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The Induction of Religious Experiences and Temporal Lobe Activation: Neuronal Source Localization Using EEG Inverse Solutions

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Abstract: Knowledge about brain source localizations for religious states of mind is still limited. Previous studies have usually not set a direct emphasis on experience. The present study investigated the phenomenon of religious experience using inverse solution calculations, and it is 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; LORETA; source localization; religious experience; worship; religious phenomenology

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1. Introduction

1.1. Religious Experience

In the psychological study of religion, various approaches are employed, depending largely on the specific facet of religion under examination (cf. [1–3]). While there is no universally accepted definition of *religion* and its related phenomena [4], there has been a significant push towards pragmatic definitions that make the terms more accessible for research within specific fields [5–8]. Within the realm of cognitive science, the focus has primarily been on the mechanisms that underpin beliefs in supernatural powers, which are frequently viewed as sacred and inviolable [9].

In our understanding of *religious experience*, we largely follow a Tavesian approach, which is often used in empirical research and has been devised specifically to this end [10,11]. This is based on foundational work in the field of religious studies by Ann Taves [12–15]. 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 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. [16–19]). Investigations on the construct system of religion, however, showed that there are five dimensions of religiosity—intellect, ideology, private practice, public practice, and experience—showing that religious practice and religious experience are *distinct* dimensions [20]. 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.

1.2. Religious Experience and the Brain

The neural underpinnings of religious cognition and emotion are an emerging field of research [21]. Some evidence suggests religious experiences may have a positive impact on mental health and wellbeing [22–31], 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 [32,33]).

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 [34] famously coined the term *Neurotheology* and applied it to the neuroscientific study of religious occurrences. Shortly after, Cunningham [35] issued a publication with the titled question "Are Religious Experiences Really Localized Within the Brain?". The article highlighted some methodological challenges but also acknowledged the progress that has been made in trying to find the neural correlates of such phenomena.

EEG and brain imaging techniques have since been applied to study a broad range of religious rituals, such as contemplative prayer [36], praying in tongues [19,37], meditation with concentration tasks [38–40], reading scriptures [16,17], religious recollections [41,42], and meditations using mantras [43].

A review by Grafman et al. [32] highlighted several key brain regions associated with religious cognitive processes:

- ***Cognitive control:*** the dorsolateral prefrontal cortex (dlPFC) is related to the down-regulation 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 [42,44–46], and (ii) the executive inhibition hypothesis [47–52]. The former claims that religious experiences are triggered by an activation of the temporal lobes and the latter holds that an inhibition of the 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 [46]. It was supplemented by studies showing that spiritual states of mind may sometimes be induced through phenomena such as temporal lobe epilepsy [53–56]. 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 connection to the limbic system further implies some motivational functions including automatic states of the vegetative nervous system [57,58].

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) [19,40]. 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 [50]. Such an executive inhibition was also discussed in the context of cognitive *dis*inhibition, thereby fostering religious creative thought and emotion [49,52,59]. 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. [60–63]). Source localization through Low Resolution Electromagnetic Tomography (LORETA) has already been applied to meditative states [39] and hence was deemed appropriate for the present purposes.

1.3. Research Goal and Hypotheses

To our knowledge, there has never been an EEG study measuring the dimension of religious experience directly with the attempt to determine the possible source localizations of these experiences using inverse solutions. With the present research, we aimed to address this absence 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.

A previous publication on the same population used microstate analyses to disentangle the involved neural networks in these experiences [64]. It was shown that microstate (MS) class 1 (*the auditory network*) showed a significant association with the average rating values of the religious experience based on its duration, contribution, and mean global field power (GFP) of the microstate. An association was also found with MS 3 (*the default mode network*) based on the mean GFP, and with MS 5 (*the salience network*) based on its duration, occurrence, contribution, and mean GFP. Due to the prevalence of the associations with the feature extractions, the latter was the strongest predictor for the religious experience. This provides important information about the involvement of neural networks in the domain of subjectively experienced sensations of the divine. However, it leaves open which frequency bands would be involved when having a closer look at topographic locations—information that would contribute to the idea that frontal and/or temporal regions might be involved in such experiences. As such, we believe that the present follow-up study adds a valuable perspective on top of the discovered microstates to the brain topography in light of the above formulated hypotheses based on the literature.

If the research sample is selected accordingly, religious experiences can be induced via worship practices with the help of music [65]. 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 standardize them for further analysis [66–74]. 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 the religious musical domains (for more on this type of design, see [75]). 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 [65,76–78]. 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. [65]). A previous study [65] discussed the neurological correlates of a special state of mind where people believed to be sensing the presence of God (*please note:* 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; this holds for all terms such as "God", "religion", and the "divine", since there is social evidence suggesting the fluidity of such constructs). 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 experience, (iii) they have a shared theological background for the mental concepts that are associated with it, and (iv) we already had access to this cohort, which made the recruitment process more effective (for more on evangelicals and worship experiences, see [77–80]).

