROIs) with the LORETA values. If this was significant, we (ii) second, computed a mixed model for each of the ROIs to see in which *ROI* there was a significant interaction effect of the frequency bands and the experience with the LORETA values. (iii) Then, for the significant ROIs, there were individual mixed models for each of the frequency bands to determine if there is a significant effect of the experience of the LORETA values *per frequency band*. (iv) Last, the directionality was tested for each significant frequency band by estimating fixed effects. The next sections delineate each of these steps.

(i) The first model was a hierarchical multi-level mixed-model (all mixed-models were operating on a type 3 sum of squares). The model accounted for the condition, which was only used to induce an experiential variance, it included the frequency band, the ROI and the within condition and subject average rating of the religious experience. Based on our hypotheses, the term of primary interest consisted of a *band x ROI x rating* interaction. The model controlled for handedness and gender and was using subject as a random factor. All frequency bands and ROIs were present in this model.

(ii) Given that in the first step, the target interaction was significant, the second step consisted of four linear mixed-models, one for each of the four ROIs (left frontal, left temporal, right frontal, right temporal). The data was hence split per ROI and the models were run with the same parameters (excluding ROIs). They still included condition, frequency band, experiential rating, and as an interaction term *band x rating*. The focus lied on this interaction effect. The models controlled for handedness and gender and were using subject as a random factor.

(iii) Third, only the significant ROIs were selected since these were considered to be the ones with a significant association of the experience with the inverse solutions calculations (LORETA values, which in all mixed-models was the dependent variable). For the significant

ROIs, separate mixed-models were created for each frequency band. The models included the rating, handedness and gender, with the first being of primary interest. The significant frequencies in the ROIs were considered to be the relevant bands for the experience in the specific region.

(iv) Eventually, for each of the significant frequency bands, we performed separate regression models as post-hoc tests to the mixed-models because we wanted to know the directionality of the associations. This occurred through the SPSS built-in estimates of fixed effects function for linear mixed-models. The models included the rating, handedness, and gender, with the first being our primary interest. The dependent variable were the LORETA values. Here, we were interested in the estimates of the fixed effects (beta values) for the religious experience ratings.

As such, we organized our statistical analyses in a funnel: starting if there are interesting associations of the experience with the inverse calculations overall, zooming in on individual ROIs and then on the respective frequency bands, with eventually looking at the directionality of the associations that were left.

Results

As seen in the methods section, first, we wanted to see if there was a significant association of the LORETA-value with the interaction effect Band x ROI x Experience (which we call the overarching model). Table 3 shows that this was the case. Hence, the analysis was run for each ROI separately. Table 4 shows that the effect was only significant for the right temporal cortex and table 5 specifies the details of the results. Table 6 therefore singles out the right temporal lobe and runs the analysis on each frequency band. This shows us that only higher frequencies (1.-3. Beta and Gamma) were significant. The parameter estimates for all of these frequency bands were positive. This demonstrates that the religious experience was associated with an increased presence of higher frequencies in the right temporal cortex. The individual results are displayed as followed.

The specific results of the overarching mixed regression model based on the regional sLORETA source density estimates are depicted in Table 3.

Table 3. Depiction of all the associations from the overarching inverse solution model calculated through hierarchical multi-level linear mixed models. The major focus lies on the interaction term (Band x ROI x Experience).
Condition = experimental condition; Band = frequency band; ROI = region of interest; Experience = averaged subjective rating of the religious experience per condition; Handedness = left- or right-handed; Gender = male or female; Df = degrees of freedom

Variable	Df	F-Value	Significance
Condition	6, 12717	1.1	.375
Band	7, 12717	2124.5	<.001
ROI	3, 12717	4217.1	<.001
Experience	1, 12717	11.3	.001
Band x ROI x Experience	31, 12717	6.9	<.001
Handedness	1, 12717	39.8	<.001
Gender	1, 12717	182.6	<.001

Dependent variable: LORETA-values

The overarching model was split and recalculated for each of the four ROIs, of which only the model for the right temporal lobe was significant. This can be seen in table 4 (only the interaction effects are displayed since they are relevant for determining whether there is a significant association of the LOREA-values with the frequency bands and the experience).

Table 4. Depiction of all the associations from the inverse solution model between the LORETA-values and the interaction effect between the frequency and the experience. Only the interaction effects are displayed.
Condition = experimental condition; Band = frequency band; ROI = region of interest; Experience = averaged subjective rating of the religious experience per condition; Handedness = left- or right-handed; Gender = male or female; Df = degrees of freedom

Interaction	ROI	Df	F-Value	Significance
Band x Experience	Left frontal	7, 3168	1.01	.422
	Left temporal	7, 3168	1.67	.113
	Right frontal	7, 3168	1.50	.163
	Right temporal	7, 3168	4.52	<.001

Dependent variable: LORETA-values

The results of the model for the right temporal cortex are found in table 5.

