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RESEARCH PAPER

Neural network involvement for religious experiences in worship measured by EEG microstate analysis

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ABSTRACT
Not much is known about large-scale brain activation patterns in religious states of mind and previous studies have not set an emphasis on experience. The present study investigated the phenomenon of religious experiences through microstate analysis, and it was the first neurocognitive research to tackle the dimension of experience directly. Hence, a total of 60 evangelical Christians participated in an experiment where they were asked to engage in worship and try to connect with God. With a bar slider, people were able to continuously rate how strongly they sensed God's presence at any given moment. A selection of songs was used to help in the induction of the desired experience. With 64 electroencephalography (EEG) electrodes, the brain activity was assessed and analyzed with five clusters of microstate classes. First, we hypothesized that the neural network for multisensory integration was involved in the religious experience. Second, we hypothesized that the same was true for the Default Mode Network (DMN). Our results suggested an association between the auditory network and the religious experience, and an association with the salience network as well as with the DMN. No associations with the network thought to be involved with multisensory integration was detected.

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Introduction

The relevance of religious experiences

Religious experiences can be of vital importance to a believer's life and how one conceptualizes the world (Wettstein, 2015). They may take the form of ordinary occurrences in a person's everyday activities or they may come as life-changing alterations of perceptions, which can be seen in conversion experiences (cf., Glenn, 1970; Halama & Halamová, 2005; Iqbal et al., 2019; Johnson & Armour, 2018). Religious experiences are special states of mind where knowledge on the biocognitive and neuroscientific underpinnings of religion and spirituality is still scarce but slowly increasing (Rim et al., 2019). There is evidence suggesting that cognition and emotion in this context can have a positive influence on mental health and wellbeing when pursued thoughtfully (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), so better understanding the psychobiological mechanisms of religiosity and spirituality may be useful for a beneficial integration of such experiences in a believer's life. Consequently, 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). There are two domains where a salient lack of understanding can be highlighted and for which we intend to contribute through the current study: (i) there is an insufficient focus on the dimension of experience; and (ii) there is an absence of large-scale brain network analyses. These two domains shall be briefly elucidated as followed.

The dimension of religious experience

There is much controversy about settling on the "right" definition of religion and associated phenomena, which is why it has been dubbed "the vexed question of defining religion" (Droogers, 2011, p. 263). It has therefore become favored to conceive of religion through frameworks that are sensitive to the context the phenomena are found in (Clarke, 2011). More so, it has become acceptable for studies to employ useful working definitions of the applicable terms to make progress in understanding the religious phenomena of interest in a specific context (Byrne, 1999; Molendijk, 1999; Platvoet, 1999). A useful definition

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of religion is supposed to help aggregate findings across disciplines, to facilitate interaction in discourse, and to evoke salient interpretative frameworks (Oman, 2013a, 2013b). Since it is sometimes difficult to differentiate the religious from the non-religious (Saler, 2000), in a famous instance, Platvoet (1999) has issued a call for a pragmatic approach to define religion. For empirical purposes such as with the present investigation, it is useful to conceive of *religion* as cognitive and emotional representations associated with beliefs in supernatural powers, sometimes perceived as sacred or inviolable (Bulbulia & Sosis, 2011).

Religious experience is an important element within these cognitive and emotional representations. William James (1902) was one of the first to psychologically tackle such phenomena and he interpreted them as fundamental human states of mind. The "problem of religious experience" (Jones, 1972) deals with how to best make sense of these experiences and if there may be something like a *sixth sense* attributed to them. One of the major conceptual questions is therefore: "What *makes* an experience religious?" In dealing with this, two opposing positions have emerged. The first position is tightly linked to the *sixth sense* idea, and it is generally referred to as the *sui generis* approach. It states that there is an inherent quality latent within these special states of mind that make such experiences a class of their own (sui generis). Whenever this quality is present, the experience becomes an inherently religious one (Eliade, 1960; Pals, 1987; Studstill, 2000). The second position is known as the *attribution* approach, whereas there is no special quality that "makes" an experience religious but it is the person's interpretation that attributes a religious status to the occurrence (Barnard, 1992; Hermans, 2015). Ann Taves (2005, 2009, 2009, 2011, 2020) has developed a building-block approach to the phenomenon of religious experience, which is useful for empirical research and therefore one of the most widely used frameworks in the domain. It states that through a process of *singularization*, the believer perceives an event as special enough so that it is seen as set apart, or, singled out from ordinary experiences (hence the wording of "singularization"). This way, an occurrence *is* not religious per se, but it is *deemed* religious by the experiencer. Although the present study appropriates the Tavesian attribution approach, we remain open to the possibility that there may be qualities or neural activation patterns that could be rather unique to religious experiences. As has been argued before, the two approaches must not necessarily be mutually exclusive positions but they might also be conceived as two ends of a spectrum where some phenomenological characteristics may be more or less unique to the event (Walter, 2021).

In an experimental setting, there are two major problems when it comes to the study of religious experience. First, there is the issue of operationalizing and thus measuring the experience. Previous studies have contended with using religious practice as a proxy for the experience itself. Measuring the biological effects of the practice is then inferred to equate with the effects of the experience. However, validated psychological models of religiosity, like the *Centrality of Religiosity Scale* (Huber & Huber, 2012), pose that there are five dimensions of religiosity: intellect, ideology, public practice, private practice, and experience. Hence, practice and experience are distinct dimensions of a believer's cognitive construct system of religion. This means that merely measuring practice and not specifically focusing on the dimension of experience is a methodological shortcoming that needs to be addressed. The present study takes this into account by letting the participants continuously rate their own experience during all experimental conditions. As such, the measurements are specifically directed at the experiential dimension and not at the practice.

