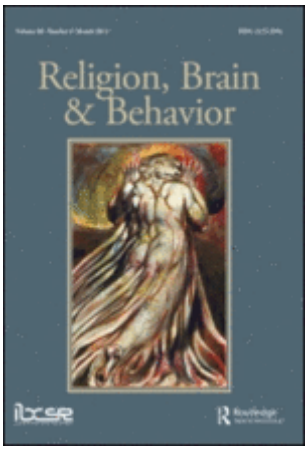


# Autonomous neural network activation during religious worship experiences using Heart Rate Variability measurements

| | |
|---|---|
| Journal: | *Religion, Brain & Behavior* |
| Manuscript ID | RRBB-2022-0059 |
| Manuscript Type: | Original Research Article |
| Keywords: | religion, worship, religious experience, heart rate variability, HRV, music |
| | |

# Autonomous neural network activation during religious worship experiences using Heart Rate Variability measurements


## Abstract

Previous studies have suggested that religious experiences in worship demand an attentional control that facilitates the desired state of mind and that there is a systemic activation of a person's peripheral physiology at play. We have hence constructed the present endeavor as a validation study and have hypothesized that the sympathetic nervous system (SNS) is activated during the experience. For this, 60 participants took part on an experiment with some religious and secular conditions where they worshipped God and indicated how strongly they sensed the presence of God. Electrocardiogram (ECG) measurements were taken to analyze the activity of the autonomous nervous network (ANS) through the heart rate variability (HRV) and to compare it to the religious experience. Our results show that there appears to be a recruitment of the SNS, which leads us to accept our working hypothesis. However, there is a negative association of Baevsky's stress index (SI) with the experience, suggesting that the parasympathetic nervous system (PNS) is co-recruited, although to a lesser degree and it is dominated by the SNS.


Keywords: religion, worship, religious experience, heart rate variability, HRV, music

## Introduction

### *Religion and experience*

In the 20th and 21st century, there have been various axiomatic paradigms by which religious ideas have been conceptualized. One evolutionary notion is that religion could be conceived as a cognitive byproduct that has emerged in the struggle of survival, attributing agency to external entities in a generous fashion (Kress, 1993). Shortly after, Pascal Boyer (1994) has suggested that religious mental concepts could be characterized by *minimally counterintuitive concepts*. By this he means that there are ideas that are somewhat counterintuitive but only slightly so that they are believed by a large amount of people. An example would be that spirits could possess a person. In ordinary life, most people are not under the impression that humans are governed by ghosts and invisible personal forces. However, if some strange behavior otherwise seemingly inexplicable could be deemed as the action of an evil spirit, then this idea may be slightly counterintuitive but not counterintuitive enough as to be discarded right away. The notion was supplemented by suggesting that humans might have a *Hyper Active Agency Detection Device* (Green, 2015), which is a fancy word for saying that perhaps our species may be prone to detect personal agency where perhaps there is none. Hence, trees, stones and otherwise inanimate objects become spirited subjects that can be related to on a personal level. This, too, is an evolutionary idea fathoming that it would be more costly to our survival if we missed some signals of agency than seeing too much of it in the outside world. More recent paradigms have gone the way to see religion as a system of prosocial adaptations useful for building communities and societies (Batara et al., 2016). Underlying these paradigms we find a definition of religion as a reference to mental representations pertaining to cognition and emotion connected to beliefs in supernatural powers, sometimes perceived as sacred or inviolable (Bulbulia & Sosis, 2011). As suggested by some scholars of religion (Byrne, 1999; Molendijk, 1999; Platvoet, 1999), this is a pragmatic definition of religion, which is also useful and employed in a biocognitive study such as the present one.

*Religious experience* is a derivative construct of religion and one that already a century ago has been dubbed a fundamental human state (James, 1902). But finding an adequate conceptualization thereof is a difficult undertaking because it is often used as a fuzzy term, which creates a problem for both its validity and interoperability. Thus it has been called “the problem of religious experience” (Jones, 1972). Conceptually, there have been two popular

approaches to frame religious experiences, namely the *sui generis approach* and the *attribution approach*.

*Sui generis* literally means a class in and of its own, meaning that such experiences carry a unique phenomenal quality with them. So, whenever this specific quality is present in the experience, the occurrence automatically becomes a religious experience (Eliade, 1960; Pals, 1987; Studstill, 2000). In a qualitative study about religious worship experiences (Walter, 2021), some participants have referred to this as a "sixth sense" that cannot be reduced to some other senses. This means that the experience is not just a matter of interpretation but that it is something wholly different, or, an experience as a class of its own ("sui generis"). The *attribution approach* claims that the exact opposite is the case, namely that there is nothing inherently unique in these experiences on a phenomenological level. Rather, it has to do with interpretation mechanisms that conceive of certain occurrences as being very different from the rest of them. These "special" experiences that are deemed "special enough" are singled out from the sea of daily events and they demand some further attentional control (Walter & Altorfer, 2022b). Ann Taves (2005, 2009, 2011, 2020; Taves et al., 2019), a psychologist of religion, is one of the leading proponents of this approach and has termed the process of *singularization* since it holds that special occurrences are singled out and set apart from the rest. Once such an event is singled out, it can be connected to already held religious beliefs and can therefore be deemed religious. This is how religious experiences are established cognitively by modes of ascription and attribution, according to the *attribution theory* (Barnard, 1992; Hermans, 2015; Taves, 2011). Although these two approaches seem to be exclusive accounts of the emergence of religious experiences, there have been attempts to argue that they might also be two ends of a spectrum, where sometimes there are inherent qualities that cannot be reduced but in any case there needs to be an attributive act of interpretation (Walter, 2021).

### *Music and induction of religious experiences*

Dealing with experiences in the religious domain means that one is often tackling a phenomenon that is deemed a central and deep occurrence for the believers themselves. At its core, it is an event where a person believes to be in direct contact with the divine or a supernatural plane of existence (Andresen, 2001; Badham et al., 2008; Bowie, 2003; Boyatzis, 2001). Often, it is perceived as a rather spontaneous experience, which is why researchers in the lab are confronted with the challenge of how to reliably induce the desired state of mind. Unfortunately for the researchers, one cannot simply count to three and tell the believers to

start having a divine experience, like for example, feeling the presence of God. It works more spontaneously than that. So, there needs to be a way of sensibly creating the right atmosphere through adequate environmental conditions so that an induction of the experience is possible. Apart from selecting the right sample for this, which is a natural prerequisite for a study like this to work, there are two methodological elements that need to be considered. The first is the distinction between practice and experience; and the second is the induction that appears to be favored by carefully selected musical conditions.

First, let us turn to the experiential dimension. It has been shown through validated psychological constructs that practice is not the same as experience, although they may be linked and can be used to positively influence each other. The construct system known as the *centrality of religiosity scale CRS-15* maps religiosity on to five dimensions: public and private practice, ideology, intellect, and experience (Huber & Huber, 2012). This shows that practice and experience are two conceptually separate things that need to be considered as set apart and one has to be aware of the fact that they are not the same thing. Most previous studies dealing with religious experiences have not taken this into account with due care. They have let the participants perform certain religious practices and then they have analyzed the behavioral and biometric responses. This approach is valid if one simply wanted to measure the effect of the practice on the person but not if one is more interested in the effect of the religious experience. For this, one actually needs to *measure* the religious experience *directly*. Here it becomes necessary to respect the finding that practice and experience are not the same, however researchers can make use of the notion that the former may help with the induction and experimental manipulation of the latter. This way, a religious practice may be used to elicit a religious experience and so then the two can go hand in hand. If the conditions are selected carefully, one can then be sure that one is measuring in fact the experience and not primarily the practice, even though the two may influence each other (for more on this, see Walter & Altorfer, 2022b).

