Brain Activation and Source Localization for Religious Experience in Worship measured by EEG Spectral Analysis and Inverse Solutions

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Abstract

We investigated the neural correlates of religious experiences in worship using EEG and this is the first study to measure the dimension of experience directly. 60 evangelical Christians were recruited to perform worship experiments. There were two hypotheses: first, we assumed that the religious experience was a deep mental state characterized by lower brain waves but that the frequencies shifted upwards when the experience got stronger. Second, we thought that the frontal relaxation hypothesis and the temporal involvement hypothesis that are both prominent in the literature would also hold true for our study. The results showed that all these hypotheses can be accepted, but the latter only to a certain degree. The frontal relaxation was observed solely on the right hemisphere and the same was true for the temporal involvement. Additionally, we found a parietal activation as well as an occipital relaxation associated with the religious experience. The latter came as a surprise because the occipital cortex is barely mentioned in the literature as having an influence on such phenomena. These findings were discussed to propose a novel neurocognitive framework for religious worship experiences that are based on three models from the literature.

Keywords: EEG, spectral analysis, inverse solutions, religious experience, worship

Introduction

The present study investigated the neural correlates of subjective religious experiences induced by worship practices with the help of songs as well as non-musical conditions. Based on the systemic activation patterns of the autonomous nervous system in such experiences (Walter & Altorfer, 2022), we hypothesized that the religious experience is a deep state characterized by whole-brain lower frequencies (delta to alpha) but that there would be a positive shift towards upper frequency bands (beta or gamma bands) as the experience got stronger. Due to the influential temporal involvement and executive inhibition hypotheses in the literature, we also hypothesized that our source localization would detect a relaxation (delta, theta or alpha bands) in the frontal areas, and an activation of the temporal regions (beta or gamma bands). The subsequent introduction explains how the study goals emerged from the literature.

Religion and experience

Cognition and emotion in the domain of religion considering their neural underpinnings are an emerging field of research. Religious experiences are an interesting branch thereof because they are reported as powerful occurrences to the believers who instantiate them (Wettstein, 2015). In the literature, so far there has been no unanimous consensus yet how to conceptualize religion and associated experiences on a cognitive level. One idea is that they are *cognitive byproducts* from our evolutionary history, carrying a beneficial element for the survival of the human species (Kress, 1993). Pascal Boyer (1994) has proposed that religious ideas are deemed as such due to the fact that they belong to a class he refers to as *minimally counterintuitive concepts*. Maximally and minimally intuitive concepts can both be adopted and transmitted from person to person but the former strike people as more realistic and hence are incorporated into people's beliefs and perceptions more easily. Another famous idea is the *Hyper Active Agency Detection Device*, which states that it is evolutionarily beneficial to see

agency where perhaps there is none so that potentially dangerous signals will not be overlooked (Green, 2015). A further view conceptualizes religious inclinations as *pro-social adaptations*. It assumes that the belief in a punishing God is useful for the stability of a social community since rational choice theory predicts that free riders will try to establish themselves by any means possible but can be better kept in check by such ideas (Batara et al., 2016).

Since there has been no shortage of such functional frameworks to contextualize religion (Clarke, 2011), settling on a clear-cut definition of religion has not resulted in an overarching consensus (Droogers, 2011), which has left empirical researchers and scholars of religion with a call for a pragmatic approach towards defining and operationalizing the necessary constructs (Byrne, 1999; Molendijk, 1999; Platvoet, 1999). Hence, the present study conceives of *religion* as cognitive and emotional representations concerning beliefs in supernatural powers that may be sacred or inviolable (Bulbulia & Sosis, 2011). The same discussion has channeled into the notion of *religious experience*, which is an associated construct where one often feels to be in contact with the supernatural world (cf. Taves & Asprem, 2017). Psychologists have come up with two avenues to frame such occurrences. On the one hand, there are the ones who hold that there is an inherent quality that *makes* an experience "religious". This is known as the *sui generis account* because it postulates that there is something unique about these sensations. If this quality or feeling is present during an experience, then it is automatically a religious one (Eliade, 1960; Pals, 1987; Studstill, 2000). The opposing view is called the *attribution account*, which claims that there is not a specific experiential quality rendering a state of mind religious. Rather, it is the act of a believer's interpretation working as a gatekeeper for deciding which phenomenal occurrences are counted amongst the domain of religious experiences (Barnard, 1992; Hermans, 2015). According to Ann Taves (2005, 2009, 2011, 2020; Taves et al., 2019), a pivotal element for this is the process of "singularization".

It works by identifying certain occurrences as being set apart from the ordinary and conceiving them as being special enough, which creates the subjective frame of *deeming* an experience religious. By and large, the present study appropriates a Tavesian approach for construing religious experience, although we do not *ex ante* exclude the possibility that there could be phenomenological qualities and therefore neural activation patterns that may be unique to the religious experiences that are currently considered.

Religious experience and the brain

The investigation of religious states of mind is no longer reserved for 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). Although scientific inquiry into these phenomena is still limited, the field is steadily being populated with more data, and researchers are taking up the task of better understanding their biological correlates (Rim et al., 2019).

A review by Grafman et al. (2020) has 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.

These findings have been embedded in the cognitive framework of *predictive processing* whereas a differential weighing of interoceptive and exteroceptive signals occurs through a trade-off between top-down and bottom-up mechanisms (for a review on this, see: van Elk & Aleman, 2017). Here, the above mentioned Tavesian approach for the cognitive emergence of religious experiences can be applied since the process of deeming an occurrence religious is seen as a top-down mechanism relying on bottom-up signaling (Taves & Asprem, 2017).

We performed an EEG frequency band analysis on subjective religious experiences and there are only very few publications that have previously done comparable research. A study has found increased theta and gamma-1 waves after the induction of mystical experiences with Catholic Carmelite nuns. It also discovered a stronger theta and long-distant alpha connectivity during the experience (Beauregard & Paquette, 2008). A longitudinal analysis over the span of two decades found that people who ranked their importance of religion and spirituality (often abbreviated with R/S) have higher posterior alpha when measured with EEG. The dominant alpha did not change substantially when the ratings declined, nor did the low levels of alpha increase when after twenty years the self-rated R/S-importance rose. The only change occurred when believers switched their attending denominations, which was

accompanied by a decrease of the posterior alpha (Tenke et al., 2013, 2017). A further study interested in the frequency of prayer and the centrality of religiosity employed neurofeedback training, which showed that people who frequently prayed had more cognitive control over the neurofeedback than people who did not pray this often. They had a higher sensorimotor rhythm based on the neurofeedback training and a stronger theta ratio (Kober et al., 2017). A meta-analysis on 25 reports studying the neural correlates of R/S has suggested that the specific brain states of R/S were distinct from their non-R/S counterparts. The regions most often associated with these experiential features of R/S were the caudate nucleus, the default mode network, the posterior cingulate network, precuneus, orbitofrontal cortex, and the medial frontal cortex. The authors make the case that "Further studies with more rigorous study designs are warranted to elucidate the neurobiological mechanisms of R/S" (Rim et al., 2019, p. 303).

Additionally, we deem further research in this domain justifiable because there is a lot of evidence suggesting that R/S emotion and cognition can have a positive impact on psychological health and wellbeing (Fabricatore et al., 2000; Fry, 2000; G. H. Koenig & Larson, 2001; Kok et al., 2013; Krause, 2011, 2015; Lambert et al., 2009; Mueller et al., 2001; Park, 2005; Rizvi & Hossain, 2017). This implies that better understanding the psychobiological mechanisms of religiosity and spirituality may be useful for a beneficial integration of such experiences in a believer's life. In this line of thought, discussions on the state of the literature demonstrate that research on experiential aspects of religiosity needs to be strengthened (for current in-depth reviews, see: Grafman et al., 2020; van Elk & Aleman, 2017).

Worship and experience

In the experimental study of religious experiences, researchers have typically focused on religious *practices* and have hitherto used them as a proxy to approximate the experience (see

for example: Azari et al., 2001, 2005; Demmrich, 2018; Newberg et al., 2006). However, scholars in psychology of religion have argued that *practice* is only one dimension among others in a believer's construct system of religion. Huber and Huber (2012) found five such dimensions, namely intellect, ideology, public practice, private practice, and experience. This means that religious *experience* is not the same as religious *practice*, although the two may be linked. It follows that equating practice with experience is a major shortcoming that we find in previous studies (for a review, see Grafman et al., 2020) and as such we hold that the experiential dimension should be targeted more directly. In the current research project, we have therefore attempted to remedy this lack by letting the participants continuously rate their own experience during the experimental conditions. This does not mean that practice is absent in our experimental design because musical practices can help to induce a desired religious experience (Belzen, 2013; Bohlman et al., 2005; Boyce-Tillman, 2007; Demmrich, 2018). For this reason, we have decided to use worship practices with music to frame and induce the experience (see, for example: Brehm Center, 2017; Demmrich, 2018; Roby, 2016; Walter, 2021; Williams, 2016).