The second problem deals with the question of how to induce the desired state of mind (the experience intended to be measured) and how to adequately guide it throughout the experiment. It has been shown that the act of worship in combination with music can be ideal to induce such religious experiences (Bennett, 1926; Brehm; Center, 2017; Chryssides, 1987; Głaz, 2021; Porter, 2016) and an evangelical sample may respond well to the task (Bielo, 2011; Ingalls, 2011, 2018; Johnson & Armour, 2018; Luhrmann, 2012). The *Feedback Loop Model for Religious Experience in Worship* shows that environmental factors such as musical tunes can help believers focus on God,[1] which in turn help to guide the attentional control in a fashion as to induce and guide the experience (Walter, 2021). Although music can trigger religious experiences (Demmrich, 2018), it is a difficult question to decide whether pre-selected songs by the researchers or self-selected ones by the participants work best to induce and guide specific states of mind (cf., Cheung et al., 2019; Koelsch, 2005, 2018; Koelsch et al., 2019). Pre-selected tunes maximize the standardization process, but self-selected songs may increase the chances of reaching the states that ought to be measured. To

[1]Since usually an academic study by virtue remains neutral on the question of a deity's existence, all references to God in this article are referring to the emic concepts of the respective believers.

take this dilemma seriously, in the present study we decided to employ both approaches: participants were asked to bring along their own religious and secular songs but for the sake of adequate references, some religious and secular songs were also preselected for them. Both approaches *together* are believed to provide a more wholesome picture than simply one of them.

Large-scale brain networks

An earlier paradigm of how the brain works holds that there are input stimuli entering the neural circuitry and get processed by being distributed on hierarchically distinct branches in a feed-forward fashion. The input stimuli were thought to enter the brain and are being processed in order to hand us an output function, which was either a cognitive and/or a behavioral outcome (Posner et al., 1988; Price, 2000). A newer picture does not contend with specific hierarchical localization of topographical areas because it has been found that the processing of stimuli operates through specialized "networks" that at any given time are more or less active (Bressler & Menon, 2010; Fries, 2005; He et al., 2007; Meehan & Bressler, 2012; Mesulam, 2008), and that the brain does even entertain an active network when the person is supposedly "not doing anything" (Fox & Raichle, 2007; Greicius et al., 2003). These large-scale networks are said to be *anticorrelated*, meaning that they are functionally separated from one another (Fox et al., 2005). They have now been discussed in terms of their temporal dynamics, associations with cognitions, spatial organization, and neurological diseases (Cabral et al., 2014; Foster et al., 2016; Fox et al., 2010; Mitra & Raichle, 2016).

Such networks have been analyzed both by means of MRI brain imaging (Biswal et al., 1995) as well as with EEG and MEG (Fries, 2015; Pasquale et al., 2010), whereas it has been proposed that the resting-state activation of these networks reflect a continuous state of thought and inner exploration (Deco et al., 2011). Multichannel EEG is increasingly used for investigating the temporal dynamics of these quasi-stable network activities. They are often referred to as "quasi-stable" because they remain stable for a short period of about 60–120 milliseconds and then quickly switch to another system. These "micro"-short and quasi-stable states are called *microstates* (Lehmann et al., 1998). Depending on the studies, there are four to seven microstate classes reported as alternating electrical field configurations on the scalp (for a conceptual and methodological review, see: Michel & Koenig, 2018).

So far, the spectral dynamics of EEG frequencies and the activations of specific brain regions assessed by either fMRI, MEG or EEG have been the main focus of investigations dealing with religion and the brain (Grafman et al., 2020). Hence, to date there is not much known about large-scale network activations during religious experiences. We wanted to introduce this new focus to the field, and, to our knowledge, the present study is the first one to deal with this via microstate analyses.

On the one hand, it has been found that certain aspects of religious and nonreligious beliefs share common neural underpinnings (Howlett & Paulus, 2015; Leshinskaya et al., 2017) and, perhaps not surprisingly, that religious beliefs recruit areas responsible for semantic storage, processing and retrieval (Berns et al., 2012). On the other hand, there have also been detectable differences in the brain activation patterns between religious and nonreligious beliefs (Harris et al., 2010) as well as in some social processing mechanisms (Huang & Han, 2014; Schjoedt et al., 2011; Thiruchselvam et al., 2017). Religious experiences appear to be interpersonal events where the mind of a deity or supernatural agent is believed to be involved. This idea stems from the observation that the theory-of-mind brain network is involved, which is associated with mentalizing – the process of attributing thoughts and emotions to agents outside of the self (Carrington & Bailey, 2009; Goel et al., 1995; Kapogiannis et al., 2009, 2014; Modestino et al., 2016; Schjoedt et al., 2009; Schurz et al., 2014). Religious processes involve valuation and motivational systems (Carter et al., 2012; Morgan et al., 2016), as for example, prayer down-regulates pain (Elmholdt et al., 2017; Good et al., 2015) and activates well-known reward pathways (Ferguson et al., 2018; Schjødt et al., 2008).

Based on an extensive literature review, Van Elk and Aleman (2017) describe five neural pathways that may be involved in religion and spirituality:

Research question & hypotheses

In the current study, the self-rated religious experiences were based upon the question of how strongly the participants sensed the presence of God during the experimental worship conditions. Subjectively believed encounters with the divine and sensations of God's presence are often empirically framed and studied under the headings of mystical experiences (e.g., Andersen et al., 2014; Beauregard & Paquette, 2008; Cook & Persinger, 1997; Cristofori et al., 2016; Ferguson et al., 2018; Taves, 2020). The descriptions of these experiences

Table 1. Overview of brain regions and mechanisms relevant for religious as well as spiritual beliefs and experiences, adopted from Van Elk and Aleman (2017).

No.	Neural pathway	Brain structures	Function	Relevance for religion and spirituality
1	Temporal brain areas	Hippocampus, Amygdala, STS, MTL, FFA	Memory retrieval, emotional coloring of experience, biological motion perception, face perception	Visions, Hallucinations, Déjà-vu experiences
2	Multisensory integration	TPJ, SPL, IPL	Bodily self-consciousness, multisensory integration	Mystical experiences, self-transcendence, out-of-body experiences, feeling a presence
3	Default Mode Network	PCC, precuneus, IPL, Lateral Temporal Cortex	Self-referential processing, mind-wandering	Mystical experiences, ego-dissolution, reflective religious beliefs
4	Theory-of-Mind Network	MPFC, STS, TPJ	Social cognition, communication, intentionality perception	Prayer, belief in personal God, over-attribution of agency
5	Error-Monitoring Mechanisms	ACC, MPFC, dopaminergic system	Prediction error-monitoring, belief-maintenance and updating	Openness to religious authority and rituals

STS = Superior Temporal Sulcus; MTL = Medial Temporal Lobes; FFA = Fusiform Face Area; TPJ = Temporo-Parietal Junction; SPL = Superior Parietal Lobe; IPL = Inferior Parietal Lobe; PCC = Posterior Cingulate Cortex; MPC = Medial Prefrontal Cortex; ACC = Anterior Cingulate Cortex.

come close to the functions of two neural pathways (no. 2 & no. 3) depicted in Table 1 (Van Elk & Aleman, 2017):

The self-transcendence and feeling of a presence associated with such events appear to involve neural networks that deal with multisensory integration (pathway no. 2), which may include the temporoparietal junction (TPJ), the superior parietal lobe (SPL) and the inferior parietal lobe (IPL). The self-referential processes with the dissolution of the self and the reflexiveness of religious beliefs required for the attribution of religious ideas to the experience appear to involve the default mode network (DMN; pathway no. 3), which is also associated with the posterior cingulate cortex (PCC), the precuneus, the inferior parietal lobe (IPL), and the lateral temporal cortex (Grafman et al., 2020; Van Elk & Aleman, 2017).