2. Materials and Methods

2.1. Participants

A total of 60 evangelical participants agreed to take part in the study, although data from three subjects had to be discarded due to recording errors during experiments. The participants' age ranged from 19 to 40 years (mean: 27 y; SD: 4.2 y); 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% had finished an apprenticeship. Auditory tests confirmed adequate hearing, written informed consent was provided, and the study was approved by the local ethics committee (approval was provided by the Swiss ethics committee of the Canon of Bern [KEK Bern] under the ID number 2021-00022).

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 that they sensed something physical, and 9% professed to receive a message from God. A total of 11% claimed that they became happy during the experience and three respondents (1.5%) reported that they became melancholic or sad during the experience.

2.2. 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, during blinking, as well as horizontal eye movement, which was later used for the pre-processing of the EEG data.

Each experiment lasted for approximately one hour with six experimental conditions plus two resting state conditions at the very beginning and the end. Every condition's duration was around 4.5 min, 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 music, can help govern and induce the religious experience by helping or distracting a person to focus on God [65]. 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 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 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. (For the Rg condition, the song *Reckless Love* by Cory Asbury (2017, Bethel Music) was selected.)
Secular subjective	Ss	Participants brought 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 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. (For the Sg condition, the song *Lose You To Love Me* by Selena Gomez (2019, Interscope Records) was selected.)
Empty (blank)	B	This was a 4.5 min 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. (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.)

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

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

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, 4.5 min later, the eyes were reopened. The reasons for closing the eyes were twofold: on the one hand, closing one's eyes reduces 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 themself 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).

2.3. EEG Recording and Processing

The electrophysiological potential on the scalp was measured using the Brain Products actiCap^{TM} system with 64 active electrodes and recorded with Brain Vision Recorder 2.2^{TM}. The sampling rate occurred at 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 were exported to Brain Vision Analyzer 2.2^{TM} for pre-processing, which occurred in two steps (cf. [81,82]): (i) we set out to create clean data, meaning that they were 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 were 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 were filtered using an infinite impulse response (IIR) band-pass filter between 1.5 Hz and 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 and contribution to the perceived artifacts, the respective factors were excluded. Through an ICA inverse method, a corrected EEG was recalculated. The reconstructed data were visually inspected one more time to make sure that the artifact correction had 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 an average reference.

Second, in a further segmentation process, each session was split into pieces of 2.048 s 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 [62], which has been validated independently [83,84]. The method implements the lead field described by Fuchs et al. [85] and the electrode coordinates described by Jurcak et al. [86]. Through allocating the respective Brodmann areas, four regions of interest (ROIs) were produced, corresponding to the frontal and temporal regions bilaterally.

2.4. 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 both hemispheres, with a negative correlation of the frontal cortex (frontal relaxation hypothesis) and a positive correlation of the temporal cortex (temporal involvement hypothesis).

The inverse solutions generated using 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 between the experience, the frequency bands, and the regions of interest (ROIs) with the LORETA values (refer to Table 2 to see how the ROIs were generated). If this was significant, we (ii) 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 whether there was 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.

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

(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, and 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* × ROI × *rating* interaction. The model controlled for handedness and gender and included subject as a random factor. All frequency bands and ROIs were present in this model.

(ii) If, 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 were hence split per ROI and the models were run with the same parameters (excluding ROIs). They still included condition, frequency band, experiential rating, and the interaction term *band* × *rating*. The focus lied on this interaction effect. The models controlled for handedness and gender and included 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 were 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 of those 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 was 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 with whether there were interesting associations between the experience with the inverse calculations overall, zooming in on individual ROIs, and then on the respective frequency bands, eventually looking at the directionality of the associations that were left.

3. Results

As seen in Section 2, first, we wanted to see if there was a significant association between the LORETA value and the interaction effect of Band × ROI × 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. In Table 6, therefore, the right temporal lobe was singled out and the analysis was run on each frequency band. This showed us that only higher frequencies (1.-3. Beta and Gamma) were significant. The parameter estimates for all of these frequency bands were positive. This demonstrated that the religious experience was associated with an increased presence of higher frequencies in the right temporal cortex.

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 × ROI × 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	0.375
Band	7, 12717	2124.5	<0.001
ROI	3, 12717	4217.1	<0.001
Experience	1, 12717	11.3	0.001
Band × ROI × Experience	31, 12717	6.9	<0.001
Handedness	1, 12717	39.8	<0.001
Gender	1, 12717	182.6	<0.001

Dependent variable: LORETA values.

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 × Experience	Left frontal	7, 3168	1.01	0.422
	Left temporal	7, 3168	1.67	0.113
	Right frontal	7, 3168	1.50	0.163
	Right temporal	7, 3168	4.52	<0.001

Dependent variable: LORETA values.