Especially for evangelical Christians, which is the type of believers recruited for the present study, religious experiences are often induced through worship with the help of music (Boyce-Tillman, 2007; Cassaniti & Luhrmann, 2014; Ingalls, 2018; Luhrmann, 2012). In this respect, a qualitative cognitive model known as the *Feedback Loop Model for Religious Worship Experiences* has recently emerged (Walter, 2021). It states that environmental stimuli, including music prone to facilitate worship, leads to mental stimulation where people can focus on God, which in turn helps to induce a religious experience where people believe to be in a divine encounter and hence sense the presence of God. This model provokes the notion that both religious and self-selected worship songs may cognitively activate a believer more than pre-selected worship songs (for the selection and effects of musical styles, see for

example: 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).

Neural sources of religious experience

Drawing from neurological research on religious states of mind, two hypotheses have become famous: (i) the Temporal Involvement Hypothesis (Beauregard, 2011; Beauregard & Paquette, 2008; Granqvist et al., 2005; Persinger, 1983; Persinger & Healey, 2002; 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 gained a lot of traction when Michael Persinger attempted to stimulate the temporoparietal junction (TPJ) with transcranial magnetic stimulation (TMS). This "god helmet", as it was popularly dubbed, was reported to elicit special and apparently spiritual experiences – although very broadly conceived as sensing some kind of presence, becoming fearful or receiving odd smells (Persinger, 1983; Persinger & Healey, 2002). Although the study has been strongly criticized (Beauregard, 2011; Granqvist et al., 2005), the temporal involvement idea not only prevailed (Tinoca & Ortiz, 2014) but it was later further supplemented, for example by evidence 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 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, whereby fostering religious creative thought and emotion (Deeley, 2003; Kapogiannis et al., 2009; Schjoedt et al., 2013).

These two influential hypotheses may be tested by using EEG data from the scalp and analyzing source localizations through inverse solutions methods (cf. Hämäläinen & Ilmoniemi, 1994; Pascual-Marqui, 1999, 2002; Pascual-Marqui et al., 2011). The inference of electric field generators that would adequately explain the electromagnetic distribution on the scalp is generally referred to as the "inverse problem" and calculations to the task are referred to as "inverse solutions" (for more information, see: Biscay et al., 2018). A method known as LORETA is generally believed to yield confident solutions to the task and it is therefore used in the present study (Grech et al., 2008; Pascual-Marqui, 1999, 2002).

Source localization through Low Resolution Electromagnetic Tomography (LORETA) was already applied to discover EEG gamma frequency (35-44 Hz) and band activities that differ between meditative states (Lehmann et al., 2001). Meditation aiming at visualization showed right posterior activation and the verbalization tasks depicted field generators in the left central area, which means that the findings agree with known functional neuroanatomy. The authors of the study conclude the following:

> The brain areas involved in the self-induced, meditational dissolution and reconstitution of the experience of the self (right fronto-temporal) are discussed in the context of neural substrates implicated in normal self-representation and reality testing… (Lehmann et al., 2001, p. 111)

These neural "fronto-temporal" regions emerge as recurring themes in the literature concerning the study of religious and spiritual experiences (Cristofori et al., 2016; Wood, 2014). Some authors put it this way:

> The two main forms of religious experience, the ongoing belief pattern and set of convictions (the religion of the everyday man) versus the ecstatic religious experience, may be predominantly localized to the frontal and temporal regions, respectively, of the right hemisphere (Devinsky & Lai, 2008, p. 636).

Considering this, the above two hypotheses may be reformulated as the (i) temporal involvement hypothesis and (ii) the frontal relaxation hypothesis as being key for triggering and processing such occurrences. We refer to the latter as "frontal relaxation" because it appears that frontal regions seem to be downregulated in a soothing fashion (e.g. characterized by the increase of alpha bands).

Research question and hypotheses

To our knowledge, there has been neither any EEG study measuring directly the dimension of experience in religious states of mind, nor any attempt to determine the possible source localizations of religious experiences using inverse solutions on the available spectral data. The present research aims to contribute in addressing this lack in the literature.

It has been argued that Christian prayer, which may share cognitive elements with Christian worship, can be compared to focused attention meditation in the sense that both recruit attentional and emotional mechanisms. This is physiologically characterized by synchronous activity of theta and alpha waves (Dobrakowski et al., 2020). As such, we assume that the same may apply to the worship experiences in our sample. Since worship experiences also invoke an activation of the peripheral physiology, we assume that that more active thinking, characterized by higher EEG frequency bands (like beta or gamma), are positively correlated with the religious experience. These ideas, in combination with the two popular ideas of the

frontal relaxation and the temporal activation upon a religious experience, lead us to formulate two hypotheses of our own:

Our first hypothesis is that religious worship experiences may be a deep and calm state characterized by lower frequencies, predominantly delta to alpha, that shifts towards higher frequencies as the experience gets stronger, namely to beta or gamma. Our second hypothesis is that our source localization analysis corresponds to the ideas of a frontal relaxation and temporal activation upon the religious experience. This would imply that in the frontal cortex we find lower frequencies, namely delta to alpha, and higher frequencies in the temporal cortex, namely beta or gamma, associated with the experience.

Materials and Methods

Participants

A study about religious experiences requires participants who are able to induce the state of mind in question. Worship with music was used in order to facilitate the induction process. Therefore, all participants had to state that they were able to easily sense the presence of God when engaging in worship with music[1]. It has been shown that evangelical Christians are likely to conform to this notion due to their focus on experience, their common worship practices, the shared goal to sense and encounter God's presence during the practice, and they are known to employ similar music and worship styles (cf. Bielo, 2011; Ingalls, 2018; Luhrmann, 2012). A further reason for recruiting evangelical Christians was that our team already had access to this cohort.

[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.

A total of 60 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 sense a divine presence and 21% feel 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.

Experimental design

Each experiment lasted for about one hour with six experimental conditions plus two resting state conditions at the very beginning and the end. The 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*

[2] The Swiss ethics committee of the Canon of Bern (KEK Bern) has approved the project under the ID number 2021-00022.

Model of Religious Worship Experiences reports 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 appears 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 makes 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]

[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.

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 in order 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 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.

Assessment

There were two questionnaires, a longer one before the experiment started, and a short one after each condition. The longer one was completed to provide an adequate understanding of their experiential dimensions, their faith and prayer lives as well as their demographic variables. Then, after each condition there was a paper sheet to indicate how well they were able to focus on God overall during the respective condition.

The religious experience was operationalized as a function of a right-hand bar slider where the respondents were advised to continuously rate their experience during each condition (except during the resting state). The slider was used to answer the question: “How strongly to you sense God’s presence at the moment?” During the songs and the empty condition, they therefore slid the bar up to indicate that the experience of the divine presence got stronger and down to indicate that it got weaker.

Subjects had to close their eyes during the songs as well as the empty condition. Hence after the beep tone the eyes were closed and after the second beep tone, 4.5mins later, the eyes were opened again. 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 EEGs with eyes closed makes it better comparable to similar research in the literature. In order to feel comfortable and to navigate the bar slider with closed eyes at ease, every participant had some time to familiarize him- or herself with the instruments, the surroundings, the screen, the speakers, and the bar slider before the experiment started. The beep tones at the beginning and end of each condition were then the command to close and reopen one's eyes.

EEG recordings were made in two rounds: on the one hand, there was the pre-experimental recording and on the other hand, there was the experimental recording. Pre-experimental recordings were made with open eyes, closed eyes, blinking and horizontal eye movement. This was later used for preprocessing the EEG data. The experimental recordings consisted of the whole experiment, including the six experimental conditions, the two resting state conditions (at the beginning and the end) as well as the concentration tasks with the letters.

EEG recording and preprocessing

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 hardware-

defined recording reference was placed at the FCz location and re-referencing was performed by recalculating the data to average reference.

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). First, we set out to create clean data, meaning that it was corrected for artifacts created by eye movement and ECG remnants. Second, we created segmented data, which were saved as separate files for the different experimental conditions per person. Both steps are further elucidated below.

Step 1: Elimination of artifacts

The pre-experimental EEG data was visually inspected, and malfunctioning channels were topographically interpolated. Thereafter, an individual spatial filter was created to correct the recordings for eye movements and heart rate artifacts. For this, first an infinite impulse response (IIR) band-pass filter between 1.5 Hz and 20 Hz was applied and an independent component analysis (ICA) was performed on the pre-experimental data. The resulting factors were visually observed both on the level of their temporal dynamics as well their topographical localizations. Their contribution to the eye movement and ECG artifacts as well as their explained variance determined which factors were eventually excluded. ICA reverse calculations were performed to screen if the exclusion resulted in data free from these artifacts. The exclusion of the respective ICA factors resulted in the generation of a subject-dependent correction filter.

Next, the raw data of each person's experimental recordings was considered, and malfunctioning channels were topographically interpolated, which were usually the same channels as in the pre-experimental recordings. The subject-dependent filters were then applied to the experimental data using a linear derivation model. This was followed up by

visual inspection of each participant's experimental EEG where time-specific muscle movement were highlighted for exclusion.

Step 2: Segmentation of data

At this point, re-referencing was performed and the re-referenced as well as artifact-corrected files were exported as "clean files". These files were used to effect two segmentation processes.