We hence formulated two hypotheses for our microstate analysis:

H1:Multisensory integration pathways are correlated with the religious experience in worship.

H2:The DMN is correlated with the religious experience in worship.

Selection of participants and experimental conditions

We tested these hypotheses with a sample of evangelical Christians and with different types of music. There were four reasons why an evangelical sample was preferred: (i) our team already had access to evangelical believers, which made the recruitment process more feasible; (ii) evangelicals place a strong focus on religious experience and (iii) this is something often sought after during their worship ceremonies; (iv) evangelical denominations use comparable music styles and songs, so it can be assumed that the tunes applicable for the present study may also be comparable.

As for the music used in the study, it has been shown that different musical conditions modulate a person's ability to focus and that this in turn modifies a believer's intensity in the religious experience during the worship practice (Walter, 2021). Hence, the present study applied several clearly delineated experimental conditions with and without music to create a variability in the religious experience and to compare it to the EEG data.

Materials and methods

Participants

The present study investigated a religious state of mind that can be induced through the help of worship with music. All participants stated that they were able to induce this state of mind during their worship practices. We recruited a total of 60 subjects from evangelical churches in Switzerland. The recruitment occurred in the churches as well as in the already present personal networks and with further contacts of the participants who might be interested in the participation of such a study. Due to recording errors with the first few participants, three subjects had to be excluded from the sample. The average age was 27 years (min: 19y, max: 40y; SD: 4.2y), 87% were right-handed, and the gender ratio was roughly equal (male: 45%; female: 55%). 70% of the respondents claimed that they played an instrument at least once per week. The highest education was spread like this: 22% held a master's degree, 23% a bachelor's, 22% a high school diploma and 33% finished an apprenticeship. An auditory test confirmed that all subjects had normal hearing abilities, and the experiments only commenced after each individual gave written informed consent. The study was approved by the local ethics committee[2] and followed the respective regulations.

Figure 1 displays some key information about how the present participants situated the act of worshipping within their general practice and religious experiences. It deals with the questions of how often they worshipped God with and without music, how often they sensed his presence during the act and how important the practice was for their personal faith lives. Figure 2 dives into the experience itself and shows how exactly they experienced God when they were in the act of worshipping him. Figure 3 then shows how strongly they experienced the divine during the experimental conditions (which can be seen best when looking at the maximal rankings, or, the peak experience per condition).

Experimental procedure

Each experiment started and ended with a 4.5 mins resting state where participants were instructed to close their eyes and relax. In between, there were six experimental conditions, each lasting about 4.5 mins and the conditions were separated by a concentration task where a series of letters had to be observed and questions had to be answered concerning the last letters. The concentration tasks had been devised to create a clear cut between the conditions and that there would be a minimized mental spillover effect from one condition to the next. The conditions were randomized to avoid a halo effect. The total time of the experiments lasted about one hour per person. We decided to use two religious worship songs and two secular songs (for each there was one provided by the researchers, and one provided by the participants), one empty condition with no music and a dissonant twelve-tone song to insert strong cognitive distraction. The conditions were carefully selected using the *Feedback Loop Model of Religious Experiences in Worship*, which reports that the focus on God based on the musical selection is a strong predictor of the experience (Walter, 2021). Table 2 portrays the six experimental conditions:

The conditions started and ended with a beep tone, and the task instruction was the same for every condition (it occurred on the screen before the condition started): participants were asked to worship God and