Second, it is worth noting that there is one practice that – given the right sample – was shown to work quite well for igniting the desired state of mind, which is extremely useful when performing an experimental study on the subject. This is the link between worship, music, and divine encounters[1]. It has been shown that in religious worship practices with the help of

[1] This study makes no claim about the existence or non-existence of God or otherwise divine, spiritual, or supernatural entities. The language that is used here to denote such ideas are purely employed as a reference to the mental concepts from the emic perspectives of the believers recruited for the current study.

music, these so-believed "encounters with the divine" are frequently reported and deliberately sought after. This appears to be especially true for evangelical Christians with the experience of sensing the divine or the presence of God (Walter, 2021). One author has even claimed that that music is a form of "trigger" for such events (Demmrich, 2018).There are many authors suggesting that music can provide a link between active practice and religious cognition/emotion (cf. Andrews, 1916; Brehm Center, 2017; Bubmann, 2009; Ingalls, 2016; Nusbaum & Silvia, 2011; Porter, 2016; Schumaker, 1995; Zweigenhaft, 2008), amongst which we even find some of the old 'classics' of psychology and religious studies (James, 1902; Otto, 1917). Hence, on several occasions music was referred to as a link to extraordinary and religious experiences (Argyle, 2000; Boyce-Tillman, 2006; Demmrich, 2018; Hills & Argyle, 1998; Ingalls, 2016; Miller & Strongman, 2002; Schumaker, 1995).

We can learn from these considerations that religious experiences should be measured on their own and that worship practices with the help of music can help to induce the state of sensing the presence of God. This has four implications for the present study:

i. An employment of direct measures for religious is advised. As seen in the methods section below, we have taken action on this by letting the participants continuously rating their religious experiences during the experience on a bar slider.
ii. Asking participants to report their individual sensations of God's presence appears to be a practical and useful way for the construct operationalization of the religious experience.
iii. Carefully selected worship conditions facilitated by music can help induce and manipulate the desired experience for the experiments in the lab. This was a major focus for constructing the study design.
iv. The participants need to be able to induce the religious state of mind and therefore have to be recruited from an environment with the respective background for this task. Hence, the sample was recruited from a specific population of evangelical Christians from whom it was known that they could conform to these prerequisites (which means they have been recruited from the same churches and were asked beforehand if they could feel the presence of God during their worship practices and could presumably do so even under sterile lab conditions).

There is one theoretical model that was foundational for the construction of the experimental design with the focus on religious worship experiences with music. This is the so-called *Feedback Loop Model for Religious Experiences in Worship*, which has been the result of a qualitative study with worship experts conducted beforehand to help establishing the present experimental design (Walter, 2021). The model effectively states that the right environmental conditions such as the right selection of music can lead to a mental stimulation that aids the believers to focus on God. This focus on God, then, helps them to engage in the religious experience, which may eventually have a self-propagating effect because the stronger the

experience becomes, the more intense the focus on God turns out to be, and so forth. This effect between the focus on God and the experience of sensing the divine has been independently validated by a subsequent experimental and statistical analysis (Walter & Altorfer, 2022b).

***Biopsychology of religious experiences***

Historically, ethnographic means were used to study religious experiences (Bowie, 2003). However, a wider range of disciplines have begun to be interested in researching special states of mind and putting an emphasis on such experiences. Apart from ethnologists and anthropologists, among others, also psychologists, cognitive scientists and biomedical researchers have become interested in these phenomena (Andersen et al., 2014; Azari et al., 2005; Beauregard & Paquette, 2008; Bender, 2010; Braun, 2011b, 2011a; Collins & Scott, 2019; Hordern, 2016; Jensen, 2003; McNamara & Butler, 2013; Paloutzian & Park, 2013; Rosado Nunes, 2001; Schnabel, 2018; Walter et al., 2020).

The neuroscientific study of religious phenomena is not new, but it is still scarce. However, it has been strongly popularized by Andrew Newberg in coining the term *Neurotheology* (Newberg, 2010, 2018). Even before him, there have been controversial figures that have gained a lot of medial attention by claiming that they could experimentally produce a religious experience by employing an electromagnetic "God helmet". The main protagonist was Michael Persinger who was known to generate some provocative headlines with this type of research (Cook & Persinger, 1997; Persinger, 1983; Persinger & Healey, 2002). Nevertheless, a follow-up study from Sweden was not able to replicate Persinger's "God helmet" findings (Granqvist et al., 2005).

As the literature has been slowly growing, there have been attempts to draw the findings together in a theoretical framework that connects the biological data with cognitive concepts on the phenomena of religious cognition and emotion. One valuable approach is found in a review paper by van Elk and Aleman (2017) who made use of the cognitive idea known as *predictive coding* and located it in Ann Taves's singularization theory of ascriptive and attributive mechanisms (as discussed above, see Taves, 2011). A few years before, Taves and Asprem (2017) linked the two models – predictive coding and Taves' attribution theory – to better explain how the creation of religious experiences might occur on a cognitive level. In short, the idea holds that there is a differential weighing of interoceptive and exteroceptive signals that need to be harmonized in a cost effective fashion as to reduce potential cognitive

dissonances. This occurs via a trade-off between top-down and bottom-up processes. An example may be in order to explain the idea: if a person thinks to be seeing someone else walking through a wall, it creates a cognitive dissonance because one is usually aware of the notion that people do not simply walk through walls. This dissonance can be easily and cost-efficiently resolved by adopting the mental concept (i.e. the religious belief) that in rare circumstances, spirits or ghosts can walk through walls. Hence, if the believer sees someone going through a wall, he or she may hold that this must have been a ghost and then the dilemma is resolved without much attentional effort (which is what the term "cost-efficient" intents to imply here). These mental concepts become especially relevant when experiences are perceived as too special to be ordinary, thereby becoming candidates that could transform into religious experiences in case they are framed with these religious mental top-down concepts (Taves, 2005, 2011; Taves & Asprem, 2017).

Based on this, a review by Grafman et al. (2020) focusing more strongly on the neurological mechanisms involved in religious cognition and emotion, has highlighted several key brain networks:

- Theory of mind: rationalizing God's intent and emotions
- Cognitive control: down-regulating supernatural interpretations of unusual experiences
- Semantic processing and storage: retrieving religious beliefs stored in semantic and episodic memory
- Reward and evaluation: evaluating established or newly acquired religious beliefs
- Multisensory integration: spiritual transcendence
- Conflict detection: detecting conflicts between religious beliefs and task stimuli or demands

***Autonomic nervous system in the psychology of religion***

Heart rate variability (HRV) provides an indirect glimpse into the autonomic nervous system (Cygankiewicz & Zareba, 2013), which is characterized by a continuous trade-off between two forces governing our bodies' system of alertness: an activating force known as the *sympathicus* and a soothing force called the *parasympathicus*. The underlying dynamics thereof are driven by several factors, such as signals from the brainstem as well as baroreceptors measuring blood pressure (Dick et al., 2014) that are influenced by both a person's physiology and psychology (Laborde, 2016). Due to the fact that the psychological predispositions and mental states are correlated with the HRV, there are "heart-brain connections" that produce detectable oscillations (Thompson et al., 2015). This makes it possible to even classify a person's sleep cycles with stunning accuracy through simple electrocardiogram (ECG) machinery that has traditionally required the use of more complex

electroencephalogram (EEG) systems (Ako et al., 2003; Dumont et al., 2004; Radha et al., 2019; Zhuang et al., 2005). Hence, patterns that were previously only detectable with brain scans can now also be seen through HRV measurements via ECGs.