First, the experimental conditions including the resting states were extracted, meaning that the distraction tasks were discarded. Hence, only the two resting states, the Rg, Rs, Sg, Ss, S12 and empty condition survived in the data and were saved as separate sessions. The two resting states were fused so that there was only one resting state condition left. The onset and offset of the conditions were cut using the marks from the beep tones, which had been recorded on the marker channel in the EEG system.

Second, every session was segmented into 2-second pieces of the same size (1,024 data points or 2.048secs) with no overlaps. Each condition per subject was exported as ASCII-files with multiplexed orientation and a CRLF (PC-style) line delimiter.

Spectral preprocessing

The files exported from Brain Vision Analyzer 2.2^{TM} were imported to Ragu, a matlab toolbox specifically created for EEG spectral analysis (T. Koenig et al., 2011). The files were created accordingly and an outlier detection based on the multi-dimensional scaling (MDS) output of the correlation matrix including data from all subjects did not reveal any noteworthy outliers, which means that no data was excluded at this point (cf. Habermann et al., 2018).

Spectral analysis

Several tests were applied on the spectral EEG data (Habermann et al., 2018):

- Two-factorial analysis of the different classes of experimental conditions (with TANOVA, followed up by T-maps) to gain a detailed understanding of how the classes relate to one another.
- Correlations of the average ratings for the religious experience from each condition with the EEG data.

For the two-factorial analysis, four classes of the experimental conditions were used based on the calculation of two dimensions (first the religion/secular dimension and second, the subjective/given dimension):

Table 2. Formation of the classes used for the two-factorial analysis.

Combination of conditions	**Resulting class**
Religious songs & subjective songs	= Religious subjective
Religious songs & given songs	= Religious given
Secular songs & subjective songs	= Secular subjective
Secular songs & given songs	= Secular given

Subjective refers to the fact that the songs were self-selected by the participants, whereas *given* refers to the notion that the songs were pre-selected by the researchers. Although these experimental classes sound the same as the Rs, Rg, Ss and Sg conditions, they are not the same because the dimensions are a calculated function of these conditions. For example, the religious dimension comprises of both the Rg and Rs conditions whereas the subjective dimension comprises of the Rs and the Ss conditions.

The religious experience was correlated with the topographic EEG frequency dispersions for each experimental condition. In order to exclude the individual background noise, the average ratings from the empty condition was subtracted from the other conditions for each person. These differences were correlated via a one-factorial within-subject-design with the topographical difference maps, where the empty condition was located on the first contrast and the condition of interest was located on the second contrast.

The EEG spectral data was analyzed by using 8 frequency bands:

Band 1	Upper Delta (1.5 – 3.5 Hz)
Band 2	Lower Theta (3.5 – 6 Hz)
Band 3	Upper Theta (6 – 8.5 Hz)
Band 4	Lower Alpha (8.5 – 10.5 Hz)
Band 5	Upper Alpha (10.5 – 12.5 Hz)
Band 6	Lower Beta (12.5 – 18.5 Hz)
Band 7	Middle Beta (18.5 – 21 Hz)
Band 8	Upper Beta (21 – 30 Hz)

sLORETA preprocessing

The ASCII-files were used for calculating source localization solutions using 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, eight regions of interest (ROIs) were produced. The ROIs allowed for a whole brain analysis broken down to the four major segments of the cortex (frontal, parietal, temporal and occipital) with exclusion of the insular region since this one did not appear to be highly relevant in the study of religious experience when consulting the literature (for a review, see: Grafman et al., 2020; van Elk & Aleman, 2017).

Table 3. Allocation of Brodmann areas to regions of interest (ROIs) for the source localization analysis.

ROI No.	Region	Brodmann areas
ROI-01	Left frontal cortex	Left: 4, 6, 8, 9, 10, 11, 24, 25, 32, 33, 44, 45, 46, 47
ROI-02	Left parietal cortex	Left: 1, 2, 3, 5, 7, 23, 29, 30, 31, 39, 40
ROI-03	Left temporal cortex	Left: 20, 21, 22, 27, 28, 34, 35, 36, 37, 38, 41, 42, 43, 52
ROI-04	Left occipital cortex	Left: 17, 18, 19
ROI-05	Right frontal cortex	Right: 4, 6, 8, 9, 10, 11,24, 25, 32, 33, 44, 45, 46, 47
ROI-06	Right parietal cortex	Right: 1, 2, 3, 5, 7, 23, 29, 30, 31, 39, 40
ROI-07	Right temporal cortex	Right: 20, 21, 22, 27, 28, 34, 35, 36, 37, 38, 41, 42, 43, 52
ROI-08	Right occipital cortex	Right: 17, 18, 19

Inverse Solutions analysis

The inverse solutions generated by sLORETA were exported and analyzed with SPSS 27 through hierarchical multi-level mixed-models with a type 3 sum of squares. Only the frequency bands that were significant in the previous analysis with Ragu were used. The averaged ratings of the religious experience were taken as the dependent variable, the conditions served as the fixed factor and the source localization data as fixed covariates. To avoid multiple testing errors, all variables were computed with one single model. The model controlled for random effects provided by the individual subjects as well as the interaction effects of the conditions, gender, and handedness.

Results

Spectral analysis

A two-factorial design was performed where one factor comprised of the religious (Rs + Rg) and the secular (Ss + Sg) dimensions and the other consisted of the subjective (self-selected; Rs + Ss) and the given (pre-selected; Rg + Sg) dimensions. The Topographical Analysis of Variance (TANOVA) based on these contrasts yielded significant effects for the religious/secular factor in the upper beta frequencies ($p < .05$) and significant effects for the subjective/given factor in the beta bands ($p < .05$). There was a significant interaction between the two factors in the lower beta band. As seen in Figure 1, the strongest distinction is found between the *religious subjective* and the *secular subjective* class.

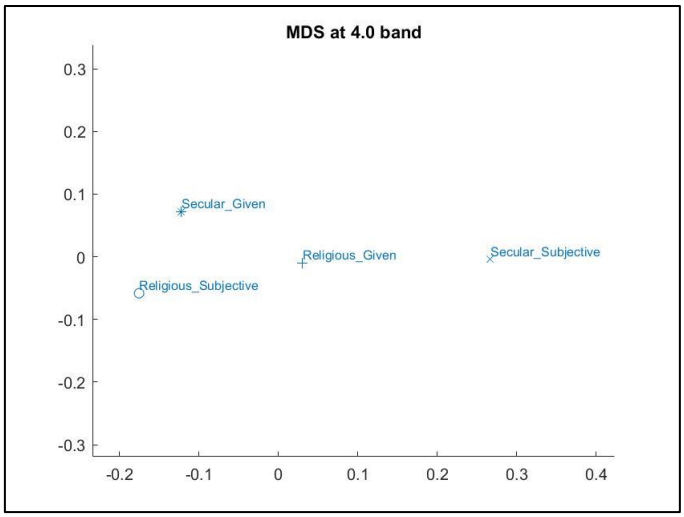


Figure 1. Multi-dimensional scaling (MDS) for the two-factorial design for the interaction of the four classes at lower alpha bands.

These findings were followed up with T-maps on the experimental conditions at the lower alpha band to distinguish the different effects, which illustrated a topographic distribution of the associated T-values. As suspected from the MDS, a significant effect was found between the Rs and Ss condition (*TANOVA*: .030; *t-min*: -3.674 at CP2; *t-max*: -0.903 at T7; cf. Figure 2).

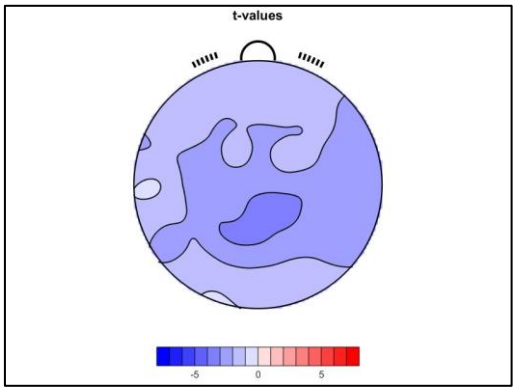


Figure 2. T-map of difference between Rs (positive contrast) and Ss (negative contrast) at the lower alpha band. Blue refers to a reduction and red refers to an increase in the respective frequency band.

As seen in Figure 2, there were less alpha waves in Rs than in Ss, which means that among the self-selected songs, the religious worship condition was associated with a higher mental activity.

This was further tested through a T-value analysis where the religious conditions (Rs + Rg) were compared with the secular ones (Ss + Sg). Since the original TANOVA yielded a significant effect in band 8, it is not surprising that we found a significant difference in the respective T-maps, as seen in Figure 3 (*TANOVA*: .009; *t-min*: -0.579 at PO3; *t-max*: 3.405 at TP7).

