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Electrodermal Activity Implicating a Sympathetic Nervous System Response under the Perception of Sensing a Divine Presence—A Psychophysiological Analysis

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Abstract: Previous studies have suggested that religious worship experiences may recruit the autonomic nervous system (ANS) in an activating fashion. For this reason, we hypothesized that measurements of the electrodermal activity (EDA) would concur with the notion that the subjective experience of sensing the presence of God recruits a sympathetic nervous system response. We analyzed the EDA of 37 evangelical participants and calculated classic galvanic skin response (GSR) measures. Our experimental design included six conditions with and without music consisting of religious and non-religious songs plus a resting-state condition, which were used to induce a variance in the religious experience suitable for statistical analyses. Results showed that both tonic and phasic signals as well as the overall electrical skin conductance (SC) were positively associated with the religious experience, defined as sensing the presence of God. This implicates that we can accept the hypothesis that such a religious experience under the influence of worship seems to recruit the sympathetic nervous system.

Keywords: electrodermal activity; EDA; galvanic skin response; GSR; psychophysiology; religious experience; phenomenology; special states of mind; psychology of religion

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1. Introduction

1.1. Religion and Experience

Although to date not much is known about the physiological activation patterns and stress responses of religious experiences when measured directly, it may be plausible that the autonomic nervous system (ANS) is activated. In the present study, we conducted electrodermal activity (EDA) analyses to test this as a hypothesis. The main question presently is whether such experiences implicate a sympathetic stress response as measured by EDA.

There is no one single definition of *religion* and so there is a call for a pragmatic working definition [1], depending on the context and the study performed [2–4]. In empirical research, it is common to conceive of religion as cognitive and emotional representations associated with beliefs in supernatural powers, which are sometimes perceived as sacred or inviolable [5]. *Religious experience* is a derivative construct thereof and has been described as fundamental human states of mind [6]. Since they can be so subjectively transformative [7], it is no simple matter to develop a ubiquitous definition for them [8]—although there would certainly be benefits to this, since there is now a lot of evidence that religion and religious experiences can have a profoundly positive impact on mental health and wellbeing [9–18]. There are effectively two main modalities to conceptualize religious experiences; one referred to as the *sui-generis approach* and the other known as the *attribution approach*. The

first idea holds that there is an inherent quality latently present in such an experience and whenever this quality emerges, then an occurrence automatically becomes a religious experience [19–21]. This is much like the perception of salty food, where this specific sensation is present whenever the food is experienced as salty. There is not much debate between people interpreting certain foods as salty and some others who might not. The second idea holds that there is not a simple phenomenological quality that creates a religious experience; rather that it is a matter of interpretation of a person who deems an experience religious, depending on the person's beliefs, priors, and geodemographic environment. Ann Taves [22–25] has developed the most widely used theory for religious attribution in her so-called building-block approach to religious experiences. The core principle lies in the notion that there are countless experiences everyday but that some stand out as extraordinary, which, if they are attributed a subjectively religious significance (depending on the mental concepts held by the experiencer), become religious experiences. This conception of subjectively deeming an experience religious is also employed in the present study's experimental design since the participants were asked to constantly evaluate and indicate their own experiences.

1.2. The Dimension of Religious Experience

There are two noteworthy issues surrounding empirical research into such states of mind. The first deals with (i) their operationalization and (ii) the second with their induction.

(i) The operationalization problem comes along with the question of how to best measure the experience and likewise how to delineate the psychological constructs in question. Most previous studies in neurobiology and psychophysiology have used religious practice as a proxy for religious experience, using a specific practice and measuring the physical responses [26,27]. However, the Centrality of Religiosity Scale CRS-15 [28], a validated psychological model for religiosity, denotes five separate dimensions for a subjective religious construct system: intellect, ideology, public practice, private practice, and experience. This shows that religious practice and religious experience are separate dimensions. We have therefore constructed our experiments in a way as to measure religious experience directly and not simply using practice as a proxy, which is something many previous studies have not equally taken into account.