Although the literature on the neurology of religion is slowly but gradually growing, to date not much is known about the involvement of the autonomic nervous system in religious cognitive processes. One study took a look at the neurophysiological correlates of religious chanting and tried to see if the delta oscillations measured on the scalp might correlate with cardiac activity or with the respiratory rate – which was not the case (Gao et al., 2019). Another study showed that mindfulness training improved the cardiac sympathovagal balance (Nijjar et al., 2014). A Muslim prayer study yielded an increase in high frequencies (HF) of the HRV as an effect of the prayer practice (Doufesh et al., 2014), although it has been criticized that the experiment used resting state instead of a sham-prayer condition as the control (Gao et al., 2019). One review paper held that not only does prayer in general appear to be good for cardiac health, but it also seemed to be associated with an increase of parasympathetic and a decrease of sympathetic nervous system elements (Tolentino, 2019). The author equally states that parasympathetic involvement seems to be dominant when correlated with measures for religiosity and spirituality. Another study performed with a purely female sample did not agree with this since it showed that the women in prayer portrayed an elevated heart rate (HR) and respiratory rate (RR) but the authors held that this was likely dependent upon the level of personal religiosity and spirituality (Riklikiene et al., 2019). Another rather exotic study examined around thirty elderly people (all were older than 80 years) and let them listen to a sermon for 30 mins for over 20 months while measuring the ECG and compared them to a non-sermon-listening control group. The high frequencies (HF) as well as the pNN50 (a measure of how often the heart rate was larger than 50 ms) of the HRV were higher in the sermon-listening group, whereas the control group had a higher LF/HF ratio (Kurita et al., 2011).

As seen from this, the evidence on the autonomic nervous system and religious cognition or emotion is rather eclectic with no clear message. To date, there is only one study that has directly measured subjective ratings of religious experiences and compared them with elements from the autonomic nervous system (Walter & Altorfer, 2022a). This is a recent study that has reported the RR and HR as a function of the sensation of the divine. There it was found that the religious experience was positively correlated with the HR and the RR. The same was true with the focus on God, which was also positively correlated with the HR

and RR. It was followed from this research that the physiological system of a believer "speeds up" and gets activated upon the religious worship experience. This is an interesting finding and suggests that probably the sympathetic nervous system is the dominant force behind this mental state, which is a suggestion we can use as a hypothesis in the current study.

### *Research aim and hypothesis*

The previous reports about the systemic activation upon a religious experience are both interesting and informative (cf. Walter & Altorfer, 2022a). They are also unprecedented because direct measures of ratings for the religious experiences have never before been used to contemplate their effect on the experience of sensing the divine. However, the publication had two major shortcomings: first, the reported HR and RR results are all within the normal and expected range (cf. Schewior-Popp et al., 2017), which means that slight changes may be indicative but are not very robust. Second, while the study may tell us something about a general systemic activation based on peripheral physiology, it does not provide us with a more nuanced picture about the autonomic nervous system involvement.

We therefore believe that a follow-up study is needed to validate the previous results through HRV analyses and to shed more light on the involved autonomic nervous processes. The present paper is therefore a confirmatory validation study with the intent to provide further knowledge about the role of the *sympathetic* and *parasympathetic nervous systems* for the currently investigated religious experience. As outlined above, previous research indicated that the biological system of a believer "speeds up" upon a religious experience. Since the peripheral physiology was positively correlated with the subjective ratings, we hence hypothesize that the religious experience is positively associated with the sympathetic nervous system (SNS).

## Materials and Methods

### *Participants*

Evangelical Christians has been a favored cohort for studies in the lab due to their strong focus on subjective experiences and comparable views around such states of mind (cf. Bialecki, 2009; J. Bielo, 2009; J. S. Bielo, 2011; Cannell, 2006; Engelke, 2007; Harding, 2018; Jenkins, 2012; Keane, 2007; Robbins, 2003, 2007). Therefore, the present study has deliberately selected an evangelical sample of Christian believers. An additional reason for this was that our team already had access to this cohort, which rendered the recruitment process much more feasible.

We hence recruited 60 participants from evangelical churches and all of them were required to be proficient worshippers. They had to be confident that they were able to induce the desired state of mind under lab conditions and needed to be frequent experiencers of the sensations of the divine during their worship practices (preliminary talks were had beforehand in order to secure this). They were on average 27 years old (SD 4.22; min 19; max 40) and the gender ratio was roughly comparable (45% male; 55% female) whereas the majority was right-handed (87%). 70% of the participants said that they played an instrument at least once per week. The highest education was distributed evenly among them (22% had a master's degree; 23% a bachelor's; 22% went to high school; and 33% had undergone an apprenticeship).

Written informed consent was provided before the experiments started and an array of questions about their personality and prayer life was obtained. In order to exclude any interference of a person's hearing capability, a hearing test was applied beforehand. The study was approved by the local ethics committee.[2]

Due to strong artifacts and initial measurement problems in the experiment, four participants had to be discarded from the data pool.

***Experimental design***

The experiments lasted about one hour per person and it was split into several conditions, each about 4.5 mins long. The beginning and end were always resting state conditions where the participants are advised to close their eyes and relax. All the other conditions were randomized across participants and separated by a time-free letter task, which was a carefully designed concentration task where they had to memorize some letters. The whole point of the letter task was to disrupt the person's state of mind after the previous condition so that there was no spillover effect from one condition to the next. This enabled us to treat the conditions as independent observations. In order to create an interesting variance in the experiential ratings, two religious, two secular and two control conditions were devised. The religious and secular conditions each had a song the participants selected themselves and one that the researchers provided. This was due to an ongoing discussion about whether it makes more sense to induce a state of mind through songs provided by the researchers or brought along by the participants. The first may increase the standardization and the second may increase the

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

validity (as discussed and employed in Walter & Altorfer, 2022a, 2022b). As such, our team has decided to implement both approaches as to maximize the benefits. The task description was the same for every condition (except for the resting state), namely to worship God and to try to induce the state of sensing the presence of God as best they could. The conditions are described in Table 1.

**Table 1.** Summary of the experimental conditions.

| Acronym | Name | Description |
|---|---|---|
| $C_{RS}$ | *Resting state* | A session where participants were asked to close their eyes and relax. |
| $R_G$ | *Religious given* | This was a religious worship song provided by the researchers. The song was the same for all participants and well known in the respective community. We selected the song *Reckless Love* by Cory Asbury (2017, Bethel Music). |
| $R_S$ | *Religious subjective* | This was a religious worship song that the participants brought along themselves. This song was different for each subject and had to be one that had a known track-record of helping them to induce the desired state of mind. |
| $S_G$ | *Secular given* | This was a secular song that was deemed to be equally popular and with similar emotional qualities as the $R_G$ condition (as was discovered in a previous qualitative research, see Walter, 2021). This song was the same for all the participants. The song *Lose you to love me* by Selena Gomez (2019, Interscope) was selected. |
| $S_S$ | *Secular subjective* | This was a secular song that the participants brought along themselves. As a consequence, it was different for each participant. They were required to select a song that they thought was comparable to the $S_S$ condition. |
| *B* | *Empty (or: blank)* | This was a 4.5 mins session where no music was played but the participants had to worship and induce the experience nonetheless. |
| *S12* | *Twelve-tone song* | This was a disharmonic opera tune that was deliberately selected to throw the participants off guard because it was deemed to be difficult to concentrate. This song was the same for the whole sample and for this, the song Pierrot Lunaire by Arnold Schönberg (1874-1951, Op.21: No. 1-4, Mondestrunken, Columbine, Der Dandy, eine blasse Wäscherin) was selected. |

The resting state consisted of two separate conditions but they were fused together and treated as one by adding the values of both and dividing it by two (thus, taking the average of them). For each condition, the participants were asked to sit still and close their eyes as to avoid any muscular artefacts and to make it comparable to the other participants

The songs were cut at natural breaks and engineered to end at about 4.5mins. The songs that were longer were reduced to this length and the songs that were shorter were made to start anew with a sound engineering tool (Audacity 2.4.2.) so that it naturally sounded like it did not finish at the original end. Eventually, all conditions were made to last for about 4.5 mins.

***Construct operationalization: measuring the religious experience***

There was a specific type of religious experience that was measured during the experiment, namely the experience of the sensation of the divine, which was deemed as an encounter with God by the believers. This was operationalized through a bar slider on the participants' right-hand side associated with the question: "How strongly do you sense the presence of God at the moment?" Depending on how strong they deemed the experience to be, they could move the cursor upwards or downwards. If they moved it all the way to the top, it meant that it was as strong as they could possibly imagine. Moving it all the way to the bottom meant that they did not sense anything of the sort. These values could then be correlated with the biometric measurements. For each of the conditions except for the resting state (and also the letter tasks), the participants were asked to move the slider.