Table 5. Depiction of all the associations from the inverse solution model of the right temporal lobe. The major focus lies on the interaction term (Band x Experience).
Condition = experimental condition; Band = frequency band; ROI = region of interest; Experience = averaged subjective rating of the religious experience per condition; Handedness = left- or right-handed; Gender = male or female; Df = degrees of freedom

Variable	Df	F-Value	Significance
Condition	6, 3168	0.1	.437
Band	7, 3168	548.9	<.001
Rating	1, 3168	15.8	<.001
Band x Experience	7, 3168	4.5	<.001
Handedness	1, 3168	4.4	.037
Gender	1, 3168	305.6	<.001

Dependent variable: LORETA-values

For this ROI, split analyses were performed where a separate model for each frequency band was calculated to discover which bands were associated with the religious experience in the right temporal cortex. The linear mixed models were significant only for upper frequencies, namely for 1st beta, 2nd beta, 3rd beta, and gamma. Post-hoc parameter estimates for the fixed effects observed for understanding the directionality of the association between the religious experience and the LORETA-values, which indicate the source localization probability. For this, only the directionality (positive or negative values) of the coefficients were of any interest. The results are summarized in table 6.

Table 6. Summary of the four significant frequency band results including their parameter estimates. Only the frequency bands for significant religious experiences are depicted. The parameter estimates refer to the non-standardized regression coefficients of the religious experience.
The F-value refers to the linear mixed model and the T-value to the associated regression coefficient.

Frequency band	Df	F-value	T-value	significance	Parameter estimates
1st Beta	1, 395	4.7	2.2	.031	.026
2nd Beta	1, 395	11.9	3.5	.001	.052
3rd Beta	1, 395	11.3	3.4	.001	.069
Gamma	1, 395	5.1	2.3	.025	.018

Dependent variable: LORETA-values

Discussion

The present findings

The current study investigated the neural activation patterns with potential source localizations of subjectively rated religious experiences in worship, operationalized as sensing the presence of the divine. We performed a spectral analysis with inverse solutions and worked with two hypotheses: the frontal relaxation and the temporal involvement hypothesis. Our results did not show any significant evidence for a frontal relaxation; however, they indicated that the right temporal lobe was significantly associated with the religious experience. Further post-hoc analyses showed that only higher frequencies – namely 1st beta, 2nd beta, 3rd beta, and gamma – were significantly correlated with the experience in this region of interest. Even though the parameter estimates were small, they all displayed a positive value, indicating that the frequencies in the right temporal cortex were positively associated with the experience. Higher frequencies are typically perceived as activation patterns and positive associations may be thus interpreted as an activation in the respective region under the influence of the religious experience. This means that our data showed a lack of evidence concerning the frontal relaxation hypothesis but it provided evidence for the temporal involvement hypothesis, specifying that the effects may lateralize stronger on the right hemisphere.

The next section briefly discusses the relevance of the temporal cortex in regard to the present findings concerning religious experiences.

Temporal involvement

Britton and Bootzin (2004, p. 254) stated that "Many studies in humans suggest that altered temporal lobe functioning, especially functioning in the right temporal lobe, is involved in mystical and religious experiences." Our present findings therefore line up well with previous studies and may significantly strengthen them since unlike previous research designs, we have set an emphasis to measure religious experience *directly* and not just via religious practice as a proxy.

According to Grafman et al. (2020), there are three key regions that have been found in this area relevant for religious cognition and emotion: the Temporopolar Region (TPR), the Superior Temporal Gyrus (STG), and the Temporoparietal Junction (TPJ).

The TPR and the STG are held to be involved in accessing religious beliefs (for a review, see Grafman et al., 2020), which appears to be a necessary act in deeming an experience religious (cf. Taves, 2011). Among other things, the TPR is implicated in social cognition and is known to play a role in prayer manifested as an interpersonal phenomenon (see Schjoedt, 2009, for a further review). This indicates that prayer and associated experiences imply the retrieval of specific religious ideas, such as conceptions of God, and reconstructing them in a social context. These patterns are not surprising since believing to be having a direct experience with God must naturally entail the belief that one has a concept of God in mind and that there is some sort of interpersonal interaction with a divine agent and the self.

The same may be true for the STG, which is said to be involved with processing abstract linguistic content (Just et al., 2004). In their fMRI study, Kapogiannis and colleagues (2009) discovered that the STG is explicitly activated in tasks testing religious knowledge. This goes hand in hand with an activation of the TPR, which is believed to be equally responsible for retrieving religious concepts in an interpersonal situation.

Kappogiannis and his team (2009) reported an activation of the inferior temporal gyrus for the perception of God’s level of involvement and the middle temporal gyrus for God’s perceived emotion. It makes sense to assume that a subjectively believed encounter with God would implicate God’s involvement as well as his perceived emotions towards the experiencer.

However, some religious experiences have been reported to recruit the temporal cortex in a broader sense. For example, a global discussion on a case-report about an epilepsy patient reported “right-sided frontotemporal sharp [EEG] waves” in relation to seizure-related hyper religiosity whereas further discussing evidence on religious sensations during temporal-lobe epilepsy (Garcia-Santibanez & Sarva, 2015, p. 2). An in-depth literature review by McCrae and Elliott (2012) further strengthens the notion that spiritual and religious experiences appear to be more frequently associated with temporal-lobe epilepsy.