(ii) The induction problem is concerned with how to best facilitate the desired experience in question so that it can be studied under laboratory conditions. The *Feedback Loop Model of Religious Experiences in Worship* [29] shows that an evangelical sample can be used to generate such an experience, ideally with a selection of music during worship practices. It has been shown that music appears to be an ideal trigger for such experiences [30–34] and evangelical Christians appear to be particularly suitable for the task [35–39]. Pre-selected and self-selected songs may be helpful to induce the desired state of mind [40–42]. It has been suggested that an interesting statistical variance can be achieved if both modalities are implemented [43], which is why a mix of pre- and self-selected songs was pursued in the present study.

1.3. Peripheral Physiology and Electrodermal Activity of Religious Experience

Although neuropsychological research on religious experience is still scarce, it is slowly increasing [44], and most of it is centered around brain-state studies using EEG, MRI, PET, and SPECT analyses [26,27]. To date, not much is known about the peripheral physiology and hence the activation patterns of the autonomic nervous system of such states. Gao et al. [45] studied the neurophysiology of religious chanting and investigated whether the EEG delta oscillations might be associated with the ECG or the respiratory rate, which apparently was not the case. The majority of available studies observed the peripheral physiology through the analysis of the heart rate variability (HRV), which allows an inference to the activation of the sympathetic and parasympathetic nervous system. For example, research on mindfulness training showed an improvement in cardiac sympathovagal balance [46]. Another study reported that Muslims in prayer experienced

an increase in higher HRV frequencies [47], although the experimental design has been criticized [45]. A review paper stated that prayer in general is good for cardiac health and that it is associated with an increase in parasympathetic as well as a decrease in sympathetic activity [48]. Other authors published findings that were conflicting with this since they found in their purely female sample that prayer was correlated with elevated heart rate and respiratory rate [49]. Kurita and colleagues [50] reported a higher HRV low-frequency/high-frequency ratio upon listening to sermons.

The autonomic nervous system can also be analyzed through electrodermal activity (EDA) measurements. One variant thereof is the galvanic skin response (GSR), which has been used to investigate the relationship between yoga, music, and stress. On the one hand, it was shown that practicing yoga breathing, listening to religious hymns, and listening to flute music all have a positive effect on stress reduction [51]. On the other hand, a group practicing prayer and meditation over the span of a month showed increased GSR [52], which is generally interpreted as a stress response. A comparison between "religious ecstatics" and "deep listeners" showed that both groups had a strong GSR reaction upon listening to their favorite music [53]. When it comes to the activation patterns of the peripheral physiology in response to direct measurements of religious experiences, there is only one study available, which reported that religious worship experiences appear to have an activating effect on the heart rate and respiratory rate [54].

1.4. Research Hypothesis

We were interested to further disentangle and strengthen the previously reported effect of the positive association of religious worship experiences on physiological measures. There appears to be an activating stress response upon sensing the presence of God, indicating the recruitment of the sympathetic nervous system [54]. Using electrodermal activity, a validation study was performed. For this, we hypothesized that skin conductivity (SC) increases under the influence of the religious experience, indicating a sympathetic response. As such, we expected to find a positive correlation between the experience with tonic, phasic as well as overall SC measures.

2. Materials and Methods

2.1. Participants

We recruited 60 evangelical Christians and recorded their electrodermal activity (EDA), although due to the extreme artifact sensitivity of the instruments, only 37 recordings survived. There were four reasons why we selected evangelical Christians: (i) they are known to have an emphasis on religious experience; (ii) they are known to successfully induce them under the influence of worship practices; (iii) they have shared theological convictions around them; and (iv) we already had access to this cohort. 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).

We started out with approaching local evangelical churches and trying to network with young, active charismatic Christians, trying to establish who would be willing to participate in a study about their religious experiences. Since this is an intimate topic to many believers, it is not self-evident that a large number of interested volunteers could be attracted. Based on the networking endeavors, the first participants were able to give us further recommendations of believers (their friends) that might be willing to partake in the study. As such, our network of participants grew up to 60 volunteers until the end of our recruitment phase.

Before the experiments started, informed consent was provided and an array of questions about their personality and prayer life was handed out. To exclude any interference from a person's hearing capability, a hearing test was applied beforehand. The study was approved by the local ethics committee (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, 6 September 2021).