***Recording and pre-processing of the biometric data***

A typical electrocardiogram ECG with three electrodes was used to measure the heart rate activity. Two electrodes were placed left and right above the heart and the grounding electrode was applied below the chest, usually slightly diagonally moved (to the left and to the top from the participant's perspective) from the belly button. The heart rate was carefully checked before the experiments began in order to make sure that the device was measuring the rhythm correctly. For this, the gain had to be adjusted per individual as to have the correct measurement threshold. The data was recorded and stored to Lab Chart, which displayed the heart rate as raw data points but also converted it to cyclic variables. The heart rhythm was recorded at 4000 Hz.

Eventually, the data had to be translated to variability metrics for which a program known as Kubios HRV 3.3 was used. After visual inspection of the cyclic variables to confirm that all was in order. In a standardized and already automatically implemented process in the program, the raw data were imported to Kubios and then processed to yield the values necessary to analyze the heart rate variability (HRV). This was done for each participant per experimental condition. The resulting HRV metrics were then summarized in a unified table file so that they could be used for statistical operations. There were four clusters of variables

that were considered for the present analyses: general indices, time-domain results, frequency-domain results, and nonlinear results. The HRV variables under consideration for the religious experience are summarized in Table 2.

**Table 2.** Summary of the calculated heart rate variability (HRV) variables that were considered for the statistical analyses.

| Domain | Variable | Description |
|---|---|---|
| General indices | PNS index | A derived index reporting on how strongly the parasympathetic nervous system (PNS) may be involved in the condition. |
| | SNS index | A derived index reporting on how strongly the sympathetic nervous system (PNS) may be involved in the condition. |
| | Stress index | A calculation based on a function of the HRV up- or downregulation to portray how strongly the autonomous nervous system appears to be activated during the condition. |
| Time-domain results | Mean HR (beats/min) | The mean heart rate during the condition, measured in beats per minute. |
| | Min HR (beats/min) | The minimal heart rate during the condition, measured in beats per minute. |
| | Max HR (beats/min) | The maximal heart rate during the condition, measured in beats per minute. |
| | RMSSD (ms) | Root mean square of successive NN (inter-beat) interval differences. This is a difference-based index strongly influenced by the PNS activity and thus often used to estimate the vagally mediated fluctuations in HR (Ciccone et al., 2017; Shaffer et al., 2014; Task Force, 1996). |
| | NNxx (beats) | Absolute number of successive NN (inter-beat) interval differences larger than 50 ms. |
| | pNNxx (%) | Derived measure of NNxx, which is the proportion of successive NN (inter-beat) interval differences larger than 50 ms. |
| | SDNN index (ms) | Mean of the standard deviations of NN (inter-beat) intervals in 5 mins segments. |
| Frequency-domain results | VLF (log) | *Very low frequency:* Logarithmic function of the power spectrum in the frequency range of 0.0033 – 0.04 Hz. |
| | LF (log) | *Low frequency:* Logarithmic function of the power spectrum in the frequency range of 0.04 – 0.15 Hz. |
| | HF (log) | *High frequency:* Logarithmic function of the power spectrum in the frequency range of 0.15 – 0.4 Hz. |
| | LF (n.u.) | Normalized units for low frequency. |
| | HF (n.u.) | Normalized units for high frequency. |
| | LF/HF ratio | Ratio of low frequency to high frequency power. |

| | | |
|---|---|---|
| Nonlinear results | SampEn | *Sample entropy:* Estimation of complexity measured as a degree in dispersion. |
| | DFA α1 | *Detrended Fluctuation Analysis (DFA), alpha-1:* Short-term fractal measure of complexity assessed by the correlations between successive NN (inter-beat) intervals at different time scales (anywhere between 4-16 heartbeats). It is a measure of the degree of the correlation for the data points within the time frame. It is therefore an indication of the homogeneity of the signal. The short-term correlations (alpha-1) correspond to the baroreceptor reflex (Echeverría et al., 2003; Gronwald & Hoos, 2020; Peng et al., 1995; Penzel et al., 2003; Shaffer & Ginsberg, 2017). |
| | DFA α2 | *Detrended Fluctuation Analysis (DFA), alpha-2:* The same as alpha-1 but for long-term correlations (anywhere between 16 to 64 heartbeats), which corresponds to regulatory mechanisms in the cardiac system (Shaffer & Ginsberg, 2017). |

The ECG data was prone to generate movement and measurement artifacts and thus after consolidation of the data in a unifying data set, an outlier detection and elimination for each of the HRV variables was performed. Outliers were calculated and removed via a standardized algorithm: the acceptable range of values was defined as the interquartile range IQR (which is the third quartile $Q_3$ minus the first quartile $Q_1$) and multiplied by a factor of 1.5 to generate the upper and lower limits. All values that exceeded this upper limit ($Q_3 + IQR \times 1.5$) and the ones underscoring the lower limit ($Q_1 - IQR \times 1.5$) were counted as outliers and thus replaced by the next nearby values within the accepted range.

***Statistical models***

The preprocessed data was eventually imported to IBM SPSS Statistics 27 to do three steps of statistical analyses. In a first step, a visual inspection of the data showed how the individual HRV variables behaved and if there were certain tendencies to be seen. Most importantly, this was done to make sure that we did not miss any relevant outliers and that the biometric data were normally distributed. In a second step, parametric Pearson correlations were performed using the maximal ratings of the religious experience (which corresponded to the peak experience per experimental condition for each subject) and comparing them to the relevant HRV variables. The analyses were done subsequently, clustered by domain of the variables, with each further domain expecting to get a clearer picture of the SNS or PNS activation upon the religious experience. Hence, there were several correlation analyses undertaken:

- Comparison of the maximal religious experience ratings with the general indices (PNS index, SNS index, stress index).
- Comparison of the maximal religious experience ratings with the time-domain results (mean HR, min HR, max HR, RMSSD, NNxx, pNNxx, SDNN index).
- Comparison of the maximal religious experience ratings with the frequency-domain results (logarithm of VLF, LF and HF, as well as normalized units of LF and HF, and the LF/HF ratio).
- Comparison of the maximal religious experience ratings with the nonlinear results (SampEn, DFA α1, DFA α2)

In a third step, we intended to strengthen the findings by respective regression analyses. Based on the results from the second step, it was deemed valuable to create two regression models to better understand the associations found in the correlational analyses (as depicted in Table 3).

**Table 3.** Regression models to further disentangle the associations between the HRV data and the religious experience.

| Regression model | Fixed factors | Dependent variable |
|---|---|---|
| 1 | SNS index | Religious experience (maximal ratings) |
| | PNS index | |
| | Stress index | |
| 2 | LF (log) | Religious experience (maximal ratings) |
| | HF (log) | |

## Results

### *Visual inspection*

The visual inspection showed that the biometric data was normally distributed and that no relevant outliers have been missed in the preprocessing. The data was therefore deemed fit for the subsequent statistical operations.

### *Correlation models*

As noted in the methods section, the peak religious experiences (maximal ratings) were compared with the domain-specific HRV variables. The results can be retrieved from table 4, which only reports the statistically significant associations.

**Table 4.** Results from the Pearson correlations between the religious experience and the HRV variables (the table shows how strongly each of the HRV variables corresponds to the maximal ratings of the religious experience). Only significant results are reported.

| Domain | HRV Variable | Significance | Correlation |
|---|---|---|---|
| General indices | PNS index | .028 | -.120 |
| | SNS index | .011 | .138 |
| Time-domain results | Mean HR | .004 | .159 |
| | Min HR | .034 | .115 |
| | Max HR | .020 | .126 |
| Frequency-domain results | LF (n.u.) | .015 | .133 |
| | HF (n.u.) | .015 | -.133 |
| | LF/HF ratio | .024 | .123 |
| Nonlinear results | SampEn | .002 | -.168 |

***Regression models***

In order to better understand the dynamics depicted with the correlations in Table 4, the following Table 5 is supposed to unify the general indices and the frequency-domain results in two separate regression models. No significant model was found for the time-domain results.