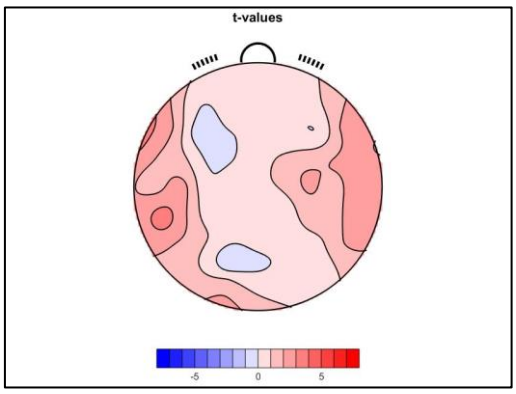


Figure 3. T-map of difference between the religious conditions (positive contrast) and the secular ones (negative contrast) at the upper beta band. Blue refers to a reduction and red refers to an increase in the respective frequency band.

Figure 3 illustrates that by and large there were more upper beta waves in the religious conditions as compared to the secular ones.

The T-maps showed that there were significant differences when the self-selected songs (Rs + Ss) were compared with the given situations (Rg + Sg) at the sixth band (*TANOVA*: .053; *t-min*: -1.510 at C2; *t-max*: 2.546 at PO8), the seventh band (*TANOVA*: .016; *t-min*: -1.533 at FC3; *t-max*: 3.756 at TP9) and at the eighth band (*TANOVA*: .006; *t-min*: -3.030 at C1; *t-max*: 3.906 at TP9).

For the difference between Rs and B (the empty condition where they worshipped without music; cf. figure 4c), there were significant interactions for the average rating of the religious experience at band 3 and band 4 ($p < .05$; cf. Figure 4a and 4b). Similarly, there was a significant interaction between the difference of Ss and empty (cf. Figure 4c) with the average rating at the upper delta and lower theta bands ($p < .05$; cf. Figure 5a and 5b).

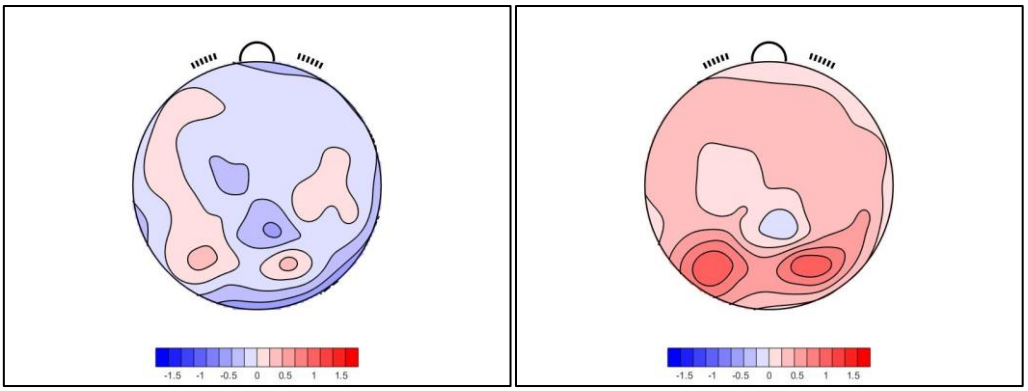


Figure 4a (left). T-map of empty condition from band 3 to band 4.
Figure 4b (right). T-map of Rs condition from band 3 to band 4.

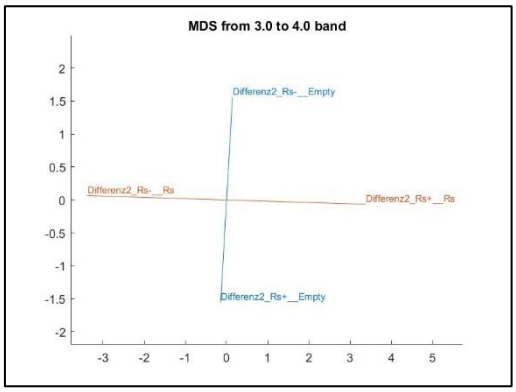


Figure 4c. Interaction plot between Rs and empty (B) for the average experiential ratings and the topographic difference maps in an MDS for the average of the upper theta to the lower alpha band.

As seen in Figures 4a-c, the Rs condition showed more upper theta and lower alpha waves the stronger the religious experience became. The result manifested most strongly in the occipital region.

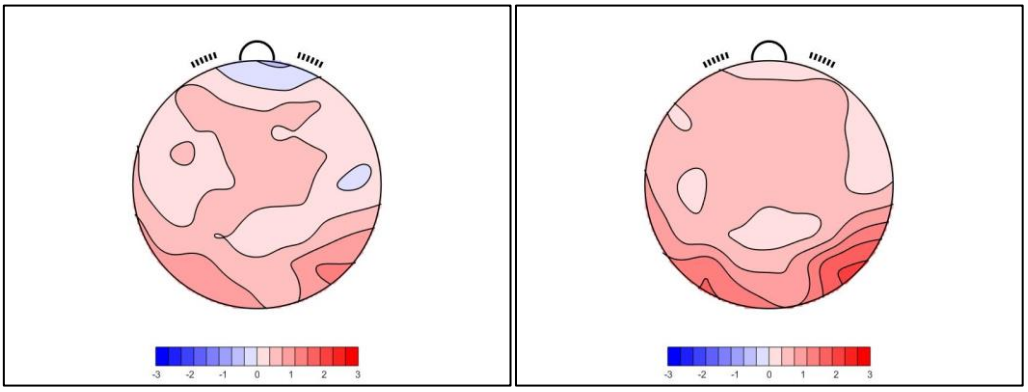


Figure 5a (left). T-map of empty condition from the upper delta to lower theta band.
Figure 5b (right). T-map of Ss condition from the upper delta to lower theta band.

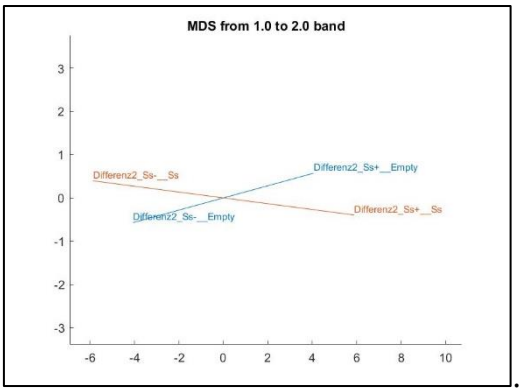


Figure 5c. Interaction plot between Ss and empty for the average experiential ratings and the topographic difference maps in an MDS for the average of the the upper delta to lower theta band.

Figures 5a-c show that there was more upper delta and lower theta waves in the Ss condition when the religious experience got more intense.

Inverse solutions

The results of the mixed regression model based on the sLORETA source localization probabilities are depicted in Table 4, whereas only the significant associations are shown.

Table 4. Significant associations of the religious experience with the frequency bands of the reconstructed sources for the respective regions of interest (ROIs). Effect sizes were calculated with the non-standardized regression beta.

ROI No.	**Brain region**	**Frequency band**	**Significance**	**Beta**
ROI-1	Left frontal	*No significant interaction found.*		
ROI-2	Left parietal	2nd Alpha	.017	-1.31
		1st Beta	.004	2.76
ROI-3	Left temporal	2nd Beta	.023	-1.61
ROI-4	Left occipital	2nd Alpha	<.001	2.22
ROI-5	Right frontal	Theta	.004	2.13
ROI-6	Right parietal	1st Alpha	.017	-1.68
ROI-7	Right temporal	2nd Alpha	<.001	-2.29
		1st Beta	.039	1.58
		2nd Beta	.023	1.70
		3rd Beta	.006	-1.45
ROI-8	Right occipital	Delta	.042	-0.96
		1st Alpha	.001	1.67

Discussion

The present study investigates the neural activation patterns and 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 have deduced two hypotheses. First, we hypothesized that the religious experience we studied would come along with a deep state predominantly characterized by lower EEG frequency waves but that it shifts to higher frequencies the stronger the experience is rated. Second, we assumed that the two classical hypotheses from the literature, which we refer to as the frontal relaxation and the temporal involvement hypotheses, might also hold true in the present study.

First hypothesis: brain activation of religious experience in worship

Although there were more upper beta waves in the temporal regions when the religious songs were compared to the secular ones, the comparison of Rs with Ss condition (that differed the most according to the MDS) showed no such thing and the results pertaining to the experiential dimension were localized most strongly in the occipital regions (frequency bands 1 to 4, which means upper delta to lower alpha, depending on the experimental condition). This is surprising because the literature barely reports findings pertaining to the occipital lobes in association with religious cognition and emotion.

At first sight, it looks like some of the findings were contradictory. On the one hand, there was less lower alpha power when the religious setting is observed but on the other hand, there was more lower alpha when the religious experience is analyzed in exactly the same condition. Upon closer inspection, though, this may be harmonized by appreciating the statistical operations that were performed in the different analyses. It is not the case that the same operations yield differing results but that in one calculation, we performed a regression and saw that there was more alpha in the experience of God's presence during the religious

condition and in the other calculation, religious conditions were compared to secular ones, which in turn resulted in a reduction of alpha for the religious setting.

Conceptually, these results may be best understood when we distinguish between two phenomenological qualities that are both present in the data at hand. The first quality may be called the "religious experience", which here was operationalized as the measurement of how strongly the participants sensed the divine presence during the worship practice within any experimental condition. The second quality may be referred to as the "religious element" that is either present or absent in the settings of the different conditions (e.g. religious songs or secular songs). These two qualities are worth being further discussed in light of the present results.