It is worth providing a note regarding concerns about the statistical power and the study's effectiveness in light of the fact that out of 60 recruited participants, only 37 intact measurements survived. Originally, we attempted to perform one of the largest EDA study in the field since usually there are not more than twenty subjects in comparable studies. Although there was a significant reduction of data due to the artifacts, eventually we still had more viable participants than similar studies since, for example, meditation EDA analysis is usually done with around 25 subjects [55].

2.2. Experimental Design

All participants went through an experiment of about one hour consisting of a resting-state at the beginning and the end, two religious songs, two secular songs, an empty condition, and a distracting twelve-tone tune. The conditions (except the resting state) were randomized to avoid any potential halo effect. Each condition lasted about 4.5 min. After each condition, there was a time-free distraction task containing letters that had to be memorized and some questions about them that had to be answered. This was implemented so that there was no spill-over effect between two conditions. The distraction task consisted of a series of letters that flashed on the experimental computer's screen. After around ten letters (at random), the flashes stopped and rested at one letter. Then the question was: "Is this letter the same than the letter that came before the previous one?" Then they had to click yes or no. It was not recorded whether the participants were correct or not since the sole goal was to make them concentrate and think of something else.

During every condition, the task was the same, namely to try to connect with God through the practice of worship with the help of music and to sense his presence. Participants were asked to continuously navigate a bar slider on the right-hand side up and down to indicate how strongly they sensed the divine presence (except for the resting state). The individual conditions are depicted in Table 1.

Table 1. Depiction of the experimental conditions.

Acronym	Name	Description
C_{RS}	*Resting state*	This was 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 29). 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 min 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 conditions (at the beginning and the end) but before the statistical analyses, they were fused together and averaged as to only count as one condition. For every condition, the participants were asked to close their eyes to make the

responses comparable. They were asked to sit still and move as little as possible so as to avoid unnecessary artifacts.

The songs were cut at natural breaks so that they lasted about 4.5 min and engineered with a sound tool called Audacity 2.4.2. Songs that were shorter were duplicated at specific events (e.g., chorus or verse) so that it naturally sounded like the songs were longer. Eventually, all conditions had a comparable duration.

The ratings of the religious experience were averaged per experimental condition and then prepared for statistical processing.

2.3. Recording and Preprocessing of the Electrodermal Activity (EDA)

There were two electrodes placed on the left hand of every participant, one fixated on the index finger and the other on the middle finger. The recording was generated with 100 Hz and visualized as well as exported through Lab Chart. Preprocessing of EDA variables occurred through Ledalab 3.4.9., which is a GUI toolbox running on Matlab. The data was imported manually for each subject and the sampling frequency was reduced from 100 Hz to 10 Hz, which is a suggested frequency rate for EDA analyses [56]. There were some data sets that consisted of negative numbers because of potential electrode shifts. For these, a constant was applied so that all values were positive. A continuous decomposition analysis (CDA) was applied to split phasic from tonic frequencies and the tool-inherent optimization function was used. This process yielded the segregation and visualization of the phasic driver, general skin conductance (SC), as well as skin conductance level (SCL). Eventually, alternating-block design variables were exported for the whole 4.5 min of every condition. Since no negative value survived, no z-scale normalization was applied. There were several EDA measures generated from the CDA, as depicted in Table 2.

Table 2. Variables exported from Ledalab for EDA analysis (values: s = seconds; µS micro Siemens).

Continuous Decomposition Analysis (CDA) (Extraction of Continuous Phasic/Tonic Activity Based on Standard Deconvolution)	
Variable	**Description**
CDA.nSCR	Number of significant (=above-threshold) SCRs
CDA.Latency	Response latency of first significant SCR [s]
CDA.AmpSum	Sum of SCR-amplitudes of significant SCRs (reconvolved from corresponding phasic driver-peaks) [µS]
CDA.SCR	Average phasic driver. This score represents phasic activity most accurately, but does not fall back on classic SCR amplitudes [µS]
CDA.ISCR	Area (i.e., time integral) of phasic driver. It equals SCR multiplied by size [µS × s]
CDA.PhasicMax	Maximum value of phasic activity [µS]
CDA.Tonic	Mean tonic activity (of decomposed tonic component) [µS]
Global measures	
Global.Mean	Mean SC value within condition [µS]
Global.MaxDeflection	Maximum positive deflection within condition [µS]

We were primarily interested in the average phasic driver, the mean tonic activity, and the mean SC value per condition. Hence, the variables CDA.SCR, CDA.Tonic, and Global.Mean were selected as primary variables of interest concerning the EDA. This is illustrated in Figure 1.