**Table 5.** Regression models for the HRV variables as influences on the religious experience. The effect size is displayed in form of the standardized Beta. Only statistically significant results are included, barely significant results are displayed in italics.

| Regression model | HRV variable | Beta | T-value | significance |
|---|---|---|---|---|
| 1 | SNS index | .451 | 2.994 | .003 |
| | Stress index | -.302 | -3.667 | < .001 |
| 2 | LF (log) | .180 | 2.679 | .008 |
| | *HF (log)* | *-.129* | *-1.922* | *.055* |

The ANOVA for the first model is strongly significant, $F(3) = 6.761$, $p < .000$, and the one for the second model is not as strongly but still adequately significant, $F(2) = 3.674$, $p = .026$.

**Discussion**

In a previous study, it was found that upon a religious experience in worship, there was an activation of the peripheral physiological system of a believer's body, characterized by an increase in the respiratory and the heart rate. This suggests that perhaps the sympathetic

nervous system might be strongly involved in this special state of mind, which has therefore been posed here as the key hypothesis in the current paper. Hence, in the present study we have set out to see if we can validate this assumption through analyses that allow to make more direct statements about the autonomic nervous system activation. This can be done with measurements of a person's heart rate variability (HRV) and its derivative calculations that are used frequently for health as well as psychological research (Pham et al., 2021).

Both branches of the autonomic nervous system (ANS), the sympathetic and parasympathetic system, are involved in regulating the heart rate. Metaphorically speaking, both systems can be seen as two ends on a rope where both sides pull and thereby regulate the peripheral physiology. Hence, both systems exert an influence on the ANS and whichever gets prioritized either upregulates or downregulates the generic system of the body (i.e. blood pressure or pulse). The sympathetic and parasympathetic nervous system thus have an opposite effect on the body. The parasympathetic cardiac activity comes along with three decisive markers: (i) decreased HR (which means that there is an increased interval between successive heart beats); (ii) an elevated respiratory sinus arrhythmia (RSA) leading to an increase in HRV (there are faster changes in RR linked to respiration because of the shorter RR intervals and the longer RR intervals during exhalation); and (iii) decreased ratio in lower frequency to higher frequency oscillations in HRV time series. The reverse is true for the sympathetic nervous system: (i) an increase in HR, (ii) a decrease in HRV, and (iii) an increase in the ratio between lower frequency and higher frequency oscillations in HRV (Berntson et al., 1997; Kubios, 2022; Rajendra Acharya et al., 2006; Task Force, 1996). The SNS index is calculated as a function of three parameters, namely the mean HR, the Baevsky's stress index (SI) and the Poincaré plot index (SD-2). The stress index (SI) is a geometric measure of HRV indicating a cardiovascular stress response. High SI-values reflect a reduced HRV and a higher sympathetic cardiac activation (R. M. Baevsky & Berseneva, 2008; Kubios, 2022).

Our results show that the PNS (parasympathetic nervous system) index was negatively correlated with the religious experience and that the SNS (sympathetic nervous system) index was positively correlated. All time-domain results, namely the mean HR (heart rate), min HR and the max HR were positively associated with the experience. In the frequency-domain results, the LF (low frequencies) in n.u. (normalized units) portrayed a positive correlation with the experience and the HF (high frequencies) in n.u. a negative one. Consequently, the LF/HF ratio was positively correlated. As to the nonlinear results, the SampEn (sample

entropy) was negatively associated with the sensation of the divine. These findings appear to be further strengthened by the two regression models. In the first one, there was a positive association of the SNS index and a negative one of the stress index (SI) to the experience and in the second model, there was a positive association of the LF (log) and a tentative negative one of the HF (log).

For all variables except for one (the stress index), the results appear to paint a unanimous picture: the negative correlation of the religious experience with the PNS index and the positive one with the SNS index indicate that our hypothesis can be accepted. This would imply that the experience came along with an activated and alert state of mind, reflected in the body via an increased activation of the sympathetic nervous system. The general activation of the system is already hinted at when observing the increase of the heart rate upon the experience, reflected in the mean HR, min HR and max HR. A stronger presence of lower frequencies (LF) is generally seen as a sign that there is an activation of the SNS whereas the dominance of higher frequencies (HF) correspond to the activation of the PNS (Pham et al., 2021). Hence the positive correlation with LF and a negative one with HF may count as further evidence to support the notion that the SNS is upregulated and the PNS is downregulated. As an index of the sympathovagal balance, the LF/HF ratio provides some insight in how the two frequency spectra relate to one another, and it can be used as a measure of the relative contributions of the SNS to PNS activity. Here, a positive correlation of the ratio implies that the stronger the experience becomes, the more LF is present when compared to HF (Rajendra Acharya et al., 2006; Seyd et al., 2008). In other words, LF increases, and HF decreases when the experience gets stronger, which is evidence for a successive augmentation of the SNS upon the sensation of the divine.

As for the nonlinear results, sample entropy (SampEn) is often used as a global index of variability because it measures the degree of signal dispersions throughout the whole time series of the given condition (Faes et al., 2019). This makes it a more consistent measure over different time lengths than approximate entropy (ApEn), although both are entropy-based measurements (Richman & Moorman, 2000). They are generally perceived to be indicators for a complexity, or, unpredictability of a signal (Delgado-Bonal & Marshak, 2019). Higher entropy thus implies greater randomness in the signal and lower entropy indicates that the cardiac activity is more predictable (Faes et al., 2019). The negative correlation of the religious experience with SampEn means that the signal becomes more stable and is less dispersed, indicating a more reliable prediction of the signal. In other words, the more the

believers report deep experiences of the divine, the more certain one can be about a strong involvement of the SNS.

The second regression model appears to corroborate these findings by showing that the variance of the religious experience can be explained through the LF and HF in the expected fashion. However, the first model seems to be contradictory because it reports a positive association of the SNS index and a negative one of the stress index (SI) with the experience. Since the SNS index is a function of three variables (mean HR, SI, and SD-2), one would usually expect that a positive association with the SNS index might also come along with a positive association with the SI (R. M. Baevsky & Chernikova, 2017; Kubios, 2022). Often, this is the case (cf. Yoo et al., 2021), which is why the SI has also been called the "sympathetic index" (Ali et al., 2021). The SI is a measure for the regulatory system of the human body (R. M. Baevsky & Berseneva, 2008; R. M. Baevsky & Chernikova, 2017) but it has been criticized that the so-called "stress index" does not truly reflect the activity of strain or stress on the body and that it is prone to generate false positives (Franke-Gricksch & Heimann, 2015). Nevertheless, the SI is generally expected to behave similarly to the SNS index, since, after all, the SNS index is also based on the SI. The results from the first regression model suggest that the following may be the case: here the positive association of the SNS index with the experience may be largely driven by the mean HR and the pointcaré plot index SD-2 (n.u.) and the SI might be a countering force because it is negatively associated with the experience. This has interesting and peculiar consequences, namely that the HR interval as well as SD-2 (similar to the LF/HF power frequencies but linked to the SDNN) likely behave as expected (Brennan et al., 2001) but that the effective HRV might counter this trend. A reduced SI implies a higher HRV, which would support the involvement of parasympathetic processes, whereas an increased HR as well as the LF/HF and the SD-2 suggest otherwise. The most straight forward explanation for this discrepancy would be to allow for the possibility that both sympathetic and parasympathetic pressured are exerted on the system, although the sympathetic system keeps the upper hand. However, the stronger the divine sensation becomes and the more the SNS is activated, the stronger the PNS pushes back, which is indicated by the negative association of the SI. To visualize this idea intuitively, the above introduced metaphor of two ends on a rope both pulling against each other comes in handy. No single side just gives in, but the SNS and the PNS both play a role, although the increase of the religious experience is by and large dominated by the SNS. However, the PNS is not completely downregulated so that the body is not in a fight-or-flight mode (which would be a complete dominance of the SNS). Rather, the body is in an attentive

state of alertness, but it is still sufficiently calm and relaxed to foster a mood where the believer can mentally stay in the present.