Perhaps one of the most interesting regions in this area reviewed by Grafman and colleagues (2020) is the temporoparietal junction (TPJ). This is because the TPJ has been mentioned frequently in spiritual as well as religious experiences, out-of-body occurrences, and mysticism. For example, a literature discussion connected mystical experiences on mountains with the TPJ (Arzy et al., 2005). The same team also provided electrical stimulation to the left TPJ under surgical conditions, which induced the sensation of an illusory shadow person (Arzy et al., 2006). A structural MRI study investigated the belief in the miracles of Lourdes via Voxel-Based Morphometry (VBM), restricted only to grey matter analysis (Schienle et al., 2019). The results showed that the belief corresponded positively with TPJ volume and negatively with MPFC volume. An fMRI study about true and false belief reasoning showed that both forms of beliefs were, among others, positively associated with the TPJ (Sommer et al., 2007). Olaf Blanke and his lab has become known for researching Out-of-Body experiences (OBE) and often, but not always, they have found an association with the TPJ. In one instance during an epilepsy evaluation, focal electrical stimulation of the right angular gyrus elicited the illusory transformation of the person’s arms and legs as well as whole-body displacements (Blanke et al., 2002). In a further study, five out of the six patients in the sample who have reported an OBE have had a diagnosed dysfunction in the TPJ (Blanke et al., 2004). Stringent reviews have highlighted the relevance of the TPJ for OBEs (Blanke,

2012) and respective frameworks have been proposed (Blanke et al., 2015). A lesion analysis showed that sensations of external vision-like apparitions were positively correlated with lesions in the temporoparietal, insular and frontoparietal regions (Blanke et al., 2014). In one interesting case report, a 50-year old woman who never before or after reported an OBE has had three such experiences when during her craniotomy the TPJ was electrically stimulated (Bos et al., 2016).

The TPJ is said to be associated with auditory signals, which are often described by mystics (Firth & Bolay, 2004), and with integrating vision, touch and hearing in a coordinated reference frame (Bremmer et al., 2001; Duhamel et al., 1998; Guldin & Grüsser, 1998; La'davas, 2002), as well as with language and understanding (see Wernicke; Cohen & Dehaene, 2004; Hutsler & Galuske, 2003). A TPJ damage on the left hemisphere is reported with a feeling or hearing of a presence in one's proximate space (Blanke et al., 2003, 2014) and such experiences have been induced experimentally by manipulation of the congruence between felt and observed sensory stimuli (Ehrsson, 2007; Lenggenhager et al., 2011). Especially the *right* TPJ is said to be involved in multisensory integration for religious experiences (for a further review, see van Elk & Aleman, 2017).

In short, the temporal lobe appears to be involved in extraordinary sensations, including the weighing and integration of these potentially differing signals by connecting them to religious beliefs about God's intents and emotions. In certain instances, this seems to be localized stronger on the right hemisphere. Our study appears to coincide well with such previous findings since our participants' reports of sensing the presence of God during worship came along with a significant activation of the right temporal cortex. A religious worship experience might therefore be a state of mind where the believer is confronted with extraordinary sensations in such a way as to invoke the attribution of divine concepts to the occurrence.

Conclusion, limitations, and future research

The present study investigated religious experiences in terms of sensing the presence of God with a sample of evangelical Christians. It was hypothesized that such an experience would be characterized by a relaxation of the frontal cortex as well as an activation of the temporal cortex. Our results showed that upon a religious experience under the influence of worship, the right temporal cortex appeared to be activated. As such, our study provides further evidence for the temporal involvement hypothesis whereas no information can be added to the frontal relaxation hypothesis, which we reformulated from the executive inhibition hypothesis.

One major limitation we were facing was a byproduct of the complex nature of these special religious states of mind, which can be summarized in three points. First, we have studied one specific phenomenon that belongs to a wider class of "religious experience". There are many more experiences that may be deemed religious but are not necessarily characterized as "sensing the presence of God" (Taves, 2005, 2011; Taves et al., 2019). Second, there are likely different psychological mechanisms that may lead to the various instances of these states of mind (as already highlighted long ago by James, 1902). And third, we deliberately selected a narrow population of evangelical Christians with shared theological presuppositions concerning such experiences. Other denominations and religions may have different dogmatic concepts and hence the cognitive constructs associated with such experiences might also differ. It is therefore possible that the neurophysiological mechanisms we have discovered are merely a small fraction of potential findings concerning religious experiences. Future studies can remedy this in three ways: (i) by focusing on other types of religious experiences, (ii) by widening the theoretical scope and including more psychological avenues for the characterization of such experiences, and (iii) by recruiting believers from other faith traditions and denominations.

Acknowledgment

We were able to recruit 60 participants for a study that touches on a very intimate subject to all of them. They deserve our appreciation since it cannot be taken for granted that so many people were willing to offer their most precious experiences under sterile lab condition where they arguably do not feel as comfortable as in their regular environment.

Conflict of interest

The authors have no conflicts of interest to declare.

Author contribution

Yoshija Walter: Conceptualization (equal), Data curation (lead), writing – original draft (lead), formal analysis (lead), Project administration (lead). **Thomas Koenig:** Conceptualization (equal), writing – review and editing (lead), formal analysis (supporting), Software (lead), Supervision (lead).

Open practice and data availability statement

The experiment was not preregistered and the data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Andersen, M., Schjoedt, U., Nielbo, K., & Sørensen, J. (2014). Mystical Experience in the Lab. *Method & Theory in the Study of Religion*, *26*, 217–245. https://doi.org/10.1163/15700682-12341323

Arzy, S., Idel, M., Landis, T., & Blanke, O. (2005). Why revelations have occurred on mountains?: Linking mystical experiences and cognitive neuroscience. *Medical Hypotheses*, *65*(5), 841–845. https://doi.org/10.1016/j.mehy.2005.04.044

Arzy, S., Seeck, M., Ortigue, S., Spinelli, L., & Blanke, O. (2006). Induction of an illusory shadow person. *Nature*, *443*(7109), 287–287. https://doi.org/10.1038/443287a

Austin, J. H. (1998). *Zen and the brain: Toward an understanding of meditation and consciousness*. MIT Press.