The preprocessed data was exported from Ledalab and then read into SPSS 27, which was used for the statistical operations. We performed three linear mixed models that were adjusted for individual variations of the subjects at the primary tier-level. The dependent variables were the biometric measurements (phasic driver, tonic activity, and mean skin conductance value respectively), the fixed factor was the experimental condition as well as the averaged religious experience per condition, and the models controlled for gender as a covariate. For the convergence of the model, type 3 sum of squares were applied. In the

present research endeavor, we were primarily interested in whether the religious experience ratings were significantly associated with the EDA items or not. After this, it was relevant to observe the directionality between the experiential values and the biometric measurements. Hence, reference-independent parameter estimates for fixed effects were calculated using only the two relevant variables, meaning that Pearson correlations between the religious experience and the EDA items were performed. The significance testing was two-tailed.

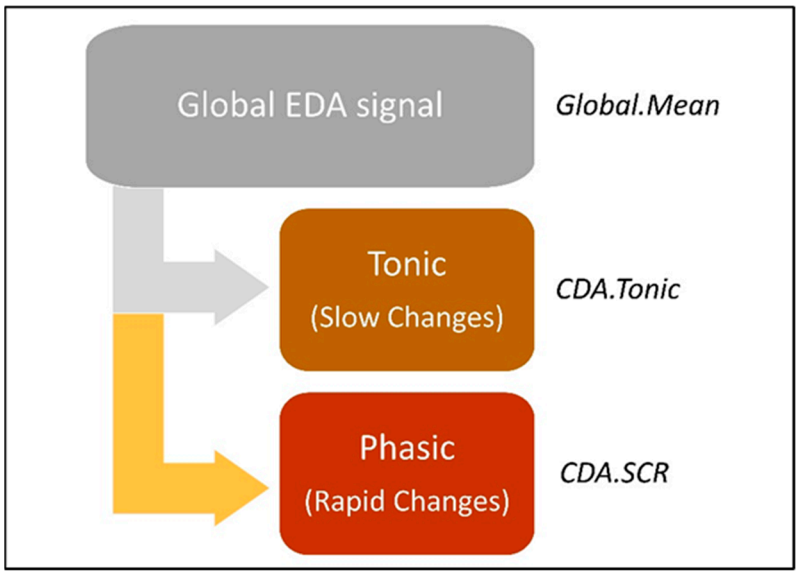

Figure 1. Illustration of the relationship between global, tonic, and phasic electrodermal shifts with the associated variables of interest from Ledalab.

The linear mixed models were chosen so that there was a single model per EDA target that could both be adjusted for the subject variations as well as to give a reference-dependent picture of how the religious experience fared when controlled for the conditions and the participant's gender. After we were certain that the effect existed, we were interested solely in the directionality between the experience and the EDA, which allowed for a reference independent correlative test.

3. Results

3.1. Tests for Fixed Effects

The results in Table 3 showed that there was a significant effect of the religious experience on the EDA when controlling for relevant factors like condition and gender. The most relevant finding in this context was the significant association of the global mean with the experience. Both the slow tonic electrodermal changes as well as the fast phasic volatility appeared to be implicated with the religious experience. These findings, however, are dependent upon the directionality of the EDA changes.

Table 3. Linear mixed models for the effect of the religious experience on electrodermal activity (EDA), including the variance of the condition and controlling for gender. The associations between the experience and the EDA were put in bold.