Let us first turn to the "religious experience" quality. The *Feedback Loop Model for Religious Worship Experiences* lends reason to assume that the religious experience is qualitatively deeper when the songs can be selected by the participants themselves and when the song is a known worship song selected by the participants (Walter, 2021). This is congruent with our discovery that both the Ss and Rs conditions showed a positive correlation with the averaged experiential ratings. There were two important results shedding light on the experiential quality, which was (i) a positive association of the experience with the neural activity in the Ss condition, and (ii) a positive correlation of the experience and the neural activity in the Rs condition.

(i) The first finding was a significant interaction when the subjective ratings of the experience were correlated with the third and fourth frequency bands in the Ss condition. In other words, we found more upper delta and lower theta waves when participants were worshipping to a secular song of their own choosing and having a stronger religious experience. The stronger the experience became, the more of these waves were present when people worshipped to a non-religious song they already knew. Hence, even without the "religious element" immanent

in the environmental context, people showed a neurocognitive reaction to the religious experience. Functionally, these bands are usually associated with rest, deep states, emotionality, creativity and insight (Stern & Engel, 2013). This means that with self-selected secular songs, participants were in a relaxed state where they were able to sink into the experience of feeling the presence of God. The stronger the experience got, the more we found this "deep state" of emotionality that may be accompanied by creative insight.

(ii) The second finding pertaining to the experiential quality was the positive association of the religious experience with the upper theta and lower alpha bands in the Rs condition. This indicates that the stronger the religious experience became during a religious song they selected themselves, the more theta and alpha waves were present. These bands are typically associated with heightened emotion and awareness (Stern & Engel, 2013). The neural activation patterns show intriguing resemblance to meditation, which is likewise accompanied with theta and alpha frequencies and they are said to be associated with calm awareness and focus (Deolindo et al., 2020).

(i & ii) Both of these findings concerning the experiential quality are consonant with the previous understanding that environmental factors, such as the musical setting, can foster a worshipper's focus on God and lead to more vivid religious experiences. It appears like sensing the divine in the Ss condition comes along with a more slumbering and calm state accompanied with heightened emotionality (cf. Stern & Engel, 2013). In unison with previous findings, our data showed that the Rs condition came along with a stronger focus on God and was therefore associated with a more vivid and active state of mind (Walter, 2021), although participants did not exit the calm state. A stronger experience emerged with more theta and alpha waves, implying that the respondents had an increased neural activity, characterized by heightened emotionality and awareness. Such a state appears to have similarities with people in deep meditation (Deolindo et al., 2020; Dobrakowski et al., 2020).

Next, let us turn to the quality of the "religious element". As seen before, a stronger religious focus through the environmental factors led to stronger mental activity. This was corroborated through comparing the religious (Rs + Rg) with the secular conditions (Ss + Sg), which yielded an increase in the upper beta waves for the religious conditions. This implies that when the religious element was present (a song that has a religious connotation based on the text or music), more cognitive activity was present, which neurophysiologically manifests itself with stronger perception, thinking, focus and sustained attention (cf. Stern & Engel, 2013).

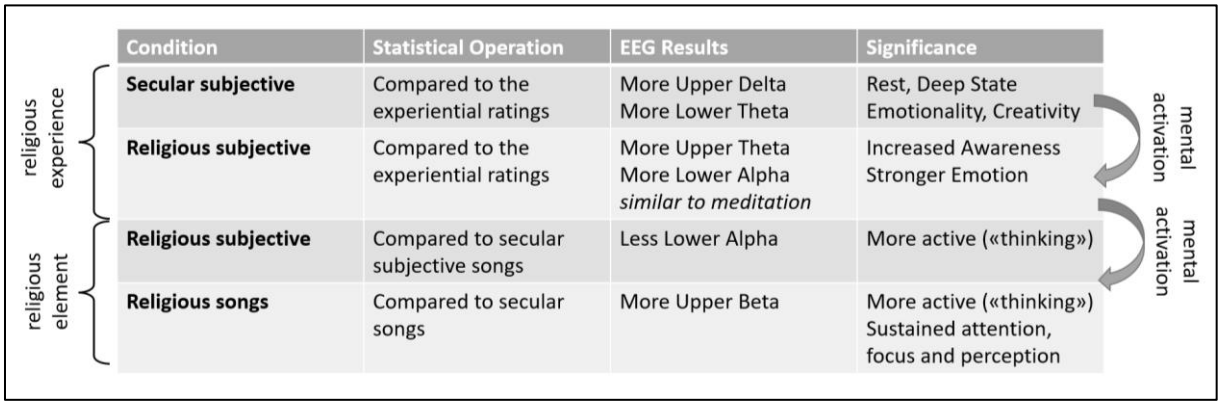
These processes were further strengthened by the fact that there was a decrease in lower alpha frequencies when Rs was compared to Ss. Here, there was a specific focus on the religious element because in both conditions the participants worshipped to self-selected songs and the only difference was that one is a religious worship song they knew and the other one was a secular song they knew. The decrease of alpha in this comparison might generally be regarded as the preponderance of more active thinking (cf. Kardan et al., 2020; Kraus et al., 2019).

Although it looks like the decreased alpha in Rs disagrees with the increased alpha of the heightened religious experience during Rs, it is not a necessary contradiction. The first deals purely with the *religious element*, which comes along with more focus and active thinking, and the second deals with the *religious experience*, which is associated with more awareness and emotionality. It is therefore no contradiction in terms to conclude that the subjective sensation of the divine presence invokes a calm state of mind with heightened emotion and awareness and that at the same time it comes along with a stronger focus and perception that is probably directed towards what believers assume to be God.

Much to the contrary, this seems to be in agreement with the previously discussed qualitative cognitive model for religious worship experience, which suggests that a stronger focus on God can lead to a heightened awareness and perception thereof (Walter, 2021). We can now

add to this the notion that it may be accompanied with stronger emotions and that the subjective descriptions match the neurocognitive underpinnings. There are striking parallels to the activation patterns in meditation, although a worship experience may perhaps be a more cognitively active state because of the religious element that comes along with the activation of upper beta waves.

In short, the religious element had an activating effect, especially when the song was selected by the participant, which is evidenced by an increase in upper beta waves in the religious songs compared to secular ones and with a decrease in lower alpha when the Rs condition is compared to Ss. At the same time, a stronger religious experience in the Ss condition came along with higher upper delta and more lower theta band activation, whereas there was an upward shift when turning to the experience in the Rs condition, which portrayed an increase in upper theta and heightened lower alpha waves (comparable to meditative states). In consequence, our first hypothesis may be accepted. The results pertaining to the first hypothesis are summarized in Figure 6.



Condition	Statistical Operation	EEG Results	Significance
Secular subjective	Compared to the experiential ratings	More Upper Delta More Lower Theta	Rest, Deep State Emotionality, Creativity
Religious subjective	Compared to the experiential ratings	More Upper Theta More Lower Alpha *similar to meditation*	Increased Awareness Stronger Emotion
Religious subjective	Compared to secular subjective songs	Less Lower Alpha	More active («thinking»)
Religious songs	Compared to secular songs	More Upper Beta	More active («thinking») Sustained attention, focus and perception

Figure 6. EEG spectral findings, which illustrate the increased mental activity in the experience through the religious element.

Second hypothesis: neural sources for religious experiences in worship

When it comes to possible sources for religious experiences, the temporal involvement and the executive inhibition hypotheses are recurrent themes in the literature (Cristofori et al.,

2016). Since reviews do not only refer to executive inhibition but more broadly to the involvement and downregulation, or, “relaxation” of frontal regions, the present study appropriates them as the temporal involvement and the frontal relaxation hypotheses (e.g. Grafman et al., 2020; van Elk & Aleman, 2017).

Our results show that the situation may be a little bit more complex and that these two hypotheses cannot simply be rejected or accepted. The neuronal sources calculated by sLORETA appeared to be associated with a broad spectrum of regions of interest when considered under the influence of the religious experience. Frontally, there was a relaxation found on the right hemisphere characterized by an increase of theta waves, but no association was found on the left hemisphere. In the parietal cortex, there appeared to be a bilateral activation due to a decrease in the first alpha band on the right hemisphere and a decrease in the second alpha band as well as an increase in the first beta band on the right hemisphere. For the temporal cortex, the two hemispheres did not show the same reaction. Whereas the left hemisphere seemed to slow down, characterized by a reduction of the second beta band, the right hemisphere experienced a mediocre activation, as seen by the positive association with the first and second beta band and the negative one with the second alpha and third beta band. In the occipital regions, there was a steady relaxation but not a full immersion into a deep state since the left hemisphere showed a positive association with the second alpha band and the right hemisphere showed a negative one with the delta band as well as a positive one with the first alpha band.

These results are summarized and connected to interesting regions associated with religious cognition and emotion as seen in table 5. They are more thoroughly discussed below.