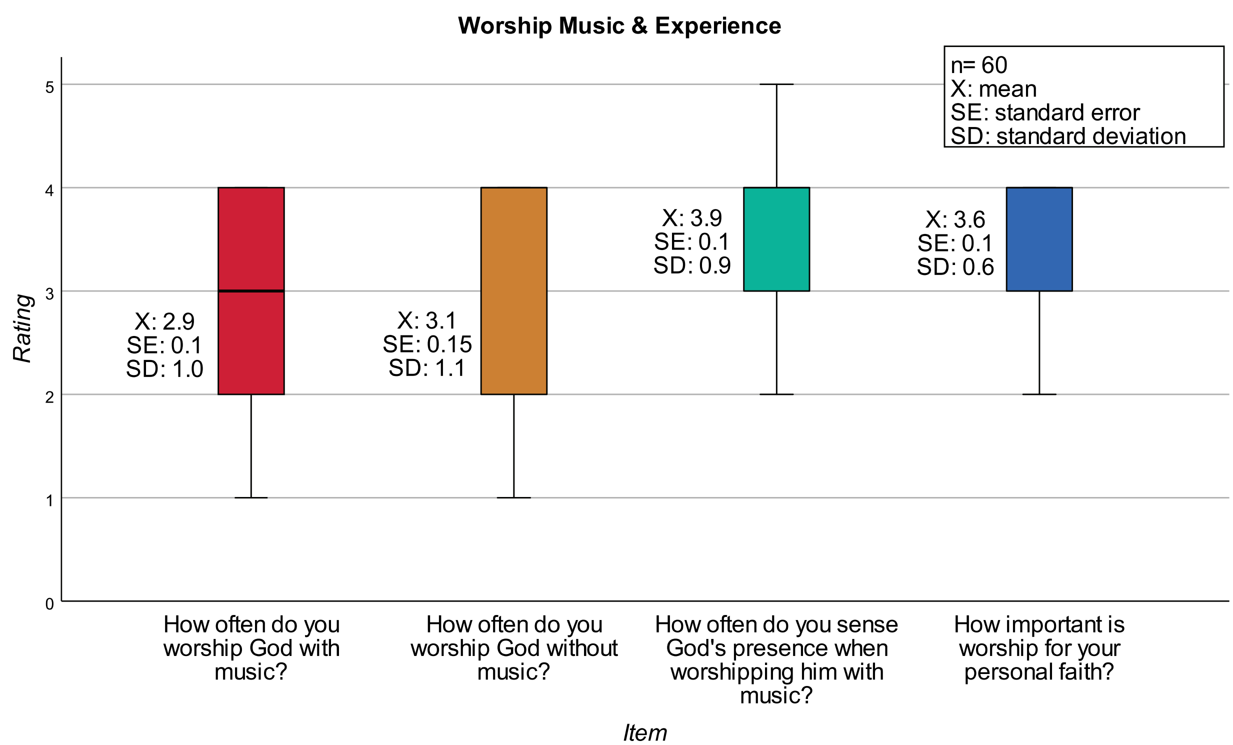

Figure 1. Box plots showing how the participants integrated worship into their faith lives and religious experiences. The rating 1 indicated the lowest value and 5 the highest one (ordinal values on a Likert scale).

[2]The responsible Swiss ethics committee is the one located in the Canton of Bern, meaning that the approval was provided by the Cantonal Bernese Ethics Committee (KEK Bern). Project ID number: 2021–00022.

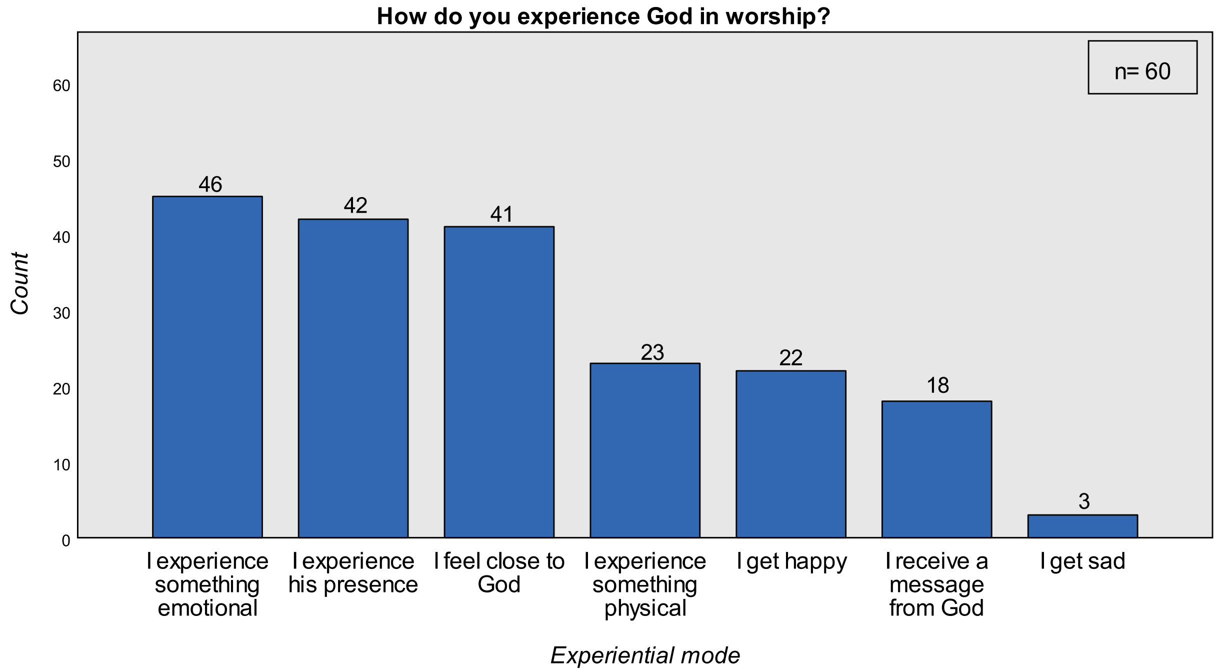

Figure 2. A histogram showing how the participants would describe the nature of their religious experiences during worship. Multiple answers were possible, and the bars refer to the importance of the mentions by the number of counts (i.e., how much the respective answer was ticked).