Azari, N. P., Missimer, J., & Seitz, R. J. (2005). Religious Experience and Emotion: Evidence for Distinctive Cognitive Neural Patterns. *International Journal for the Psychology of Religion*, *15*(4), 263–281. https://doi.org/10.1207/s15327582ijpr1504_1

Azari, N. P., Nickel, J., Wunderlich, G., Niedeggen, M., Hefter, H., Tellmann, L., Herzog, H., Stoerig, P., Birnbacher, D., & Seitz, R. J. (2001). Neural correlates of religious experience. *The European Journal of Neuroscience*, *13*(8), 1649–1652. https://doi.org/10.1046/j.0953-816x.2001.01527.x

Beauregard, M. (2011). Neuroscience and Spirituality – Findings and Consequences. In H. Walach, S. Schmidt, & W. B. Jonas (Eds.), *Neuroscience, Consciousness and Spirituality* (Vol. 1, pp. 57–73). Springer Netherlands. https://doi.org/10.1007/978-94-007-2079-4_4

Beauregard, M., & O'Leary, D. (2008). *The spiritual brain: A neuroscientist's case for the existence of the soul* (1. Auflage, Nachdruck 2008). HarperCollins.

Beauregard, M., & Paquette, V. (2008). EEG activity in Carmelite nuns during a mystical experience. *Neuroscience Letters*, *444*(1), 1–4. https://doi.org/10.1016/j.neulet.2008.08.028

Bielo, J. S. (2011). *Emerging Evangelicals: Faith, modernity, and the desire for authenticity*. New York University Press.

Blanke, O. (2012). Multisensory brain mechanisms of bodily self-consciousness. *Nature Reviews Neuroscience*, *13*(8), 556–571. https://doi.org/10.1038/nrn3292

Blanke, O., Landis, T., Spinelli, L., & Seeck, M. (2004). Out-of-body experience and autoscopy of neurological origin. *Brain: A Journal of Neurology*, *127*(Pt 2), 243–258. https://doi.org/10.1093/brain/awh040

Blanke, O., Ortigue, S., Coeytaux, A., Martory, M.-D., & Landis, T. (2003). Hearing of a presence. *Neurocase*, *9*(4), 329–339. https://doi.org/10.1076/neur.9.4.329.15552

Blanke, O., Ortigue, S., Landis, T., & Seeck, M. (2002). Stimulating illusory own-body perceptions. *Nature*, *419*(6904), 269–270. https://doi.org/10.1038/419269a

Blanke, O., Pozeg, P., Hara, M., Heydrich, L., Serino, A., Yamamoto, A., Higuchi, T., Salomon, R., Seeck, M., Landis, T., Arzy, S., Herbelin, B., Bleuler, H., & Rognini, G. (2014). Neurological and Robot-Controlled Induction of an Apparition. *Current Biology*, *24*(22), 2681–2686. https://doi.org/10.1016/j.cub.2014.09.049

Blanke, O., Slater, M., & Serino, A. (2015). Behavioral, Neural, and Computational Principles of Bodily Self-Consciousness. *Neuron*, *88*(1), 145–166. https://doi.org/10.1016/j.neuron.2015.09.029

Bos, E. M., Spoor, J. K. H., Smits, M., Schouten, J. W., & Vincent, A. J. P. E. (2016). Out-of-Body Experience During Awake Craniotomy. *World Neurosurgery*, *92*, 586.e9-586.e13. https://doi.org/10.1016/j.wneu.2016.05.002

Boyce-Tillman, J. (2007). Spirituality in the Musical Experience. In L. Bresler (Ed.), *International Handbook of Research in Arts Education* (pp. 1405–1424). Springer Netherlands. https://doi.org/10.1007/978-1-4020-3052-9_96

Bremmer, F., Schlack, A., Duhamel, J. R., Graf, W., & Fink, G. R. (2001). Space coding in primate posterior parietal cortex. *NeuroImage*, *14*(1 Pt 2), S46-51. https://doi.org/10.1006/nimg.2001.0817

Britton, W. B., & Bootzin, R. R. (2004). Near-Death Experiences and the Temporal Lobe. *Psychological Science*, *15*(4), 254–258. https://doi.org/10.1111/j.0956-7976.2004.00661.x

Bulbulia, J., & Sosis, R. (2011). Signalling theory and the evolution of religious cooperation. *Religion*, *41*(3), 363–388. https://doi.org/10.1080/0048721X.2011.604508

Byrne, P. (1999). The definition of religion: Squaring the circle. In J. Platvoet & A. L. Molendijk (Eds.), *The pragmatics of defining religion: Contexts, concepts, and contests* (pp. 379–396). Brill.