Table 5. Summary of source localization regions and associations with religious cognitions and experiences. *Regions:* dlPFC= dorsolateral Prefrontal Cortex; IFG= Inferior Frontal Gyrus; ACC= Anterior Cingulate Cortex; dmPFC= Dorsomedial Prefrontal Cortex; vmPFC= ventromedial Prefrontal Cortex; NAcc= Nucleus Accumbens, vlPFC= ventrolateral Prefrontal Cortex; STG= Superior Temporal Gyrus; TPJ= Temporoparietal Junction // *Association to religious cognition:* Theory of Mind= Rationalizing God's intent and emotions; Cognitive control = Downregulating supernatural interpretations of unusual religious experiences; Semantic processing and storage = Retrieving religious beliefs stored in semantic and episodic memory; Reward and evaluation = Evaluating established or newly acquired beliefs; Multisensory integration = Spiritual transcendence; Conflict detection = Detecting conflicts between religious beliefs and task stimuli and demands (see Grafman et al., 2020)

ROIs	**Brain regions (Grafman et al., 2020)**	**Associations to religious cognition (Grafman et al., 2020)**	**Associations to sources of religious experiences**
Frontal	dlPFC	Cognitive control	*Right relaxation* <u>Right hemisphere</u> + Theta band
	IFG	Theory of mind	
	ACC	Conflict detection	
	dmPFC vmPFC NAcc	Reward and evaluation	
	vlPFC	Semantic processing	
Temporal	Temporopolar region STG	Semantic processing & storage	*Left relaxation and right activation* <u>Left hemisphere</u> - 2. Beta band <u>Right hemisphere</u> - 2. Alpha band +1. Beta band +2. Beta band - 3. Beta band
Parietal	Parietal lobe	Multisensory integration	*Activation* <u>Left hemisphere</u> - 2. Alpha band +1. Beta band <u>Right hemisphere</u> - 1. Alpha
	TPJ	Theory of Mind	
Occipital	Precuneus	Theory of mind	*Relaxation* <u>Left hemisphere</u> + 2. Alpha band <u>Right hemisphere</u> - Delta band + 1. Alpha band

Frontal relaxation

The dorsolateral Prefrontal Cortex (dlPFC) is said to be associated with the downregulation of supernatural interpretation. Lower activities in this region are hence seen as an impetus for less skeptical scrutiny and higher affinity to attribute a religious interpretation to an experience (Cristofori et al., 2016; Zhong et al., 2017). In other words, "Executive functions controlled by the dlPFC causally contributed to the down-regulation of mystical experiences" (Grafman et al., 2020, p. 130). It appears as though stronger religious experiences evoke a downregulation of executive functions in the dlPFC, which may indicate that the cognitive process of *deeming* an experience religious (for a discussion about the singularization of religious experiences, see Taves, 2011) comes along with stronger predictive coding processes (for a discussion of predictive processing in religious cognition, see van Elk & Aleman, 2017). In other words, the more a person believes an occurrence to be a religious experience, the more the act of interpretation is accompanied by a downregulation of the dlPFC, which itself my be informed by the theology (religious cognitive constructs) present used for the top-down regulation. This idea is further strengthened by the fact that the Anterior Cingulate Cortex (ACC) is held to be responsible for conflict detection between religious beliefs and outward stimuli (Botvinick et al., 2001; Grafman et al., 2020). The frontal relaxation hypothesis may also be connected to an ACC activity reduction and therefore a lessened conflict monitoring, making a believer more receptive for a variety of interpretations and experiences, which would otherwise be filtered out by the critical thinking faculties that could in principle detect discrepancies between different ideas and sensations. In other words, a decrease in ACC activation is held to imply a reduced error monitoring, which fits nicely with the frontal relaxation observed in the present religious experiences and the religious predictive processing descriptions made by van Elk and Aleman (2017).

There are two further interesting religious cognitive processes corresponding to the present frontal findings: (i) theory of mind; and (ii) reward and evaluation.

(i) For the theory of mind aspect, one needs to have a closer look at the responsible regions in the neural model for religious cognition (Grafman et al., 2020) since there are several regions associated therewith that are located in different lobes. Theory of mind involvement is said to be connected to the rationalization of God's intent and emotions. In the frontal regions, there are two areas relevant for this, namely the Inferior Frontal Gyrus (IFG) and the Medial Prefrontal Gyrus (MPFC). The IFG contains what has often been referred to as Broca's area involved with speech production in language processing (Elmer, 2016). It may be assumed that a frontal relaxation could in principle be associated with the IFG during an elevated spiritual experience since according to the *Centrality of Religion Scale CRS-15* (Huber & Huber, 2012), religious experience is an explicitly receptive dimension in a person's construct system of religion. Among others, the MPFC is held to be involved with reflections about God (Cristofori et al., 2016; Urgesi et al., 2010) and with social cognition (Grossmann, 2013), specifically with self-other distinctions (Gusnard et al., 2001). This function of the MPFC in light of the frontal relaxation observation may indicate that the experience would be rather absorbing, making no differentiation between whether God's presence is felt as an outward source or simply exists within one's self.

(ii) The dorsomedial Prefrontal Cortex (dmPFC), the ventromedial Prefrontal Cortex (vmPFC) and the Nucleus Accumbens (NAcc) are frontal regions described to invoke the evaluation of religious beliefs and linking them to reward pathways (Grafman et al., 2020). It is believed that the IFG as part of the Theory of Mind network forms a pathway to the dmPFC, which modulates the cognitive reflections of religious beliefs (Kapogiannis et al., 2014). A study by Zhong et al. (2017) found that lesions in the dlPFC and vmPFC are correlated with an increase in fundamentalist beliefs (see also Asp et al., 2012), which

indicates a decrease a decline of critical reflection towards religious ideas in correspondence to the activity of the dlPFC and the vmPFC. This notion appears to be congruent with the frontal relaxation thesis. The NAcc, together with the vmPFC and the striatum are involved with religious beliefs to ensure their evaluation as well as their reinforcement. Frontal relaxation would imply a diminishing of such evaluative processes, at least during the most intense phases of sensing God's presence.

According to Grafman (2020), both the temporal as well as the frontal regions are associated with semantic processing and storage for retrieving religious beliefs stored in episodic and semantic memory. For the frontal part, the ventrolateral Prefrontal Cortex (vlPFC) is supposed to play a role, e.g. in the perception of sacred values (Berns et al., 2012). However, for the vlPFC, there appear to be two main functional theories. One theory suggests that it is responsible for motor inhibition, where control is exerted to diminish motor responses (Aron et al., 2004). The other theory holds that it is involved in spatial attention and reflexive reorienting (Badre & Wagner, 2007; Corbetta et al., 2008; Corbetta & Shulman, 2002). If the latter theory may be merited, then a frontal relaxation might implicate that a religious experience in worship blurs the spatial boundaries around the self, which would be congruent with previous studies concerning religious experiences (Newberg et al., 2002, 2006). Lee, Blumenfeld and Esposito (2013) found that the vlPFC constitutes an end point of the ventral pathway, meaning that it provides information about a stimuli's characteristics. A downregulation, or "relaxation", would imply that a sensation's characteristics are not particularly registered with a high degree of detail and granularity. The experience would hence be of a diffuse and ineffable kind. This would match the participants' descriptions perfectly because they often describe their divine experiences as hard to explain and difficult to put into words. Perhaps, so the vlPFC would suggest, it may be the case that the perception itself is not very specific and this in turn makes it difficult to articulate.

Our second hypothesis stated that there might be a relaxation of frontal regions and an activation of temporal ones. The positive association with the theta band implies that we can accept the frontal relaxation part of the hypothesis, but only for the right hemisphere. For the left hemisphere, no up- or downregulation was found.

Temporal involvement

One prominent notion in the domain of religious cognition and emotion is the temporal involvement hypothesis. According to Grafman et al. (2020), there are three key regions that have been found in this area: 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 (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 (Schjoedt, 2009). 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 the 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). 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.

Some religious experiences have been reported to recruit the temporal cortex in a broader sense still (e.g. Garcia-Santibanez & Sarva, 2015; McCrae & Elliott, 2012; Persinger, 1983). Kappogiannis and his team (2009) have 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.

Perhaps one of the most interesting regions in this area reported 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 (e.g. Arzy et al., 2005, 2006; Blanke, 2012; Blanke et al., 2002, 2004, 2015; Fondevila et al., 2012; Nakul & Lopez, 2017; Schienle et al., 2019; Sommer et al., 2007). 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 (van Elk & Aleman, 2017).

In short, the temporal cortex appears to be involved in the generation of extraordinary sensations, including the weighing and integration of these potentially differing signals by connecting them to religious beliefs about God's intents and emotions. This seems to be localized most strongly on the right hemisphere. From our study, we can corroborate this idea

because we found a downregulation of the left temporal cortex (characterized by a reduction of the second beta band) and an activation of the right temporal cortex (evidenced by a positive association with the first and second beta band as well as a negative one with the second alpha and third beta band). As such, we can accept the temporal involvement hypothesis, although only for the right hemisphere.

Parietal activation

The positive association of the parietal cortices with the religious experience in our results is not completely surprising. However, we did not account for it in our hypotheses because we did not assume that it would carry a strong weight in explaining the phenomenon next to the two hypotheses we already had.