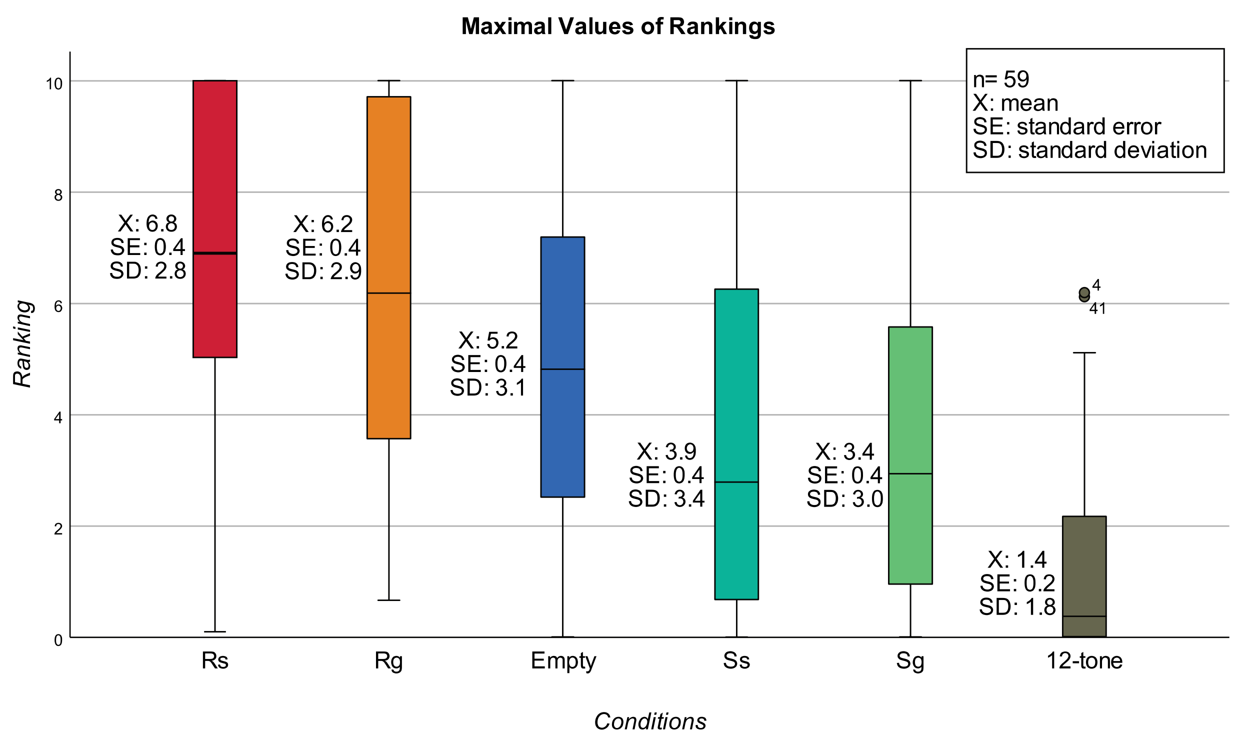

Figure 3. Box-plots showing how strongly they ranked their experiences of the divine during each condition (best visible when displayed with the peak experiences per condition). Conditions: Rs = religious subjective; Rg = religious given; Ss = secular subjective; Sg = secular given.

Table 2. 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 comparable but 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 in 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 have selected. This song was different for all individuals.
Secular given	Sg	Based on aforegoing interviews, the researchers selected a secular song that appeared to work well for the induction of the experience in the denominations of the present sample. This song was the same for all individuals and it was selected to evoke similar feelings to the Rg condition.[4]
Empty (or *blank*)	B	This was a 4.5 mins session where no music was played so that the participants had the opportunity to engage in worship and the experience with no musical guidance or distraction.
Twelve-tone song	S12	Since the religious experience was our phenomenological variable of interest, we wanted to increase the variability by introducing a dissonant song that made it hard for participants to focus on God, therefore dampening the experience.[5]

to try to induce the experience in each of the conditions, regardless of whether music was played or not. They knew that every condition consisted of a different song during which they had to worship, and that one condition did not contain any music. They did not know the purpose of the songs and they were not aware that one song was deliberately chosen to distract them with dissonant melodies.

The conditions were sound engineered to have the same volumes and longer songs were cut at natural breaks so that they lasted about 4.5 mins. Songs that were shorter were inserted with elements from the same song so that the track naturally sounded like it was longer (e.g., the verse was played twice but it was carefully engineered using the music software Audacity 2.4.2. to sound like this is meant to be).[4]

It can be seen from Table 2 that we had a balanced design based on an alternating block design. As there are always auditory stimulations in most experimental environments, there is also an auditory stimulation at play during the measurements. However, we have been careful in trying to make sure that the main variable of "experience" can be analyzed separately, which is, first, why we had a direct measurement of experience and not just practice (which was the case for previous studies), and (ii) we had different songs with secular and religious elements as well as musical variations, like an empty song with no music, a 12-tone song with disharmonic components and harmonic songs (religious and secular). It is visible in Table 3 that we have been successful in employing the musical tasks as to measure primarily the experience and not the musical effects. This can be seen when appreciating that the religious songs elicit the strongest experiences and that the empty song comes right after, even before the secular songs, which are musically similar to the religious ones. Hence, although the music helps in the induction process of the experience, it is not primarily the music but the experience that is measured here that can be correlated to the EEG data.[5]

Assessment

Before the experiments started, a short survey was completed to assess the demographic variables and to gain information about the faith and prayer lives of the participants'. For the experiment, there was a bar slider on the right-hand side and the subjects were asked to use it to continuously indicate how strongly they sensed God's presence during each experimental condition. Driving the slider to the very top means that one could not fathom a stronger intensity of the experience and driving it to the very bottom means that one does not sense God at all at the moment. After each condition, there was a sheet where participants were asked to mark how strongly they were able to focus on God.

During the conditions (in other words, in between the beep tones), the subjects had to close their eyes. For this, before the experiment started, they were able to familiarize themselves with their surroundings and used the slider with open and closed eyes so that they were able to use it without looking during the experimental conditions.

EEG data was assessed in a pre-experimental and an experimental phase. The pre-experimental recordings consisted of data acquisition with open eyes, closed eyes, blinking and horizontal eye movements. This was later used for the preprocessing of the EEG data. The

[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.

Table 3. Associations of the present microstate classes with potential source localizations.

Present microstate classes (cf., Figure 1)	Microstate maps by Custo et al. (2017)	Activations (Custo et al., 2017)
1	**A**	• Left temporal lobe (middle & superior) • Primary auditory cortex • Wernicke • Left insula • Left lingual gyrus
2	**B**	• Left & right occipital cortices (cuneus) • Primary visual cortex • Right insula (extending to claustrum & frontal eye field)
3	**C**	• Precuneus • Posterior Cingulate Cortex (PCC) • Left angular gyrus
4	**D**	• Right inferior parietal lobe • Right frontal gyri (middle & superior) • Right insula
5	**F**	• Dorsal anterior cingulate cortex (ACC; extending to superior frontal gyrus) • Bilateral frontal gyrus (middle) • Bilateral insula

experimental recordings consisted of the whole experiments, starting and ending with the resting state, the six experimental conditions and the concentration tasks.

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 active electrodes were placed with an elastic cap according to the international 10–20 montage system with Ag/AgCl gel. The hardware-defined recording reference was placed at the FCz location and the maximum impedance level was fixed at 20 kOhm. The sampling rate was 500 Hz and the EEG was amplified and digitized using two Brain Amps. A marker channel was introduced to trace the exact positioning of the onset and end of the experimental condition (characterized by the beep tones).

The raw data was pre-processed with Brain Vision Analyzer 2.2™. Preprocessing was performed in two steps (cf., C. Mikutta et al., 2012; C. A. Mikutta et al., 2014): (i) the creation of clean data, meaning that it was corrected for artifacts created by eye movement and muscular activity, and (ii) the creation of segmented data, which produced separate files for the different experimental conditions that was ready to use for our analyses. Both steps are elaborated on as follows.