Cassaniti, J. L., & Luhrmann, T. M. (2014). The Cultural Kindling of Spiritual Experiences. *Current Anthropology*, *55*(S10), S333–S343. https://doi.org/10.1086/677881

Cheung, V. K. M., Harrison, P. M. C., Meyer, L., Pearce, M. T., Haynes, J.-D., & Koelsch, S. (2019). Uncertainty and Surprise Jointly Predict Musical Pleasure and Amygdala, Hippocampus, and Auditory Cortex Activity. *Current Biology*, *29*(23), 4084-4092.e4. https://doi.org/10.1016/j.cub.2019.09.067

Cheung, V. K. M., Meyer, L., Friederici, A. D., & Koelsch, S. (2018). The right inferior frontal gyrus processes nested non-local dependencies in music. *Scientific Reports*, *8*(1), Article 1. https://doi.org/10.1038/s41598-018-22144-9

Clarke, P. B. (2011). Introduction: Towards a more organic unerstanding of religion within a global framework. In P. B. Clarke (Ed.), *The Oxford Handbook of the Sociology of Religion* (pp. 1–30). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199588961.013.0015

Cohen, L., & Dehaene, S. (2004). Specialization within the ventral stream: The case for the visual word form area. *NeuroImage*, *22*(1), 466–476. https://doi.org/10.1016/j.neuroimage.2003.12.049

Cunningham, P. F. (2011). Are Religious Experiences Really Localized Within the Brain? The Promise, Challenges, and Prospects of Neurotheology. *The Journal of Mind and Behavior*, *32*(3), 223–249.

Deeley, P. Q. (2003). Social, Cognitive, and Neural Constraints on Subjectivity and Agency: Implications for Dissociative Identity Disorder. *Philosophy, Psychiatry, & Psychology*, *10*(2), 161–167. https://doi.org/10.1353/ppp.2003.0095

Deeley, P. Q., Oakley, D. A., Walsh, E., Bell, V., Mehta, M. A., & Halligan, P. W. (2014). Modelling psychiatric and cultural possession phenomena with suggestion and fMRI. *Cortex*, *53*, 107–119. https://doi.org/10.1016/j.cortex.2014.01.004

Demmrich, S. (2018). Music as a trigger of religious experience: What role does culture play? *Psychology of Music*, *48*(1), 35–49. https://doi.org/10.1177/0305735618779681

Devinsky, O., & Lai, G. (2008). Spirituality and religion in epilepsy. *Epilepsy & Behavior: E&B*, *12*(4), 636–643. https://doi.org/10.1016/j.yebeh.2007.11.011

Droogers, A. (2011). Defining Religion. In P. B. Clarke (Ed.), *The Oxford Handbook of the Sociology of Religion* (pp. 263–279). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199588961.013.0015

Duhamel, J.-R., Colby, C. L., & Goldberg, M. E. (1998). Ventral Intraparietal Area of the Macaque: Congruent Visual and Somatic Response Properties. *Journal of Neurophysiology*, *79*(1), 126–136. https://doi.org/10.1152/jn.1998.79.1.126

Ehrsson, H. H. (2007). The Experimental Induction of Out-of-Body Experiences. *Science*, *317*(5841), 1048–1048. https://doi.org/10.1126/science.1142175

Fabricatore, A. N., Handal, P. J., & Fenzel, L. M. (2000). Personal Spirituality as a Moderator of the Relationship between Stressors and Subjective Well-Being. *Journal of Psychology and Theology*, *28*(3), 221–228. https://doi.org/10.1177/009164710002800305

Firth, P. G., & Bolay, H. (2004). Transient high altitude neurological dysfunction: An origin in the temporoparietal cortex. *High Altitude Medicine & Biology*, *5*(1), 71–75. https://doi.org/10.1089/152702904322963708

Fry, P. S. (2000). Religious involvement, spirituality and personal meaning for life: Existential predictors of psychological wellbeing in community-residing and institutional care elders. *Aging & Mental Health*, *4*(4), 375–387. https://doi.org/10.1080/713649965

Fuchs, M., Kastner, J., Wagner, M., Hawes, S., & Ebersole, J. S. (2002). A standardized boundary element method volume conductor model. *Clinical Neurophysiology: Official Journal of the*

International Federation of Clinical Neurophysiology, *113*(5), 702–712. https://doi.org/10.1016/s1388-2457(02)00030-5

Garcia-Santibanez, R., & Sarva, H. (2015). Isolated Hyperreligiosity in a Patient with Temporal Lobe Epilepsy. *Case Reports in Neurological Medicine*, *2015*, 235856. https://doi.org/10.1155/2015/235856

Gloor, P. (1997). *The temporal lobe and limbic system*. Oxford University Press.

Grafman, J., Cristofori, I., Zhong, W., & Bulbulia, J. (2020). The Neural Basis of Religious Cognition. *Current Directions in Psychological Science*, *29*(2), 126–133. https://doi.org/10.1177/0963721419898183

Granqvist, P., Fredrikson, M., Unge, P., Hagenfeldt, A., Valind, S., Larhammar, D., & Larsson, M. (2005). Sensed presence and mystical experiences are predicted by suggestibility, not by the application of transcranial weak complex magnetic fields. *Neuroscience Letters*, *379*(1), 1–6. https://doi.org/10.1016/j.neulet.2004.10.057

Greenblatt, R. E., Ossadtchi, A., & Pflieger, M. E. (2005). Local linear estimators for the bioelectromagnetic inverse problem. *IEEE Transactions on Signal Processing*, *53*(9), 3403–3412. https://doi.org/10.1109/TSP.2005.853201