The parietal regions have been described to be connected with multisensory integration, whereby interoceptive and exteroceptive signals are weighed against each other, as well as with what has been referred to as "spiritual transcendence". This is believed to be a sacred experience that helps people to deal with their ordinary but also with their difficult life experiences. This state, including similar experiences produced by psychoactive drugs or by environmental factors (like winning a sports game or losing a loved one), has been found to be associated with the parietal lobes and the frontoparietal attention network (Lifshitz et al., 2019).

Especially the right parietal lobe has been taken to be a center piece for self-other distinctions and when downregulated, a sense of selflessness may emerge. This function has previously been dubbed a neuropsychological basis for spiritual transcendence (Johnstone et al., 2012). "Self-transcendence", as it is sometimes referred to, has been suggested to be based on a large fronto-parieto-temporal network, although lesions to the inferior posterior parietal regions

were found to induce a specific increase in self-transcendence (Urgesi et al., 2010). Some authors claim the following:

> Therefore, modifications of neural activity in temporoparietal areas may induce unusually fast modulations of a stable personality trait related to transcendental self-referential awareness. These results hint at the active, crucial role of left and right parietal systems in determining self-transcendence and cast new light on the neurobiological bases of altered spiritual and religious attitudes and behaviors… (Urgesi et al., 2010, p. 309)

A study found that frontal and parietal ERPs were associated with empathy related to people with similar beliefs, referring to a neural coding of religious in-group preferences. The researchers showed the participants pictures of painful or neutral faces of Christians and atheists. The participants themselves were also either Christians or atheists. It was shown that frontal signals were stronger when people viewed suffering images of subjects pertaining to the same beliefs, and an additional late central as well as parietal signal was found in the Christian participants (Huang & Han, 2014).

Perhaps one of the strongest forces bringing the parietal functions on the map for considering their influence on religious experience and cognition was when Andrew Newberg, the father of the term *Neurotheology*, ventured a single-photon emission computer tomography (SPECT) study on the neural mechanisms of a prayer form known as *glossolalia*, or, *praying in tongues* (Newberg et al., 2006). Unlike other publications in the domain of religious emotion and cognition, this study did not report a decrease but an increase in activation of the left Superior Parietal Lobe (SPL). A downregulation of the SPL is sometimes interpreted as a somewhat relaxed and meditative phenomenon with an altered state of self (Lynch, 1980; Newberg et al., 2001). However, the authors expected an upregulation of the SPL since glossolalia is an active practice where participants try to let the divine work through the self and a person's body. One might speculate from this, for example, that an activation of the parietal networks in this context may hint at that we are dealing with a more active meditative state of mind.

Sensory perception may also be modulated by religious beliefs (Good et al., 2015) and it has been shown that certain prayer forms can help in a believer's coping mechanisms during physical pain (Elmholdt et al., 2017). This was seen during an fMRI experiment where devout Protestants were exposed to painful electrical stimulation. When the researchers compared a religious prayer condition with a secular prayer contrast, the religious condition was accompanied with lower pain and unpleasantness ratings as well as with diminished frontoparietal activity. Due to frequent reports of the significance in the frontoparietal areas, especially homing in on the DLPFC and the Inferior Parietal Lobe (IPL), a study performed transcranial magnetic stimulation (TMS) on believers. The specific regions of interest were the DLPFC and the IPL with a focus on whether modulations of these regions influenced subjective ratings of religiousness and spirituality (R/S). Whereas the inhibition of the DLPFC did not appear to be associated with the ratings, a specific increase of the R/S values seemed to follow the modulation of the IPL, which may be "demonstrating its causative role in inducing fast plastic changes of religiousness/spirituality." (Crescentini et al., 2014, p. 1)

Although in our hypotheses we did not expect that the parietal cortex would help to explain the experience of subjectively believed divine sensations in worship, the results showed that there was a bilateral parietal activation upon the religious experience. This was shown by a reductio of the second alpha as well as an increase in the first beta band on the left hemisphere, and by a reduction of the first alpha band on the right hemisphere.

Occipital relaxation

Previous studies did not highlight an involvement of the occipital cortex in respect to religious cognition and emotion (Cristofori et al., 2016; Grafman et al., 2020; Kapogiannis et al., 2014). Therefore, it came as a considerable surprise to us that our results showed an occipital relaxation on both hemispheres of the brain, characterized by an increase of the second alpha

band on the left, and a decrease of delta as well as an increase of the first alpha band on the right side.

Hans Berger (1929), the inventor of the EEG, already described that occipital alpha waves are predominantly found during wakeful relaxation with closed eyes (see also Bagherzadeh et al., 2020; Domino et al., 2009; Niedermeyer, 1997; Vries et al., 2021). A "wakeful relaxation" may in fact be a suitable description of the present religious experiences when considering the behavioral a neurocognitive data. Such alpha waves are downregulated when the eyes are opened, or when the participant gets sleepy or drowsy. It was argued that an upregulation implied active inhibition of certain brain areas (perhaps in our case, contributing to frontal relaxation), and that thereby they contribute to the coordination and communication of neural networks (Palva & Palva, 2007).

It has also been shown that mindfulness meditation increases alpha wave power in both healthy subjects and patients, which was described as "a state of relaxed alertness" (Lomas et al., 2015, p. 401), and meditation experts show a strong posterior alpha and theta localization (D. J. Lee et al., 2018). This provides further evidence that there may be a link between the religious experience in worship from our sample and meditation experiences.

Since the visual cortex is located in the occipital lobes, it makes sense to assume that the preponderance of alpha frequencies may also have a connection to the processing of visual information and that this might be associated with the experience of the divine. A study connected the appearance of occipital alpha frequencies with visual information processing in working memory (S. A. Kozlovskiy & Rogachev, 2021) and it was shown that the timing of alpha activity had to do with the exact types of stimuli in the working memory. In another paper, they suggested that posterior alpha rhythms with open eyes are an indication for inhibition of visual information processing in the primary visual cortex and that instead the analysis of images in the visual memory processing areas are taking place (S. Kozlovskiy &

Rogachev, 2021). This may indicate that during the experience, visual or episodic memory processing could be at work where the believers mentally play around with instances where the divine has already been experienced before.

We are not completely sure why our results indicate a relaxation of the occipital lobes whereas in previous studies on religious states of mind this was largely absent. The most plausible explanation might be that we have performed one of the first studies to measure the dimension of experience directly by providing a continuous rating of the sensations. Additionally, we have introduced considerable statistical controls, such as testing for the effects of the experimental conditions when considering the experiential ratings. Hence, it may be the case the experience in fact recruits visual memory processing, which could either have been filtered out by the task conditions of the previous studies, or that the lack of measuring experience and instead focusing on the dimension of religious practice oversteered the signals from the occipital cortex.

A neurocognitive framework for religious worship experiences

Our initial findings showed that in our sample the religious experience in worship was a deep state that came along with a relaxed mentality, emotionality, and creativity. This was especially visible in the Ss condition since there was a positive correlation of the experience with the upper delta and the lower theta waves. When the experience got stronger in the Rs condition, there was an upwards shift in the positive association to the upper theta and the lower alpha frequencies, which – apart from an increased emotional salience – implies a heightened awareness. The religious element appeared to suggest that there was more active thinking at play when the religious content was more saliently present. This was seen when the Rs condition was compared to the Ss condition, which yielded a reduction of lower alpha waves. A broader perspective was gained through comparing the religious songs with the secular ones. There, a positive association with the upper beta band was found, indicating not

only more active thinking but also sustained attention, focus and perception. The neural sources in the frontal and parietal regions can strengthen and enrich this picture. Frontally, there is a relaxation on the right hemisphere, which may indicate somewhat of a relaxed state through the positive association with the theta band. Hence, the experience may evoke a relaxed and emotional state whereas the religious element, which is the explicit religious content, may be accompanied with more cognitive activity and hence may be the reason why the experience itself is *deemed* to be *religious* after all. For the parietal lobes, the positive association with the first beta band and the negative one with the alpha bands further enrich this image by indicating that there is a self-transcendence and expanding of the classical boundaries of the self during the religious experience at play. Our study further corroborates the classical image of the right temporal cortex being also responsible for mystical experiences. However, what is new is that our data seems to suggest that visual memory processes in the occipital lobes are involved as well.

There appear to be three nested cognitive and neural models, which together may form a neurocognitive framework that seems to be suitable to conceptualize the present findings. They are the following:

- The singularization model for the cognitive attribution of religious concepts to extraordinary experiences. This is the process of deeming such experiences religious, which is characterized by Ann Taves (2005, 2009, 2011, 2020; Taves et al., 2019; Taves & Asprem, 2017).
- The predictive processing model for religious cognition and emotion dealing with the differential weighing of interoceptive and exteroceptive neural signals in regards to the trade-off of top-down and bottom-up mechanisms, which are described by van Elk & Aleman (2017) and further employed by Grafman et al. (2020).
- The temporal involvement and executive inhibition hypotheses (Cristofori et al., 2016) here appropriated as the temporal involvement and frontal relaxation theses that specify the neural processes in religious cognition and emotion. They characterize the modulation of attentional control, emotion and sensation integration as well as the downregulation of error monitoring mechanisms. Our findings further suggest that the parietal activation and the occipital relaxation ideas should also be added to the set up hypotheses.