First, the pre-experimental EEG recordings of each person was inspected for malfunctioning channels. If there were deficient channels, they were topographically interpolated. Then, the pre-experimental recordings were used to create an individual filter for eye movement and, at times, heartbeat artifact correction. For this purpose, the data was filtered using an infinite impulse response (IIR) band-pass filter between 1.5 Hz to 20 Hz and an independent component analysis (ICA) was applied to the pre-experimental data. The factors were inspected visually by observing them in their temporal dynamics and by screening their topographical localizations. Depending on their explained variance and contribution to the perceived artifacts, the factors were excluded and through an ICA inverse method, the raw data was recalculated. The reconstructed pre-experimental data was again visually inspected to make sure that the artifact correction worked. Based on the exclusion of the respective ICA factors, an individual spatial correction filter was created.

Second, the raw data of the experimental recordings was inspected for malfunctioning channels (by and large deficient channels were the same as with the pre-experimental recordings). In case of problematic channels, they were topographically interpolated. Next, the subject-dependent spatial ICA filter was applied to the experimental raw data, followed by a visual raw data inspection for each participant to mark places for exclusion where the muscle and movement artifacts distorted the experimental signals. Re-referencing was performed by recalculating the data to average reference. The revised experimental EEG data were then exported as “clean files”, which were first segmented according to the time stamps based upon the onset and offset markers for the experimental conditions (congruent with the beep tones). As such, only the experimental conditions survived in the clean files and the recordings of the distraction tasks were discarded. The clean files thus consisted of seven sessions per participant, where each condition formed one session and the two resting state recordings at the beginning and end of the experiments were fused to form one resting state session.

Microstate processing

The matlab toolbox EEGLab (Delorme & Makeig, 2004, updated version of Deolindo et al., 2021) was used to run an in-house microstate analysis script created to appropriate Brain Vision Analyzer output files. First, the data from each individual was read and band-pass filtered between 1–20 Hz, which is a standard choice in broadband EEG microstate analysis (Michel & Koenig, 2018). Second, the global field power peaks were considered to calculate a microstate cluster solution for each person. All solutions were calculated with a k-means clustering to form four to seven classes. Third, for each experimental condition, a mean solution of the clusters was calculated. This resulted in the *Grand Mean* map per condition. Fourth, for each set of clusters (four to seven clusters), the mean across all the conditions was calculated, resulting in an averaged map applicable to all conditions and persons. This resulted in the *GrandGrand Mean* solution per set of clusters. The topographical sequence was selected according to the normative neuroimage template by Koenig et al. (2002). Fifth, for each of the sets of microstate clusters, the clustering solution of the *GrandGrand Mean* maps was then applied to each experimental EEG recording, which means that per individual and experimental condition there was now information on the microstate clusters.

The relevant features for the present investigation were the *microstate duration* (how long was a given MS present when it occurred?), the *microstate occurrence* (how often did the MS occur per second?), the *microstate contribution* (how much percent is the brain in the given MS when all MS combined make up a hundred percent?), and the *mean Global Field Power GFP* (how many electrode sources are activated, or, how strong is the EEG signal at a given point in a given time on the scalp?).

Currently, it remains a delicate question in any microstate study of how to settle for the adequate number of clusters. Reducing the data to fewer numbers increases its generalizability and allowing for more clusters increases its justice toward specificity. Hence, the "the most appropriate choice for the number of cluster maps may not necessarily correspond to the 'true' number of clusters, but may instead result from a pragmatic compromise" (Michel & Koenig, 2018, p. 581), whereas the idea that there would eventually be a "true" number of clusters is a philosophical assertion that must not necessarily be correct. Many studies have settled for four clusters (Britz et al., 2010; Brodbeck et al., 2012; T. Koenig et al., 1999), albeit often to be comparable to other research. Whereas Seitzman et al. (2017) hold that fifteen clusters are needed to explain 80% of the variance, Tomescu et al. (2014) found that the same can be achieved with only four clusters. Another group found that choosing seven clusters can increase the explained variance to 84% across all subjects (Custo et al., 2017). A detailed literature discussion of clustering criteria by Michel and Koenig (2018) employed a derived meta-criterion taking a wide array of concerns into consideration, arguing that a number of five microstate maps optimally explained the presented data. Hence, following the call for a pragmatic compromise, in the present study we have decided to evaluate all four commonly used sets of clusters (four to seven microstate maps) and, if the sets do not conflict with each other, report the findings that explain the data the best on the level of the hierarchical multilevel analysis and in light of the available literature on religious experiences of this kind. Notwithstanding, the meta-criterion argument for using five clusters and the trade-off between specificity and generalizability provide us with an *a priori* preference for five microstate classes (Michel & Koenig, 2018).

Hierarchical multilevel analyses

The microstate data generated by EEGLab was exported and analyzed with IBM SPSS Statistics 27 through hierarchical multi-level mixed models analyses. The averaged ratings of the religious experience per condition were taken as the dependent variables. The conditions, the microstate variables of interest (e.g., duration) and the microstate classes served as fixed factors, whereas each microstate variable of interest times the microstate class (e.g., duration x MS 1, duration x MS 2, etc.) was inserted as a covariate. The model was controlling for random effects provided by the individual subjects, and it also accounted for interaction effects between the experimental conditions and the covariates.

The mixed models were operating on a type 3 sum of squares analysis as this is standard practice in comparable statistical operations. For each variable of interest, a separate model was calculated. This was due to the fact that the calculations of the models were codependent (for example, the feature contribution – under the operation of the type 3 sum of squares – can only be performed once the results from both the effects of duration and occurrence are known).

Results

Microstate classes

All four sets of clusters (microstate classes four to seven) were analyzed and show comparable results. There did not seem to be noteworthy discrepancies, indicating

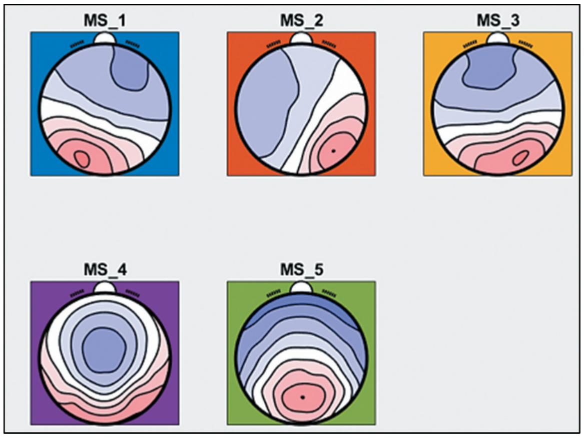

Figure 4. Topographic representation of the five microstate classes based on the EEG data of the worship conditions as generated by the overall GrandGrandMean.

that there was an inter-operability across the different sets of clusters, almost working like a magnifying glass where some sets point more strongly at the results than others. The most stringent results, when squared with the internal consistency, the statistical significance, and the conjunction to the literature, were found when applying five MS classes. This was in line with our *a priori* preference for five clusters informed by Michel and Koenig (2018) and their call for a pragmatic trade-off for best explaining the data and associations at hand. Figure 1 portrays the topographic representation of the five microstate maps.