Guldin, W. O., & Grüsser, O. J. (1998). Is there a vestibular cortex? *Trends in Neurosciences*, *21*(6), 254–259. https://doi.org/10.1016/s0166-2236(97)01211-3

Hämäläinen, M. S., & Ilmoniemi, R. J. (1994). Interpreting magnetic fields of the brain: Minimum norm estimates. *Medical & Biological Engineering & Computing*, *32*(1), 35–42. https://doi.org/10.1007/BF02512476

Huber, S., & Huber, O. W. (2012). The Centrality of Religiosity Scale (CRS). *Religions*, *3*(3), 710–724. https://doi.org/10.3390/rel3030710

Hutsler, J., & Galuske, R. A. W. (2003). Hemispheric asymmetries in cerebral cortical networks. *Trends in Neurosciences*, *26*(8), 429–435. https://doi.org/10.1016/S0166-2236(03)00198-X

Ingalls, M. (2018). *Singing the Congregation: How contemporary worship music forms evangelical community*. Oxford University Press.

James, W. (1902). *The Varieties of Religious Experience* (Centenary Edition). Taylor & Francis.

Johnstone, B., Holliday, G., & Cohen, D. (2016). Heightened religiosity and epilepsy: Evidence for religious-specific neuropsychological processes. *Mental Health, Religion & Culture*, *19*(7), 704–712. https://doi.org/10.1080/13674676.2016.1238449

Joseph, R. (2011). *Temporal Lobes: Occipital Lobes, Memory, Language, Vision, Emotion, Epilepsy, Psychosis*. University Press.

Jurcak, V., Tsuzuki, D., & Dan, I. (2007). 10/20, 10/10, and 10/5 systems revisited: Their validity as relative head-surface-based positioning systems. *NeuroImage*, *34*(4), 1600–1611. https://doi.org/10.1016/j.neuroimage.2006.09.024

Just, M. A., Newman, S. D., Keller, T. A., McEleney, A., & Carpenter, P. A. (2004). Imagery in sentence comprehension: An fMRI study. *NeuroImage*, *21*(1), 112–124. https://doi.org/10.1016/j.neuroimage.2003.08.042

Kapogiannis, D., Barbey, A. K., Su, M., Zamboni, G., Krueger, F., & Grafman, J. (2009). Cognitive and neural foundations of religious belief. *Proceedings of the National Academy of Sciences*, *106*(12), 4876–4881. https://doi.org/10.1073/pnas.0811717106

Koelsch, S. (2005). Investigating Emotion with Music: Neuroscientific Approaches. *Annals of the New York Academy of Sciences*, *1060*(1), 412–418. https://doi.org/10.1196/annals.1360.034

Koelsch, S. (2018). Investigating the Neural Encoding of Emotion with Music. *Neuron*, *98*(6), 1075–1079. https://doi.org/10.1016/j.neuron.2018.04.029

Koelsch, S., Bashevkin, T., Kristensen, J., Tvedt, J., & Jentschke, S. (2019). Heroic music stimulates empowering thoughts during mind-wandering. *Scientific Reports*, *9*(1), Article 1. https://doi.org/10.1038/s41598-019-46266-w

Koelsch, S., & Siebel, W. A. (2005). Towards a neural basis of music perception. *Trends in Cognitive Sciences*, *9*(12), 578–584. https://doi.org/10.1016/j.tics.2005.10.001

Koelsch, S., Skouras, S., & Lohmann, G. (2018). The auditory cortex hosts network nodes influential for emotion processing: An fMRI study on music-evoked fear and joy. *PLOS ONE*, *13*(1), e0190057. https://doi.org/10.1371/journal.pone.0190057

Koelsch, S., Vuust, P., & Friston, K. (2019). Predictive Processes and the Peculiar Case of Music. *Trends in Cognitive Sciences*, *23*(1), 63–77. https://doi.org/10.1016/j.tics.2018.10.006

Koenig, G. H., & Larson, D. B. (2001). Religion and mental health: Evidence for an association. *International Review of Psychiatry*, *13*(2), 67–78. https://doi.org/10.1080/09540260124661

Kok, B. E., Coffey, K. A., Cohn, M. A., Catalino, L. I., Vacharkulksemsuk, T., Algoe, S. B., Brantley, M., & Fredrickson, B. L. (2013). How Positive Emotions Build Physical Health: Perceived Positive Social Connections Account for the Upward Spiral Between Positive Emotions and Vagal Tone. *Psychological Science*, *24*(7), 1123–1132. https://doi.org/10.1177/0956797612470827

Krause, N. (2011). Religion and Health: Making Sense of a Disheveled Literature. *Journal of Religion and Health*, *50*(1), 20–35. https://doi.org/10.1007/s10943-010-9373-4

Krause, N. (2015). Religious Doubt, Helping Others, and Psychological Well-Being. *Journal of Religion and Health*, *54*(2), 745–758. https://doi.org/10.1007/s10943-014-9977-1

La'davas, E. (2002). Functional and dynamic properties of visual peripersonal space. *Trends in Cognitive Sciences*, *6*(1), 17–22. https://doi.org/10.1016/s1364-6613(00)01814-3

Lambert, N. M., Fincham, F. D., Braithwaite, S. R., Graham, S. M., & Beach, S. R. H. (2009). Can prayer increase gratitude? *Psychology of Religion and Spirituality*, *1*(3), 139–149. https://doi.org/10.1037/a0016731