Model	EDA Target Variable	Independent Factors	Degrees of Freedom (df)	F-Value	*p*-Value
1	**Global.Mean**	Condition	1, 35	3.678	0.063
		Religious Experience	**216, 35**	**1.996**	**0.008**
		Gender	1, 35	0.849	0.363
2	**CDA.Tonic**	Condition	1, 35	3.154	0.084
		Religious Experience	**216, 35**	**1.942**	**0.010**
		Gender	1, 35	0.934	0.341
3	**CDA.SCR**	Condition	1, 35	7.320	0.010
		Religious Experience	**216, 35**	**4.859**	**<0.001**
		Gender	1, 35	0.123	0.728

3.2. Tests for Directionality

The associations in Table 3 were clarified by the results in Table 4, which showed the directionality of the EDA changes based on the religious experience. Since the models in Table 3 were significant, there was no need for the correlations from Table 4 to be statistically significant as well since their purpose was to indicate whether by and large there was a positive or a negative relationship between the experience and the electrodermal responses. As such, the overall findings provided the most relevant information (depicted in bold) and showed that there was a positive effect of the experience on the global EDA as well as the slow tonic changes. The high *p*-value and low r-value in the fast phasic changes (CDA.SCR) indicated that there might not be a uniform effect throughout the conditions, which was confirmed by observing the individual conditions since the associations between the experience and the phasic values were positive in the B, $S_{12,}$ and the S_G conditions, but were negative in the R_G, $R_{S,}$ and the S_S conditions. This means that, whereas the association between the religious experience and the global as well as the tonic EDA were positive, no clear image could be inferred for the phasic changes, which was to be expected since the present experimental block design worked with longer periods of 4.5 min and not with rapid event-related potentials (ERPs).

Table 4. Pearson correlations for estimating the associations between the religious experience and the electrodermal activity (EDA). The associations between the experience and the EDA over all the experimental conditions were put in bold.

	Condition	EDA Variables	Degrees of Freedom (df)	*p*-Value	Correlation
Religious Experience	**Overall**	**Global.Mean**	**35**	**0.107**	**0.270**
		CDA.Tonic	**35**	**0.088**	**0.284**
		CDA.SCR	**35**	**0.648**	**−0.078**
	Empty (B)	Global.Mean	35	0.144	0.245
		CDA.Tonic	35	0.169	0.231
		CDA.SCR	35	0.413	0.139
	R_G	Global.Mean	35	0.302	0.174
		CDA.Tonic	35	0.287	0.180
		CDA.SCR	35	0.677	−0.071
	R_S	Global.Mean	35	0.218	0.207
		CDA.Tonic	35	0.174	0.228
		CDA.SCR	35	0.506	−0.113
	S_{12}	Global.Mean	35	0.489	0.117
		CDA.Tonic	35	0.471	0.122
		CDA.SCR	35	0.891	0.023
	S_G	Global.Mean	35	0.019	0.383
		CDA.Tonic	35	0.020	0.381
		CDA.SCR	35	0.293	0.178
	S_S	Global.Mean	35	0.582	0.093
		CDA.Tonic	35	0.543	0.103
		CDA.SCR	35	0.779	−0.048

4. Discussion

Electrodermal activity (EDA), such as the galvanic skin response (GSR), has been used for more than a century to measure sweat secretion as a consequence of autonomic nervous system (ANS) activation in the domain of peripheral physiology. Since sweat glands are only innervated by sympathetic and not by parasympathetic nerve tracts, the EDA is a useful measurement of sympathetic (de-)activation patterns. As such, it comes as an indication of the physiological stress response that provides information about a person's emotional and attentional arousal. The EDA is hence a core analytical tool

for psychophysiological responses, where—especially for our present study—slow tonic changes (skin conductance level SCL), rapid phasic changes (skin conductance response SCR), and global skin conductance (a combination of tonic and phasic developments) were of interest. Since the present study was implementing an experimental block design and was not working with rapid ERPs, it was expected that the global skin conductance and the slow tonic changes were predominantly affected by the religious experience. An increase in electrodermal activity can generally be viewed as an upregulation of the sympathetic nervous system, which is associated with the prevalence of psychological arousal (for a thorough and in-depth discussion on EDA, please refer to [57]).