Custo et al. (2017) have provided extensive research on source localizations of microstates. Upon visual inspection, our microstates (see, Figure 4) can be matched to their templates to fathom which brain structures could be involved with the networks that predict the religious experience. The findings are summarized in Table 4.

Associations with religious experience

Discussion

We investigated the large-scale brain networks involved in religious experiences, here operationalized as a state of mind concerning the sensation of God's presence during worship practices, which have now been analyzed in terms of quasi-stable networks called *microstates*. Based on an extensive review of neural correlates in religious cognition and emotion (Van Elk & Aleman, 2017), we hypothesized that microstates associated with multisensory integration and the default mode network (DMN) were correlated with the experience. The microstate involvements were measured in terms of their duration, occurrence, contribution, as well as mean GFP, and they were compared to the averaged values of the subjectively rated religious experience per condition.

In the present study, microstate class (MS) 1 showed a positive association with the ratings of the religious experience. This was strongly significant for duration as well as mean GFP, and almost significant for occurrence and contribution. There was a negative association between MS 3 and the experience, although only when considered by the mean GFP. The strongest predictor of the experience was found in the negative association with MS 5, which was strongly significant on all values (duration, occurrence, contribution, and mean GFP). No associations were found for MS 2 and MS 4.

In the literature, the four canonical microstate classes (maps A to D) have often been referred to as the visual network, auditory network, salience network and attention/executive networks (Britz et al., 2010; Smith et al., 2009; J. Xu et al., 2020). Custo et al. (2017) also identified microstate network activity in the precuneus, the PCC and ACC, which are said to be associated with the DMN. As such, these five networks correspond to our MS classes 1 to 5. We merged the notion of networks and the topographic activations (Custo et al., 2017). They were then matched with our MS classes (Figure 1 & Table 3) and with what is known about the neural involvement in religious cognition and emotion (strongly drawn from: Grafman et al., 2020; Van Elk & Aleman, 2017) in light of the present results.

Our first hypothesis assumed that the network for multisensory integration was at play. MS 4 is said to be associated with executive control and multisensory integration (J. Xu et al., 2020) and as such may be active in mystical experiences (Van Elk & Aleman, 2017). In our analysis, this network was neither a positive nor a negative predictor of the divine experience. Since we have hypothesized that this one is involved in the divine experience, this led us to reject our hypothesis 1. A reason for this may be that we have measured the religious experience directly and regressed it with the EEG data whereas previous studies have often used specific practices and tasks as a proxy for the experience. Hence, it could be that the multisensory integration network may be a task-specific activation pattern.

Our second hypothesis stated that there might be an involvement of the Default Mode Network (DMN) in the religious experience. Due to its connection to the precuneus, the PCC and the angular gyrus, MS 3 is believed to correspond to the DMN (X. Xu et al., 2016). The negative correlation of the mean GFP with the religious experience indicated that there appeared to be an association of the DMN with the experience. We can thus accept our second hypothesis, which stated that the

Table 4. Depiction of the results based on the hierarchical multilevel mixed models using Type 3 sum of squares. The Beta (B) is the non-standardized B-value. The df refers to the degrees of freedom. Significant results are bold. The association column shows if there are overall positive or negative associations of the microstate class to the religious experience. These are the associations *after* controlling for the effects from the experimental conditions, gender, and handedness on the religious experience.

Microstate class (MS)	Duration	Occurrence	Contribution[6]	Mean GFP	Association
MS 1	**df = 1, 384 F = 8.678 p = .003 B = 27.76**	df = 1, 384 F = 3.508 p = .062 B = 0.28	**df = 1, 387 F = 5.088 p = .025 B = 3.37**	**df = 1, 384 F = 21.202 p < .001 B = 1.94**	+
MS 2	df = 1, 384 F = 0.499 p = .481 B = −7.60	df = 1, 384 F = 0.256 p = .613 B = 0.07		df = 1, 384 F = 0.878 p = .349 B = 0.31	
MS 3	df = 1, 384 F = 0.01 p = .981 B = 0.07	df = 1, 384 F = 2.931 p = .088 B = −0.27		**df = 1, 384 F = 5.251 p = .022 B = −0.82**	-
MS 4	df = 1, 384 F = 1.072 p = .301 B = 9.56	df = 1, 384 F = 0.834 p = .362 B = 0.10		df = 1, 384 F = 0.390 p = .533 B = −0.20	
MS 5	**df = 1, 384 F = 8.912 p = .003 B = −20.42**	**df = 1, 384 F = 16.539 p < .001 B = −0.50**	**df = 1, 387 F = 10.041 p = .002 B = −3.50**	**df = 1, 384 F = 11.062 p = .001 B = −1.10**	-

DMN would be correlated with the religious experience in our sample. However, there is evidence suggesting that an association of a microstate might be inversely correlated with the activity of a specific network. If this were the case, a positive correlation would imply an inhibition of a given network and *vice versa* (Deolindo et al., 2021). Hence, it remains yet to be seen if the negative association with MS 3 means that there was an excitatory or inhibitory effect on the DMN.

There were also two unexpected findings that did not correspond to our hypotheses, which were found in an association of MS 1 and MS 5 with the religious experience. We have seen that MS 1 is a positive predictor for the experience in our experiment. MS 1 depicts the auditory network that is connected to the temporal brain areas (cf., Table 3). It has been said that they are involved with visions, hallucinations and déjà-vu experiences (Arzy et al., 2005; Cassaniti & Luhrmann, 2014; Coltheart et al., 2011; Fletcher & Frith, 2009). More importantly, the auditory network is associated with semantic storage, processing and retrieval, which has been described as a core neural constituent of religious beliefs (Grafman et al., 2020). It may perhaps be thought that this finding is a result of the prayer in worship, although for our present study the participants were asked to be still and worship solely in their minds with no singing or praying out loud. Nevertheless, inner speech may have an activating effect on the network and could explain the positive association with the experience.