Lehmann, D., Faber, P. L., Achermann, P., Jeanmonod, D., Gianotti, L. R. R., & Pizzagalli, D. (2001). Brain sources of EEG gamma frequency during volitionally meditation-induced, altered states of consciousness, and experience of the self. *Psychiatry Research: Neuroimaging*, *108*(2), 111–121. https://doi.org/10.1016/S0925-4927(01)00116-0

Lenggenhager, B., Halje, P., & Blanke, O. (2011). Alpha band oscillations correlate with illusory self-location induced by virtual reality. *European Journal of Neuroscience*, *33*(10), 1935–1943. https://doi.org/10.1111/j.1460-9568.2011.07647.x

Lindeman, M., Svedholm, A. M., Riekki, T., Raij, T., & Hari, R. (2013). Is it just a brick wall or a sign from the universe? An fMRI study of supernatural believers and skeptics. *Social Cognitive and Affective Neuroscience*, *8*(8), 943–949. https://doi.org/10.1093/scan/nss096

Luhrmann, T. M. (2012). *When God Talks Back: Understanding the american evangelical relationship with God* (1st ed). Alfred A. Knopf.

Martin, S., Mikutta, C., Leonard, M. K., Hungate, D., Koelsch, S., Shamma, S., Chang, E. F., Millán, J. del R., Knight, R. T., & Pasley, B. N. (2018). Neural Encoding of Auditory Features during Music Perception and Imagery. *Cerebral Cortex*, *28*(12), 4222–4233. https://doi.org/10.1093/cercor/bhx277

McCrae, N., & Elliott, S. (2012). Spiritual experiences in temporal lobe epilepsy: A literature review. *British Journal of Neuroscience Nursing*, *8*(6), 346–351. https://doi.org/10.12968/bjnn.2012.8.6.346

Mikutta, C. A., Maissen, G., Altorfer, A., Strik, W., & Koenig, T. (2014). Professional musicians listen differently to music. *Neuroscience*, *268*, 102–111. https://doi.org/10.1016/j.neuroscience.2014.03.007

Mikutta, C., Altorfer, A., Strik, W., & Koenig, T. (2012). Emotions, Arousal, and Frontal Alpha Rhythm Asymmetry During Beethoven's 5th Symphony. *Brain Topography*, *25*(4), 423–430. https://doi.org/10.1007/s10548-012-0227-0

Molendijk, A. L. (1999). In defense of pragmatism. In J. Platvoet & A. L. Molendijk (Eds.), *The pragmatics of defining religion: Contexts, concepts, and contests* (pp. 3–19). Brill.

Mueller, P. S., Plevak, D. J., & Rummans, T. A. (2001). Religious Involvement, Spirituality, and Medicine: Implications for Clinical Practice. *Mayo Clinic Proceedings*, *76*(12), 1225–1235. https://doi.org/10.4065/76.12.1225

Newberg, A. (2010). *Principles of neurotheology*. Ashgate Publication.

Newberg, A., D'Aquili, E. G., & Rause, V. (2002). *Why God won't go away: Brain science and the biology of belief* (1. trade edition). Ballantine Books.

Newberg, A., Pourdehnad, M., Alavi, A., & d'Aquili, E. G. (2003). Cerebral blood flow during meditative prayer: Preliminary findings and methodological issues. *Perceptual and Motor Skills*, *97*(2), 625–630. https://doi.org/10.2466/pms.2003.97.2.625

Newberg, A., Wintering, N. A., Morgan, D., & Waldman, M. R. (2006). The measurement of regional cerebral blood flow during glossolalia: A preliminary SPECT study. *Psychiatry Research: Neuroimaging*, *148*(1), 67–71. https://doi.org/10.1016/j.pscychresns.2006.07.001

Oman, D. (2013a). Defining Religion and Spirituality. In R. F. Paloutzian (Ed.), *Handbook of the psychology of religion and spirituality* (2. ed, pp. 23–47). Guilford.

Oman, D. (2013b). Spiritual modeling and the social learning of spirituality and religion. In K. I. Pergament, J. Exline, & J. Jones (Eds.), *APA handbook of psychology, religion, and spirituality: Context, theory, and research* (Volume 1, pp. 187–204). American Psychological Association.

Paloutzian, R. F., & Park, C. L. (2013). *Handbook of the Psychology of Religion and Spirituality, Second Edition*. Guilford Press.

Paloutzian, R. F., & Park, C. L. (2021). The psychology of religion and spirituality: How big the tent? *Psychology of Religion and Spirituality*, *13*(1), 3–13. https://doi.org/10.1037/rel0000218

Park, C. L. (2005). Religion as a Meaning-Making Framework in Coping with Life Stress. *Journal of Social Issues*, *61*(4), 707–729. https://doi.org/10.1111/j.1540-4560.2005.00428.x

Pascual-Marqui, R. D. (1999). Review of Methods for Solving the EEG Inverse Problem. *International Journal of Bioelectromagnetism*, *1*(1), 75–86.

Pascual-Marqui, R. D. (2002). Standardized low-resolution brain electromagnetic tomography (sLORETA): Technical details. *Methods and Findings in Experimental and Clinical Pharmacology*, *24 Suppl D*, 5–12.