It was shown that religious worship experiences correlate with the believer's attentional control mechanisms, namely that the more a person can concentrate on God during the worship practice, the stronger he or she senses the presence of God when deliberately allowing for the experience [43]. At the same time, there was evidence that a believer's peripheral physiology speeded up upon such an experience, which was indicated by an increase in heart rate and respiratory rate activity [54]. This makes the notion plausible that there may be an active involvement of the sympathetic nervous system in these processes. In the present study, we therefore used this as our hypothesis and wanted to find out whether we could detect any sympathetic activity based on EDA patterns induced by a religious experience, operationalized as sensing the divine under the influence of worship practices with the help of music.

We used EDA variables concerning global, tonic, and phasic skin conductance and calculated statistical models with the averaged religious experience, accounting for the experimental conditions and controlled for gender as well as adjusted for inter-individual variations. Our results showed that there was a significant association of the religious experience ratings with all EDA variables. The directionality was overall positive, meaning that an increase in the experience came along with an increase in electrical skin conductivity. There was no noteworthy effect of gender on this outcome, and the experimental conditions—which were deliberately constructed to induce a variance in the experiential values—were not relevant. Naturally, the only place where there may be an association of the condition is with the phasic electrodermal values since this variable is sensitive to rapid changes. This, however, is not likely to be relevant for the present hypothesis since, first, it does not diminish the significant effect observed from the religious experience and, second, phasic changes over a 4.5 min period may topically also confound with some non-systemic (i.e., non-stimulus-oriented) fluctuations.

Taken together, the three findings stemming from the associations of the religious experience with the global, the tonic as well as the phasic SC appear to provide strong evidence for accepting our hypothesis, namely that sensing the presence of God came along with the recruitment of psychophysiological arousal patterns and thus the sympathetic nervous system.

Previous neuroscientific research on religious practice and experience showed that there appeared to be delineated cognitive processes involved, which were associated with distinct brain regions with religious cognition and emotion [26,27]. There are, so to speak, neuropsychological activation patterns that can be found under the pretext of such special states of mind. One EEG microstate study deliberately performed on religious worship experiences showed three distinct brain networks that were associated with these phenomenological states. Among them we find the auditory-temporal network, the default mode network, and the salience network, with the latter being the strongest predictor for the experience [58]. Having the salience network as the strongest predictor is telling, since it clearly demonstrates a cognitive shift that occurs when the experience emerges. It seems like this shift is accompanied with a more alert attentional focus [43] and with an upregulated activity in peripheral physiological responses [54]. The present study can now add to this the notion that there appears to be strong evidence based on EDA measurements that these activating psychophysiological arousal responses are most likely generated by the recruitment of the sympathetic nervous system.

5. Conclusions and Limitations

There is not much research on direct measurements of religious experiences, and this is one of the first to do so while including biological measurements of the psychophysiological responses generated thereof. Previous research indicated that there might be an activating effect on the autonomous nervous system (ANS) when a believer reports to be sensing the divine. In the present study, we have therefore formulated the hypothesis that such a religious experience was associated with a recruitment of the sympathetic nervous system. For this, the electrodermal activity (EDA) was measured and the experiments yielded the result that all investigated EDA variables positively corresponded with the religious experience, which was operationalized as sensing God's presence. As such, we were able to accept our hypothesis that the experience came along with a decisively sympathetic response.

There were some limitations with our approach. First, EDA measurements are less complex than, for example, heart rate variability (HRV) responses, since they only allow for statements about sympathetic and not about parasympathetic activity patterns due to the fact that there are only sympathetic nerve tracts innervating the sweat glands. Second, our experimental design was geared towards a clearly evangelical–Christian sample and it would be interesting to see if these results could be extrapolated to samples from other denominations and religions. Third, the experience induced in the lab may not be the same as such an experience "out in the wild", such as at home or in a church setting, which is where they usually occur. Our lab conditions were constructed in a way as to maximize the scientific validity and statistical effectiveness, but this may be a rather sterile setting in contrast to the believer's natural environment. Fourth, we have only looked at one specific form of religious experience; however, it is known that there are other types of experiences that could be mentioned and analyzed.

Apart from these limitations, we believe that the present study enriches the body of knowledge by noting that subjective religious worship experiences may be associated with the recruitment of the sympathetic nervous system and thus have an activating effect on psychophysiological arousal systems. This sits well with the already published, albeit scarce, literature on the topic.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Upon reasonable request, data can be acquired by the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

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