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 × Experience). Condition = experimental condition; Band = frequency band; 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	0.437
Band	7, 3168	548.9	<0.001
Rating	1, 3168	15.8	<0.001
Band × Experience	7, 3168	4.5	<0.001
Handedness	1, 3168	4.4	0.037
Gender	1, 3168	305.6	<0.001

Dependent variable: LORETA values.

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

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 LORETA values with the frequency bands and the experience).

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	0.031	0.026
2nd Beta	1, 395	11.9	3.5	0.001	0.052
3rd Beta	1, 395	11.3	3.4	0.001	0.069
Gamma	1, 395	5.1	2.3	0.025	0.018

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 frequencies. Post-hoc parameter estimates for the fixed effects were calculated to determine the directionality of the association between the religious experience and the LORETA values, which indicated the source localization probability. For this, only the directionality (positive or negative values) of the coefficients was of interest. The results are summarized in Table 6.

4. Discussion

4.1. 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 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 strongest in the right hemisphere.

These findings add interesting information to the discovery that, in part, the auditory as well as the default mode network, but most poignantly the salience network, appear to be implicated in such experiences [64]. The next section briefly discusses the relevance of the temporal cortex in regard to the present findings concerning religious experiences.

4.2. Temporal Involvement

An early study linking temporal regions to religious experiences was found with Persinger and colleagues [87–90], as well as with Ramachandran and Blakeslee [91]. Although there have been methodological criticisms thereof, especially in Persinger's "God helmet" to induce a sensed presence deemed divine [41,45], further studies have solidified the notion that the temporal cortex is involved in such phenomenological states [46,54,56,92]. As such, Britton and Bootzin [92] 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 align well with previous studies and may significantly strengthen them, since, unlike in previous research designs, we set an emphasis on measuring religious experience *directly* and not just via religious practice as a proxy.

According to Grafman et al. [32], 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 [32]), which appears to be a necessary act in deeming an experience religious (cf. [14]). 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 [51] for a further review). This indicates that prayer and associated experiences imply the retrieval of specific religious ideas, such as conceptions of God, and reconstruct 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 between 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 [93]. In their fMRI study, Kapogiannis and colleagues [49] 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 [49] 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 while further discussing evidence on religious sensations during temporal lobe epilepsy [54]. An in-depth literature review by McCrae and Elliott [56] further strengthened 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 [32], is the temporoparietal junction (TPJ). This is because the TPJ has been mentioned frequently in spiritual and religious experiences, out-of-body occurrences, and mysticism. For example, a literature discussion connected mystical experiences on mountains with the TPJ [94]. The same team also provided electrical stimulation to the left TPJ under surgical conditions, which induced the sensation of an illusory shadow person [95]. A structural MRI study investigated the belief in the miracles of Lourdes via Voxel-Based Morphometry (VBM), restricted only to grey matter analysis [96]. 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 [97]. Blanke and his lab became known for researching Out-of-Body experiences (OBE) and they have often, but not always, 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 [98]. In a further study, five out of the six patients in the sample who had reported an OBE also had a diagnosed dysfunction in the TPJ [99]. Stringent reviews have highlighted the relevance of the TPJ for OBEs [100] and respective frameworks have been proposed [101]. A lesion analysis showed that sensations of external vision-like apparitions were positively correlated with lesions in the temporoparietal, insular, and frontoparietal regions [102]. In one interesting case report, a 50-year-old woman who had never before or after reported an OBE, had three such experiences when, during her craniotomy, the TPJ was electrically stimulated [103].

The TPJ is said to be associated with auditory signals, which are often described by mystics [104], and with integrating vision, touch, and hearing in a coordinated reference frame [105–108], as well as with language and understanding (see Wernicke [109,110]). A TPJ damage on the left hemisphere is reported with a feeling or hearing of a presence in one's proximate space [102,111] and such experiences have been induced experimentally using manipulation of the congruence between felt and observed sensory stimuli [112,113]. In particular, the *right* TPJ is said to be involved in multisensory integration for religious experiences (for a further review, see [33]).

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 in 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.

5. Conclusions, 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 faced was a byproduct of the complex nature of these special religious states of mind, which can be summarized in four points. First, we 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" [12,14,114]. Second, there are likely different psychological mechanisms that may lead to the various instances of these states of mind (as already highlighted long ago in [115]). 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. Fourth, the class of "evangelicals" is itself a heterogenous one and the participants were not all recruited from a single church, which means that there may be the risk of instantiating somewhat different phenomenal states, even though we tried our best to minimize this possibility. It is therefore possible that the neurophysiological mechanisms we have discovered are merely a small fraction of the 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. It should be noted that religious experiences are likely not immune to social and cultural influences, and studying these dependencies would further benefit the field.

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