The strongest predictor of a religious experience in worship was the downregulation of MS 5, which appears to correspond to the salience network that may involve the dorsal anterior cingulate cortex, the bilateral middle frontal gyrus and the bilateral insula (Table 3). There are three key points to be highlighted in this respect: (i) the general function of the salience network, (ii) its potential contribution to error monitoring mechanisms, and (iii) the mental inward-to-outward shift that the participants appear to experience during this religious state of mind.

First, the salience network has been suggested to be responsible for the processing of attentional information. More specifically, it is involved in the detection and screening of emotional, interoceptive and autonomic signals (Dosenbach et al., 2007; Hu et al., 2021; Menon, 2011). Hence, the weighing of interoceptive signals and the management of executive control may be central to the network. Second, its topography may be connected to error monitoring mechanisms (Grafman et al., 2020) and it has previously been found that religious beliefs and experiences reduce error monitoring activities (Good et al., 2015). As a consequence, the downregulation of error- and conflict monitoring is argued to be connected with the toleration of religious authority and rituals (Grafman et al., 2020; Van Elk & Aleman, 2017). Third, due to the nature of the present religious phenomenon, it may just as well be the case that the experience is associated with the increase of openness to new and extraordinary experiences (Walter, 2021). One may argue that a decrease in the salience network can be interpreted as a decrease in one's bodily representation (Britz et al., 2010) and emotional salience (Thu et al., 2010), which has been assumed to come at the cost of higher attention processes (Faber et al., 2021). The negative association in our results could imply that there is a shift from introspection to extrospection accompanying the religious experience. However, as already discussed with MS 3, there is evidence suggesting that an inverse correlation of a microstate with a network's cognitive function is at play – and this might also apply to MS 5 (Deolindo et al., 2021). Our data therefore indicates that there was a cognitive shift occurring through the salience network when the experience occurred, although we cannot determine in which direction the shift emerged. In any case, the finding that the salience network was involved with the religious experience of our participants was one of our most surprising results since we did neither expect nor hypothesize for it.

This leaves an ambiguous stance when comparing the present data with the literature. The results agree with the literature in the sense that we too have no evidence for any occipital or visual involvement in the religious experience (cf. the review by Grafman et al., 2020). We have hypothesized that the network associated with multisensory integration (MS 4) would be correlated with the experiential ratings (Van Elk & Aleman, 2017). However, we have no evidence for an involvement of the respective network.[6]

The negative association of the experience with MS 5 would square nicely with previous notions that religious cognition and emotion came along with reduced error monitoring (Good et al., 2015). The same is true for MS 3, the DMN. It has previously been stated that some religious experiences provoke the dissolution of the self and reflexiveness of religious beliefs which appear to be required for the attribution of religious ideas to the experience and involve the DMN (Van Elk & Aleman,

[6]The hierarchical multilevel analysis for the contribution only used MS 1 and MS 5 as covariate input variables due to the fact that all microstates add up to 100% of the contribution and cannot therefore be mathematically computed in one single mixed model. Since MS 1 and 5 were relevant in duration and occurrence, the model tested their effects on contribution.

2017). Nevertheless, due to the possibility of inverse correlation of the microstate with the network's cognitive function, the associations might turn out to be reverse (cf., Deolindo et al., 2021).

These findings may be helpful because they show that auditory and temporal networks appear to be involved in phenomenal states that activate the processing of beliefs and matching them to corresponding experiences that transcend the self. Nonetheless, self-referential mechanisms seem to be at play due to the recruitment of the DMN. Most importantly, we learn from this that such subjectively intense experiences may invoke a cognitive shift in attentional control, accompanied by a modulation of the salience network. This would be congruent with findings from previous studies dealing with the cognitive processes of religious experiences (Walter, 2021; Walter & Altorfer, 2022a, 2022b).

Conclusion

The present study investigated the large-scale activation patterns of religious experiences operationalized as sensing the presence of the divine through microstate analyses. We have no support for the first hypothesis, namely that the multisensory integration pathways are correlated with the religious experience in worship. In fact, we did not find an association of the respective MS 4 with the experience. The second hypothesis states that the same is true for the DMN. We found a negative association of the respective MS 3 with the experiential ratings, which means that the second hypothesis cannot be rejected since there appears to be an involvement of the DMN. Regardless of the directionality of the association, the correlation of the DMN with the religious experience suggests that the second hypothesis can be accepted.

Our results suggest that auditory and temporal networks are involved in a state of sensing God's presence, which is congruent with the notion that semantic processing play a role in religious cognition (Grafman et al., 2020).

It seems that not only the DMN was associated with the religious experience but also the salience network and its respective error monitoring mechanisms. The later was the strongest predictor of the experience, which came as a surprise since we did not hypothesize that it would play an interesting role during the worship process. For both of these networks, however, we cannot clearly settle on the direction of the relationship due to the possibility of inverse correlations (Deolindo et al., 2021). There was no evidence that the visual network was involved in the religious experience, which is congruent with previous studies on religious cognition that do not mention any involvement thereof (Grafman et al., 2020; Van Elk & Aleman, 2017).

Limitations & future research

The present study investigated a special state of consciousness through experimental procedures in the lab. This means that the participants had to engage in worship and try to connect with God in a different fashion than they are used to. Sometimes, body movements can be of use in the worship practice and a community can greatly facilitate the process. Normally, there is space to move, to stand, or sit down – basically, one can find the place and pose one pleases to get ready for the experience. The performed experiments are very artificial in contrast: every subject was alone, eyes had to be closed and any muscle movement was prohibited in order to avoid EEG artifacts and to make the results comparable to other studies.

Another problem is that there appears to be a plethora of possible religious experiences (James, 1902; Taves, 2009). We have operationalized a very specific and narrow selection of the phenomenological occurrences, which of course does not do justice to the diversity of occurrences in the real world. However, this is a first approach to an analysis based on large-scale brain networks (known as microstates) and we believe that it provides valuable insights into the nature of this specific experience and can give direction for future research in the area.

Future research should try alternative approaches to operationalize religious experiences, specifically the sensation of the divine, and perhaps find ways to probe more experiences than simply the sensation of God's presence. Spectral analysis and inverse solutions should be applied to such EEG data to receive more insight into the matter and to find possible source localizations of the signals that accompany such special states of consciousness.

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