The current findings concur with the *frontal relaxation hypothesis*, which lends credence to the notion that spiritual and religious experiences ought to be deemed as such by the believers and that predictive processes play their part. These "special experiences" need to be deemed religious by the believer in order to become religious in nature and a frontal relaxation, characterized by a reduced error monitoring mechanism, may increase the chances for deeming the broad sensations of religious environments and practices as pleasant religious experiences. However, since there are still active cognitive elements at work, as seen in the presence of higher frequencies corresponding to the religious element, it makes sense to assume that the experience is actively deemed religious by the participants. When it comes to the *temporal involvement hypothesis*, there is plenty of research demonstrating some connection of the temporal lobes to religious cognition and emotion. Our study corroborates this idea, although only for the right hemisphere. Furthermore, our findings suggest that te framework should be enriched by the *parietal involvement hypothesis*, stating that it is also an experience involving self-transcendence and the broadening of the regular boundaries of the self, and the *occipital relaxation hypothesis*, implying visual memory processing.

This is largely congruent with a review on brain mechanisms for religion and spirituality by van Elk and Aleman (2017), who stated the following:

> Together these findings suggest that top-down influences on multisensory integration result in a differential weighting of sensory information, which may underlie the dissociation between the observed and the felt perspective in out-of-body-experiences or the experience of a felt presence. Of course, these experiences – though strange and bizarre – are not intrinsically religious or spiritual. Rather, it is often through a process of cultural learning that these experiences are framed within a religious or spiritual framework, e.g., as presenting evidence for an afterlife (e.g., as in near-death experiences) or the existence of invisible supernatural agents. Thus, extraordinary experiences may be 'deemed' religious based on one's specific cultural and religious background – in line with the predictive processing model according to which one's prior expectations shape perception and experience (van Elk & Aleman, 2017, p. 366).

Our proposed framework thus starts with the building-block approach for the emergence of religious experiences that strongly draws on *singularization* as a cognitive process responsible

for *deeming* some experiences religious. The idea holds that special occurrences standing out as "special enough" are perceived as set apart (singled out – hence, *singularization*) from ordinary experiences. These special experiences are attributed with religious content, which are already present as preconceived theological concepts, and hence become religious experiences. This theory has been discussed above as the Tavesian attribution approach (Taves, 2005, 2009, 2011, 2020; Taves et al., 2019; Taves & Asprem, 2017). We believe that such attributive mechanisms are at work in our experiments because participants have been deliberately asked to rate their own experience of sensing God's presence during the worship activities.

The attribution approach can be adequately expanded by the psychological predictive processing account for religious cognition by both Grafman et al. (2020) as well as van Elk and Aleman (2017), which state that there are different top-down and bottom-up signals that need to be weighed and eventually integrated with as little cognitive dissonance as possible. First, there are the sensory inputs that have to be interpreted to create a harmonious outlook. If the sense perceptions deliver conflicting signals, then the attentional control needs to be redirected to these input factors in order to make proper sense of what happens. Second, an economic and efficient conceptualization of the perceptual signals requires ready-made cognitive constructs that allow for the information to be integrated as fast as possible. Hence, for example, seeing a table is a process that works very fast since the concept of a table is ready to use. Something that appears to look *like* a table is interpreted as a table in a manner of milliseconds. Only if the vision becomes ambiguous and it is unclear whether the perception is more *like* or more *unlike* a table, the brain needs to give it more attention to disentangle if this is really a table or something else. The cognitive concepts are therefore continuously superimposed on the sense data and only in case of emerging discrepancies there will be a closer inspection and a continuous updating of the mental constructs in question.

This is the basic idea of predictive processing, and it is applied to religious experiences in the sense that religious constructs (of God, angels, demons, *jinns*, etc.) are seen as ideal concepts to reduce cognitive dissonance in situations where the perceptual signals are so extraordinary, or "special", that it is the most effective alternative to single them out and to deem them religious. For example, if one appeared to see a person walking through the wall, it would require some serious reconfiguration of the mental concepts about the world and one's perceptions, which implied a very costly allocation of mental resources. However, if one believed to have reason to think that it must have been a spirit walking through the wall, then the dissonant problem is efficiently solved.

This sits well with the present findings because, first, a partial frontal relaxation may indicate a reduced error monitoring as well as a diminished critical reflexivity, which helps to reduce any possible ambiguity about perceptual signals through theological constructs without having to philosophically tackle them. And second, the parietal and temporal activation imply an interpersonal experience pattern and expansion of the self, as well as a multisensory integration, which is most likely a testament to the nature the religious concept being used – in this case, an encounter with a personal deity that exceeds the regular self. At the same time, it hints to the predictive differential weighing of the interoceptive and exteroceptive signals.

As such, the three nested models may serve as a useful neurocognitive framework for religious experiences in worship.

Conclusion, limitations, and future research

The present study investigates religious experiences in terms of sensing the presence of God with a sample of evangelical Christians. It was hypothesized: (i) that the experience comes along with a deep state of mind characterized by lower EEG frequencies, which shift towards

higher frequencies when the experience gets stronger; (ii) and that the neural sources of the religious experience correspond to the *frontal relaxation* and the *temporal involvement hypothesis*, which both already have a standing in the literature. The results show that both hypotheses can be accepted – but the latter only to a certain degree. The frontal relaxation was found to hold true only for the right hemisphere and the same was true for the temporal involvement idea. Additionally, we did not account for an involvement of the parietal and the occipital cortices.

When people start to worship and feel comfortable enough to open up (indicated by the ratings during the Ss condition), the believers get into a calm and deep state with latent emotionality and creativity. In this state, some believers may have the impression to receive new spiritual insights since problem solving, feelings and insight is sometimes associated with the preponderance of delta and theta oscillations (Stern & Engel, 2013). Once people get into a strong religious experience in an environment they feel most comfortable (as indicated by the ratings of the Rs condition), their mind becomes more active with strong awareness and emotion. It was discussed that it makes sense to discern the religious element from the religious experience. The cognitive activation in the experience is dependent upon the presence of the *religious element* (which came along with lower alpha and increased upper beta waves) – and this may exactly be the key difference to the meditation practices. Meditation is often characterized by theta and alpha, and it is functionally associated with calm attention and awareness (Deolindo et al., 2020). Whereas this is also the case for the *religious experience*, measured here as the subjective intensity of the sensation of God's presence, it is associated with more emotion, perception and active thinking.

There may be a simple reason for this: worship and the associated religious experience are a process where the believer actively focuses on God (Walter, 2021). Hence, the cognitive processes are revolving around this central mental construct. The person's attention is directed

outward to engage with in a connection with the divine. There is an active search for God, which is a mental activity featured by attentiveness, awareness, and focus. Likewise, once the experience gets stronger, the perception of the divine gets more intense and this in turn is characterized by stronger emotional reactions and awareness. This means that an experience of the divine during worship may be a meditative state with the added cognitive dimensions of higher emotion and active thinking in the religious domain.

These findings are well situated with previous knowledge about meditation (Deolindo et al., 2020) as well as religious worship practices with music (Brehm Center, 2017; Demmrich, 2018, 2020; Walter, 2021). One surprising discovery is that the spectral results have a tendency to manifest themselves most strongly in the occipital lobes. It is not common to find associations with religious cognition and emotion in these areas. However, it is worth positing that future studies might benefit from having a closer look thereupon since our data shows that the increased experience of the divine came along with more alpha and less delta waves in the occipital regions.

The source reconstructions through sLORETA found activation patterns in the parietal and right temporal lobes, as well as relaxation tendencies in the occipital and right frontal lobes. The right frontal relaxation may indicate a downregulation of mental faculties responsible for critical thinking, error monitoring and the deliberate usage of present religious concepts for framing the experience. The parietal and right temporal activation suggest that we are dealing with spiritual self-transcendence and a form of multisensory integration where interoceptive and exteroceptive stimuli are weighed against each other. The occipital relaxation, coming along with an increase in alpha waves, suggests that visual memory processing may also be involved.

These findings can be situated within three nested models, namely the singularization process in the building-block approach by Ann Taves (2011), the predictive coding approach by

Grafman and colleagues (2020) as well as van Elk and Aleman (2017), and the frontal relaxation hypothesis in combination with the temporal involvement hypothesis (drawn and modified from Cristofori et al., 2016). To this, our results suggest that we would have to add the parietal activation and occipital relaxation hypotheses.

One major limitation in the present study is 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 can be deemed religious that may not necessarily be 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 such states of mind (as already highlighted long ago by James, 1902). And third, to have a strong validity in our operationalization, we have 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 would also differ. It is therefore possible that the neurophysiological mechanisms we have discovered are merely a small fraction of possible 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 for the participation in comparable experimental studies.

Acknowledgments

We have been 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 are willing to offer their most intimate experiences under sterile lab condition where they most certainly do not feel as comfortable as in their natural environment.

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