This seems to be consistent with previous findings about the nature of religious experiences in worship. First, the believer is in an activated state of alertness because there is an attentive process at play where the focus on God is required to elicit the mental response necessary for this type of the so-believed encounter with the divine (Walter & Altorfer, 2022b). As opposed to some authors (Green, 2015), there does not seem to be a hyper-active mental processing responsible for the effects. Rather, a relaxed state where the attentional control is employed to connect the emergent sensations with religious mental constructs (Walter, 2021). These ideas are supported by the attribution theory formulated by Ann Taves (2005, 2009, 2011, 2020; Taves et al., 2019; Taves & Asprem, 2017) who has laid the groundwork for conceptualizing religious experiences through an attribution framework. Our results supplement the model by showing that the here-measured religious experiences may induce some sort of relaxed state characterized by an increasing alertness. The results also validate the previous findings that the peripheral physiology in fact generally speeds up under the influence of the SNS (Walter & Altorfer, 2022a).

**Conclusion, limitations, and future research**

Previous research on religious experiences in worship made the case that there is a systemic activation of the body under the influence of the experience (Walter & Altorfer, 2022a). We have therefore hypothesized that the sympathetic nervous system (SNS) is largely activated under the influence of the experience. Almost all measures of our results show that this was true and that therefore the working hypothesis could be accepted. The exception was that there appeared to be a negative association of Baevsky's stress index (SI), which can be interpreted as a recruitment of the parasympathetic nervous system (PNS) due to an increase in the heart rate variability (HRV). This provides us with a more nuanced picture of what is going on in the believer's autonomic nervous system (ANS) when one is having this kind of experience. It shows that, although the SNS is dominant, it may be balanced out via a low-threshold co-recruitment of the PNS. With low-threshold we mean that the PNS does not overturn the main effects of the SNS. Like this, the SNS is not the only force at play so that the believer does not get into a complete fight-or-flight response but rather in an activated and alert state of attentiveness, while still being relaxed enough that one can remain calm and

perhaps in a focused, meditative state. As such, the present validation study indeed corroborates the previously made assertions about the systemic activation of the body (Walter & Altorfer, 2022a) due to the focus and alertness under the religious experience (Walter & Altorfer, 2022b) but it provides it with a more nuances picture about the processes of the ANS.

The main limitations of this project have to do with the nature of the experiences that have been studied. Naturally, there are many different types of religious experiences but we have only looked at one (Walter, 2021). At the same time, we had a narrow sample of evangelical Christians stemming from only one specific religious background working solely with Christian concepts. Likewise, we have only worked with peripheral physiological measurements and future studies could expand this with other measures, such as galvanic skin response (GSR), and with brain activation patterns.



## Acknowledgments

Our main appreciation goes out to all the participants who have taken part in this study. Without them, such a research project touching on a very intimate human experience could not have happened.

## References

Ako, M., Kawara, T., Uchida, S., Miyazaki, S., Nishihara, K., Mukai, J., Hirao, K., Ako, J., & Okubo, Y. (2003). Correlation between electroencephalography and heart rate variability during sleep. *Psychiatry and Clinical Neurosciences*, *57*(1), 59–65. https://doi.org/10.1046/j.1440-1819.2003.01080.x

Ali, M. K., Liu, L., Chen, J.-H., & Huizinga, J. D. (2021). Optimizing Autonomic Function Analysis via Heart Rate Variability Associated With Motor Activity of the Human Colon. *Frontiers in Physiology*, *12*. https://www.frontiersin.org/article/10.3389/fphys.2021.619722

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

Andresen, J. (2001). *Religion in Mind: Cognitive Perspectives on Religious Belief, Ritual, and Experience*. Cambridge University Press.

Andrews, G. W. (1916). Music as an expression of religious feeling. *The Musical Quarterly*, *II*(3), 331–338. https://doi.org/10.1093/mq/II.3.331

Argyle, M. (2000). *Psychology and Religion: An introduction*. Routledge.

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

Badham, P., Davies, D., & Bocking, B. (2008). Religious Experience—Discussion Topic. *BASR (British Association for the Study of Religions) Bulletin*, *112*, 14–22.

Baevsky, R. M., & Berseneva, A. P. (2008). *Use kardivar system for determination of the stress level and estimation of the body adaptability*. Standards of measurements and physiological interpretation.

Baevsky, R. M., & Chernikova, A. G. (2017). Heart rate variability analysis: Physiological foundations and main methods. *Cardiometry*, *10*, 66–76. https://doi.org/10.12710/cardiometry.2017.10.6676

Barnard, G. W. (1992). Explaining the Unexplainable: Wayne Proudfoot's "Religious Experience." *Journal of the American Academy of Religion*, *60*(2), 231–256. JSTOR.

Batara, J. B. L., Franco, P. S., Quiachon, M. A. M., & Sembrero, D. R. M. (2016). Effects of religious priming concepts on prosocial behavior towards ingroup and outgroup. *Europe's Journal of Psychology*, *12*(4), 635–644. https://doi.org/10.5964/ejop.v12i4.1170

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

Bender, C. (2010). *The New Metaphysicals: Spirituality and the american religious imagination*. The University of Chicago Press.

Berntson, G. G., Bigger, J. T., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., Nagaraja, H. N., Porges, S. W., Saul, J. P., Stone, P. H., & van der Molen, M. W. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology*, *34*(6), 623–648. https://doi.org/10.1111/j.1469-8986.1997.tb02140.x

Bialecki, J. (2009). Disjuncture, Continental philosophy's new "political Paul," and the question of progressive Christianity in a Southern California Third Wave church. *American Ethnologist*, *36*(1), 110–123. https://doi.org/10.1111/j.1548-1425.2008.01102.x

Bielo, J. (2009). *Words Upon The Word: An ethnography of evangelical group bible study*. NYU Press. https://muse.jhu.edu/book/7513

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

Bowie, F. (2003). An anthropology of religious experience: Spirituality, gender and cultural transmission in the Focolare movement. *Ethnos*, *68*(1), 49–72. https://doi.org/10.1080/0014184032000060362

Boyatzis, C. J. (2001). A Critique of Models of Religious Experience. *International Journal for the Psychology of Religion*, *11*(4), 247–258. https://doi.org/10.1207/S15327582IJPR1104_04

Boyce-Tillman, J. (2006). Music as Spiritual Experience. *Modern Believing*, *47*(3), 20–31. https://doi.org/10.3828/MB.47.3.20

Boyer, P. (1994). *The Naturalness of Religious Ideas: A Cognitive Theory of Religion*. University of California Press.

Braun, W. (2011a). Exprience. In T. Fitzgerald & R. T. McCutcheon (Eds.), *Guide to the study of religion* (pp. 125–139). Continuum.

Braun, W. (2011b). Religion. In T. Fitzgerald & R. T. McCutcheon (Eds.), *Guide To The Study Of Religion* (pp. 3–20). Continuum.

Brehm Center. (2017, January 5). Impact of Christian Music in Worship [Official Website]. *Fuller Theological Seminary*. https://www.fuller.edu/posts/the-impact-of-global-christian-music-in-worship/

Brennan, M., Palaniswami, M., & Kamen, P. (2001). Do existing measures of Poincaré plot geometry reflect nonlinear features of heart rate variability? *IEEE Transactions on Bio-Medical Engineering*, *48*(11), 1342–1347. https://doi.org/10.1109/10.959330

Bubmann, P. (2009). *Musik, Religion, Kirche: Studien zur Musik aus theologischer Perspektive*. Evangelische Verlagsanstalt.