Pascual-Marqui, R. D., Lehmann, D., Koukkou, M., Kochi, K., Anderer, P., Saletu, B., Tanaka, H., Hirata, K., John, E. R., Prichep, L., Biscay-Lirio, R., & Kinoshita, T. (2011). Assessing interactions in the brain with exact low-resolution electromagnetic tomography. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences*, *369*(1952), 3768–3784. https://doi.org/10.1098/rsta.2011.0081

Platvoet, J. (1999). Contexts, concepts and contests: Towards a pragmatics of defining “religion.” In J. Platvoet & A. L. Molendijk (Eds.), *The pragmatics of defining religion: Contexts, concepts, and contests* (pp. 463–516). Brill.

Rim, J. I., Ojeda, J. C., Svob, C., Kayser, J., Drews, E., Kim, Y., Tenke, C. E., Skipper, J., & Weissman, M. M. (2019). Current Understanding of Religion, Spirituality, and Their Neurobiological Correlates. *Harvard Review of Psychiatry*, *27*(5), 303–316. https://doi.org/10.1097/HRP.0000000000000232

Rizvi, M. A. K., & Hossain, M. Z. (2017). Relationship Between Religious Belief and Happiness: A Systematic Literature Review. *Journal of Religion and Health*, *56*(5), 1561–1582. https://doi.org/10.1007/s10943-016-0332-6

Saler, B. (2000). *Conceptualizing religion: Immanent anthropologists, transcendent natives, and unbounded categories*. Berghahn.

Schienle, A., Höfler, C., & Wabnegger, A. (2019). Belief in the miracles of Lourdes: A voxel-based morphometry study. *Brain and Behavior*, *10*(1), e01481. https://doi.org/10.1002/brb3.1481

Schjoedt, U. (2009). The Religious Brain: A General Introduction to the Experimental Neuroscience of Religion. *Method & Theory in the Study of Religion*, *21*(3), 310–339. https://doi.org/10.1163/157006809X460347

Schjoedt, U., Sørensen, J., Nielbo, K. L., Xygalatas, D., Mitkidis, P., & Bulbulia, J. (2013). Cognitive resource depletion in religious interactions. *Religion, Brain & Behavior*, *3*(1), 39–55. https://doi.org/10.1080/2153599X.2012.736714

Sekihara, K., Sahani, M., & Nagarajan, S. S. (2005). Localization bias and spatial resolution of adaptive and non-adaptive spatial filters for MEG source reconstruction. *NeuroImage*, *25*(4), 1056–1067. https://doi.org/10.1016/j.neuroimage.2004.11.051

Sommer, M., Döhnel, K., Sodian, B., Meinhardt, J., Thoermer, C., & Hajak, G. (2007). Neural correlates of true and false belief reasoning. *NeuroImage*, *35*(3), 1378–1384. https://doi.org/10.1016/j.neuroimage.2007.01.042

Stigsby, B., Rodenberg, J. C., & Moth, H. B. (1981). Electroencephalographic findings during mantra meditation (transcendental meditation). A controlled, quantitative study of experienced meditators. *Electroencephalography and Clinical Neurophysiology*, *51*(4), 434–442. https://doi.org/10.1016/0013-4694(81)90107-3

Taves, A. (2005). Religious experience. In *Encyclopedia of religion* (2nd edition). Thompson-Gale.

Taves, A. (2009). Rereading the Varieties of Religious Experience in transatlantic perspective. *Zygon(r)*, *44*(2), 415–432. https://doi.org/10.1111/j.1467-9744.2009.01006.x

Taves, A. (2011). *Religious Experience Reconsidered: A building-block approach to the study of religion and other special things* (Second printing, and first paperback printing). Princeton University Press.

Taves, A. (2020). Mystical and Other Alterations in Sense of Self: An Expanded Framework for Studying Nonordinary Experiences. *Perspectives on Psychological Science*, *15*(3), 669–690. https://doi.org/10.1177/1745691619895047

Taves, A., Wolf, M. G., Ihm, E. D., Barlev, M., Kinsella, M., & Vyas, M. (2019). *What Counts as Religious Experience? The Inventory of Nonordinary Experiences as a Tool for Analysis across Cultures* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/ux28d

Tinoca, C. A., & Ortiz, J. L. (2014). Magnetic Stimulation of the Temporal Cortex: A Partial “God Helmet” Replication Study. *Journal of Consciousness Exploration & Research*, *5*(3), 234–257.

van Elk, M., & Aleman, A. (2017). Brain mechanisms in religion and spirituality: An integrative predictive processing framework. *Neuroscience & Biobehavioral Reviews*, *73*, 359–378. https://doi.org/10.1016/j.neubiorev.2016.12.031

Walter, Y. (2021). Towards a Qualitative Model of Religious Worship Experiences: Perceived encounters with the divine in the ritual context of musical devotion practices. *American Journal of Qualitative Research*, *5*(1), 94–141. https://doi.org/10.29333/ajqr/10814

Walter, Y., & Altorfer, A. (2022). The psychological role of music and attentional control for religious experiences in worship. *Quarterly Journal of Experimental Psychology*, 174702182210753. https://doi.org/10.1177/17470218221075330

Walter, Y., Dieguez, S., Mouthon, M., & Spierer, L. (2020). Brain structural evidence for a frontal pole specialization in glossolalia. *IBRO Reports*, *9*, 32–36. https://doi.org/10.1016/j.ibror.2020.06.002