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

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

Cannell, F. (2006). The Anthropology of Christianity. In *The Anthropology of Christianity*. Duke University Press. https://www.degruyter.com/document/doi/10.1515/9780822388159/html

Ciccone, A. B., Siedlik, J. A., Wecht, J. M., Deckert, J. A., Nguyen, N. D., & Weir, J. P. (2017). Reminder: RMSSD and SD1 are identical heart rate variability metrics. *Muscle & Nerve*, *56*(4), 674–678. https://doi.org/10.1002/mus.25573

Collins, M. E., & Scott, J. C. (2019). Intersection of race and religion for youth in foster care: Examining policy and practice. *Children and Youth Services Review*, *98*, 163–170. https://doi.org/10.1016/j.childyouth.2019.01.003

Cook, C. M., & Persinger, M. A. (1997). Experimental induction of the "sensed presence" in normal subjects and an exceptional subject. *Perceptual and Motor Skills*, *85*(2), 683–693. https://doi.org/10.2466/PMS.85.6.683-693

Cygankiewicz, I., & Zareba, W. (2013). Chapter 31—Heart rate variability. In R. M. Buijs & D. F. Swaab (Eds.), *Handbook of Clinical Neurology* (Vol. 117, pp. 379–393). Elsevier. https://doi.org/10.1016/B978-0-444-53491-0.00031-6

Delgado-Bonal, A., & Marshak, A. (2019). Approximate Entropy and Sample Entropy: A Comprehensive Tutorial. *Entropy*, *21*(6), 541. https://doi.org/10.3390/e21060541

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

Dick, T. E., Hsieh, Y.-H., Dhingra, R. R., Baekey, D. M., Galán, R. F., Wehrwein, E., & Morris, K. F. (2014). Chapter 10 - Cardiorespiratory Coupling: Common Rhythms in Cardiac, Sympathetic, and Respiratory Activities. In G. Holstege, C. M. Beers, & H. H. Subramanian (Eds.), *Progress in Brain Research* (Vol. 209, pp. 191–205). Elsevier. https://doi.org/10.1016/B978-0-444-63274-6.00010-2

Doufesh, H., Ibrahim, F., Ismail, N. A., & Wan Ahmad, W. A. (2014). Effect of Muslim prayer (Salat) on α electroencephalography and its relationship with autonomic nervous system activity. *Journal of Alternative and Complementary Medicine (New York, N.Y.)*, *20*(7), 558–562. https://doi.org/10.1089/acm.2013.0426

Dumont, M., Jurysta, F., Lanquart, J.-P., Migeotte, P.-F., van de Borne, P., & Linkowski, P. (2004). Interdependency between heart rate variability and sleep EEG: Linear/non-linear? *Clinical Neurophysiology*, *115*(9), 2031–2040. https://doi.org/10.1016/j.clinph.2004.04.007

Echeverría, J. C., Woolfson, M. S., Crowe, J. A., Hayes-Gill, B. R., Croaker, G. D. H., & Vyas, H. (2003). Interpretation of heart rate variability via detrended fluctuation analysis and αβ filter. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, *13*(2), 467–475. https://doi.org/10.1063/1.1562051

Eliade, M. (1960). *Myths, Dreams and Mysteries (translated by Philip Mairet)*. Harper & Bros.

Engelke, M. (2007). *A Problem of Presence: Beyond scripture in an african church*. University of California Press.

Faes, L., Gómez-Extremera, M., Pernice, R., Carpena, P., Nollo, G., Porta, A., & Bernaola-Galván, P. (2019). Comparison of methods for the assessment of nonlinearity in short-term heart rate variability under different physiopathological states. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, *29*(12), 123114. https://doi.org/10.1063/1.5115506

Franke-Gricksch, N., & Heimann, J.-F. (2015). *Der Puls des Lebens: Die Signale des Herzens verstehen*. PACs Verlag.

Gao, J., Leung, H. K., Wu, B. W. Y., Skouras, S., & Sik, H. H. (2019). The neurophysiological correlates of religious chanting. *Scientific Reports*, *9*(1), 4262. https://doi.org/10.1038/s41598-019-40200-w

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

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

Green, A. (2015). The Mindreading Debate and the Cognitive Science of Religion. *Sophia*, *54*(1), 61–75. https://doi.org/10.1007/s11841-014-0450-0

Gronwald, T., & Hoos, O. (2020). Correlation properties of heart rate variability during endurance exercise: A systematic review. *Annals of Noninvasive Electrocardiology*, *25*(1), e12697. https://doi.org/10.1111/anec.12697

Harding, S. F. (2018). The Book of Jerry Falwell. In *The Book of Jerry Falwell*. Princeton University Press. https://www.degruyter.com/document/doi/10.1515/9780691190464/html

Hermans, C. A. M. (2015). Towards a Theory of Spiritual and Religious Experiences: A Building Block Approach of the Unexpected Possible. *Archive for the Psychology of Religion*, *37*(2), 141–167. https://doi.org/10.1163/15736121-12341306

Hills, P., & Argyle, M. (1998). Musical and religious experiences and their relationship to happiness. *Personality and Individual Differences*, *25*(1), 91–102. https://doi.org/10.1016/S0191-8869(98)00004-X

Hordern, J. (2016). Religion and culture. *Medicine*, *44*(10), 589–592. https://doi.org/10.1016/j.mpmed.2016.07.011

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

Ingalls, M. (2016). *Christian Congregational Music: Performance, identity and experience*. Routlegde.

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

Jenkins, T. (2012). The Anthropology of Christianity: Situation and Critique. *Ethnos*, *77*(4), 459–476. https://doi.org/10.1080/00141844.2012.669775

Jensen, J. S. (2003). *The Study of Religion in a New Key: Theoretical and philosophical soundings in the comparative and general study of religion*. Aarhus University Press.

Jones, J. W. (1972). Reflections on the Problem of Religious Experience. *Journal of the American Academy of Religion*, *40*(4), 445–453. JSTOR.

Keane, W. (2007). *Christian Moderns: Freedom and fetish in the mission encounter*. University of California Press.

Kress, O. (1993). Oliver Kress - A new approach to cognitive development: Ontogenesis and the process of initiation. *Evolution and Cognition*, *2*, 319–332.

Kubios. (2022). HRV in evaluating ANS function. *Kubios Resources*. https://www.kubios.com/hrv-ans-function/

Kurita, A., Takase, B., Shinagawa, N., Kodani, E., Okada, K., Iwahara, S., Kusama, Y., & Atarashi, H. (2011). Spiritual activation in very elderly individuals assessed as heart rate variability and plasma IL/10/IL-6 ratios. *International Heart Journal*, *52*(5), 299–303. https://doi.org/10.1536/ihj.52.299

Laborde, S. (2016). Chapter 17 - Bridging the Gap between Emotion and Cognition: An Overview. In M. Raab, B. Lobinger, S. Hoffmann, A. Pizzera, & S. Laborde (Eds.), *Performance Psychology* (pp. 275–289). Academic Press. https://doi.org/10.1016/B978-0-12-803377-7.00017-X

McNamara, P., & Butler, P. M. (2013). The Neuropsychology of Religious Experience. In R. F. Paloutzian & C. L. Park (Eds.), *Handbook of the Psychology of Religion and Spirituality* (2nd edition, pp. 215–233). The Guilford Press.

Miller, M. M., & Strongman, K. T. (2002). The emotional effects of music on religious experience: A study of the Pentecostal-charismatic style of music and worship. *Psychology of Music*, *30*(1), 8–27. https://doi.org/10.1177/0305735602301004

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

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

Newberg, A. (2018). *Neurotheology: How science can enlighten us about spirituality*. Columbia University Press.

Nijjar, P. S., Puppala, V. K., Dickinson, O., Duval, S., Duprez, D., Kreitzer, M. J., & Benditt, D. G. (2014). Modulation of the autonomic nervous system assessed through heart rate variability by a mindfulness based stress reduction program. *International Journal of Cardiology*, *177*(2), 557–559. https://doi.org/10.1016/j.ijcard.2014.08.116

Nusbaum, E. C., & Silvia, P. J. (2011). Shivers and Timbres: Personality and the Experience of Chills From Music. *Social Psychological and Personality Science*, *2*(2), 199–204. https://doi.org/10.1177/1948550610386810

Otto, R. (1917). *Das Heilige*. C.H. beck.

Paloutzian, R. F., & Park, C. L. (Eds.). (2013). Recent progress and core issues in the science of the psychology of religion and spirituality. In *Handbook of the Psychology of Religion and Spirituality* (2nd edition, pp. 3–22). The Guilford Press.

Pals, D. L. (1987). Is religion a sui generis phenomenon? *Journal of the American Academy of Religion*, *LV*(2), 259–284. https://doi.org/10.1093/jaarel/LV.2.259

Peng, C. -K., Havlin, S., Stanley, H. E., & Goldberger, A. L. (1995). Quantification of scaling exponents and crossover phenomena in nonstationary heartbeat time series. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, *5*(1), 82–87. https://doi.org/10.1063/1.166141

Penzel, T., Kantelhardt, J. W., Grote, L., Peter, J. H., & Bunde, A. (2003). Comparison of detrended fluctuation analysis and spectral analysis for heart rate variability in sleep and sleep apnea. *IEEE Transactions on Biomedical Engineering*, *50*(10), 1143–1151. https://doi.org/10.1109/TBME.2003.817636

Persinger, M. A. (1983). Religious and Mystical Experiences as Artifacts of Temporal Lobe Function: A General Hypothesis. *Perceptual and Motor Skills*, *57*(3_suppl), 1255–1262. https://doi.org/10.2466/pms.1983.57.3f.1255

Persinger, M. A., & Healey, F. (2002). Experimental facilitation of the sensed presence: Possible intercalation between the hemispheres induced by complex magnetic fields. *The Journal of Nervous and Mental Disease*, *190*(8), 533–541. https://doi.org/10.1097/00005053-200208000-00006

Pham, T., Lau, Z. J., Chen, S. H. A., & Makowski, D. (2021). Heart Rate Variability in Psychology: A Review of HRV Indices and an Analysis Tutorial. *Sensors*, *21*(12), 3998. https://doi.org/10.3390/s21123998

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

Porter, M. (2016). *Contemporary Worship Music and Everyday Musical Lives*. Taylor & Francis.

Radha, M., Fonseca, P., Moreau, A., Ross, M., Cerny, A., Anderer, P., Long, X., & Aarts, R. M. (2019). Sleep stage classification from heart-rate variability using long short-term memory neural networks. *Scientific Reports*, *9*(1), 14149. https://doi.org/10.1038/s41598-019-49703-y

Rajendra Acharya, U., Paul Joseph, K., Kannathal, N., Lim, C. M., & Suri, J. S. (2006). Heart rate variability: A review. *Medical & Biological Engineering & Computing*, *44*(12), 1031–1051. https://doi.org/10.1007/s11517-006-0119-0

Richman, J. S., & Moorman, J. R. (2000). Physiological time-series analysis using approximate entropy and sample entropy. *American Journal of Physiology-Heart and Circulatory Physiology*, *278*(6), H2039–H2049. https://doi.org/10.1152/ajpheart.2000.278.6.H2039

Riklikiene, O., Poskaite, G., & Vainoras, A. (2019). Spiritual needs, prayer and cardiac function changes in healthy young women – the interconnection of spirituality with human physiology. *Journal of Complexity in Health Sciences*, *2*(2), 77–86. https://doi.org/10.21595/chs.2019.21235

Robbins, J. (2003). What is a Christian? Notes toward an anthropology of Christianity. *Religion*, *33*(3), 191–199. https://doi.org/10.1016/S0048-721X(03)00060-5

Robbins, J. (2007). Continuity Thinking and the Problem of Christian Culture: Belief, Time, and the Anthropology of Christianity. *Current Anthropology*, *48*(1), 5–38. https://doi.org/10.1086/508690

Rosado Nunes, M. J. F. (2001). Religion and Gender. In N. J. Smelser & P. B. Baltes (Eds.), *International Encyclopedia of the Social & Behavioral Sciences* (pp. 13034–13037). Pergamon. https://doi.org/10.1016/B0-08-043076-7/04067-5

Schewior-Popp, S., Sitzmann, F., Ullrich, L., Anton, W., Bartholomeyczik, S., Bartoszek, G., Becker, C., Beyer, H., & Boczkowski, C. (Eds.). (2017). *Thiemes Pflege: Das Lehrbuch für Pflegende in Ausbildung* (13. aktualisierte und erweiterte Auflage). Georg Thieme Verlag.

Schnabel, L. (2018). More religious, less dogmatic: Toward a general framework for gender differences in religion. *Social Science Research*, *75*, 58–72. https://doi.org/10.1016/j.ssresearch.2018.06.010

Schumaker, J. F. (1995). *The Corruption of Reality: A unified theory of religion, hypnosis, and psychopathology*. Prometheus Books.

Seyd, P. T. A., Ahamed, V. I. T., Jacob, J., & K, P. J. (2008). Time and Frequency Domain Analysis of Heart Rate Variability and their Correlations in Diabetes Mellitus. *International Journal of Medical and Health Sciences*, *2*(3), 85–88.

Shaffer, F., & Ginsberg, J. P. (2017). An Overview of Heart Rate Variability Metrics and Norms. *Frontiers in Public Health*, *5*. https://www.frontiersin.org/article/10.3389/fpubh.2017.00258

Shaffer, F., McCraty, R., & Zerr, C. L. (2014). A healthy heart is not a metronome: An integrative review of the heart's anatomy and heart rate variability. *Frontiers in Psychology*, *5*. https://www.frontiersin.org/article/10.3389/fpsyg.2014.01040

Studstill, R. (2000). Eliade, phenomenology, and the sacred. *Religious Studies*, *36*(2), 177–194. https://doi.org/10.1017/S0034412500005175

Task Force. (1996). Standards of Measurement, Physiological Interpretation and Clinical Use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Circulation*, *93*, 1043–1065.

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

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

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

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

Taves, A., & Asprem, E. (2017). Experience as event: Event cognition and the study of (religious) experiences. *Religion, Brain & Behavior*, *7*(1), 43–62. https://doi.org/10.1080/2153599X.2016.1150327

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

Thompson, M., Thompson, L., & Reid-Chung, A. (2015). Chapter 8—Combining LORETA Z-Score Neurofeedback with Heart Rate Variability Training. In R. W. Thatcher & J. F. Lubar (Eds.), *Z Score Neurofeedback* (pp. 159–188). Academic Press. https://doi.org/10.1016/B978-0-12-801291-8.00008-X

Tolentino, J. C. (2019). Cardiac autonomic modulation related to prayer may contribute to the reduced cardiovascular mortality associated with religiosity/spirituality. *Journal of Integrative Cardiology Open Access*, *2*(2), 1–5. https://doi.org/10.31487/j.JICOA.2019.02.05

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

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

Walter, Y., & Altorfer, A. (2022a). Physiological Foundations for Religious Experiences in Devotional Worship Practices with Music Using Heart Rate and Respiration Rate Analyses. *European Journal of Investigation in Health, Psychology and Education*, *12*(2), 127–143. https://doi.org/10.3390/ejihpe12020011

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

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

Yoo, H. H., Yune, S. J., Im, S. J., Kam, B. S., & Lee, S. Y. (2021). Heart Rate Variability-Measured Stress and Academic Achievement in Medical Students. *Medical Principles and Practice*, *30*(2), 193–200. https://doi.org/10.1159/000513781

Zhuang, Z., Gao, X., & Gao, S. (2005). The relationship of HRV to sleep EEG and sleep rhythm. *The International Journal of Neuroscience*, *115*(3), 315–327. https://doi.org/10.1080/00207450590520911

Zweigenhaft, R. L. (2008). A Do Re Mi Encore: A Closer Look at the Personality Correlates of Music Preferences. *Journal of Individual Differences*, *29*(1), 45–55. https://doi.org/10.1027/1614-0001.29.1.45