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Error processing and religious conviction: A multi-lab replication

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Abstract

One function of religion might be to reduce cognitive conflict and anxiety. In a highly-cited paper, Inzlicht and colleagues' Study 1 (2009) assessed the association between self-reported religious zeal and conflict monitoring. Conflict monitoring was measured using the error-related negativity (ERN), an event-related potential that is sensitive to the conflict between an erroneous behavioral response and cognitive representation/knowledge of the correct response. Results showed that individuals with higher levels of self-reported religious zeal had smaller ERNs on a color-word Stroop task, suggesting less cognitive conflict when faced with opposing response tendencies leading to errors. In addition, individuals higher in religious zeal were slower and more accurate on incongruent trials, suggesting deliberate responding in which they sacrificed speed for accuracy. Work that has examined closely related concepts (e.g., religious fundamentalism) has failed to corroborate Inzlicht and colleagues' (2009) findings, though other work has provided broad support for the original results. No direct replication of Inzlicht and colleagues (2009) has been attempted. As part of the #EEGManyLabs initiative (Pavlov et al., 2021), we will perform an international, multi-site replication of Study 1 from Inzlicht and colleagues (2009).

Keywords: error-related negativity (ERN), religious zeal, religion, #EEGmanylabs, error monitoring, event-related potential (ERP)

1. Introduction

Religion has been termed “the opium of the people” (Marx, 1994, p. 57) because it may quell anxiety about uncertainty and reduce cognitive conflict. Experimental manipulations of uncertainty and personal threat have been shown to increase self-reported religiosity (McGregor et al., 2008). A related question is whether – on a neural level – individuals who are higher in trait religiosity are characterized by reduced response to cognitive conflict. One way of testing this idea is by examining the association between religiosity and neural indices of error monitoring, which detects inappropriate behaviors that occur when individuals are confronted with conflicting response tendencies. The error-related negativity (ERN) is an event-related potential (ERP) that is larger (more negative) for error versus correct responses (Carter et al., 1998; Garavan et al., 2003; Gehring et al., 1993) and is thought to measure error processing and conflict monitoring. It originates in the anterior cingulate cortex (ACC; Iannaccone et al., 2015), which is connected to the amygdala – a key node in the processing of threatening stimuli (Bishop, 2008; Bishop et al., 2004; Frankland et al., 2004). The ERN is increased in obsessive compulsive disorder (Gehring et al., 2000; Olvet & Hajcak, 2008; Riesel, 2019) and trait anxiety (for a meta-analysis see Moser et al., 2013), reflecting the role of threat-sensitivity and self-monitoring in these disorders. The ERN is also sensitive to within-subject manipulations of the perceived severity, type, and frequency of errors (Dignath et al., 2020; Segalowitz & Dywan, 2009; van Veen & Carter, 2002). Therefore, due to the ERN’s sensitivity to individual differences and motivational factors, it is well-suited to examining how religion might reduce conflict monitoring and play a role in the management of error-related negative affect.

Indeed, a variety of studies have examined the association between religion and the ERN. In a seminal paper that has been cited over 400 times at the time of writing (Google Scholar), Inzlicht and colleagues (2009) examined associations between *religious zeal* and the ERN (Study 1). As one of several ways of measuring the significance of religion in an individual's life, religious zeal refers to "active integrity and empowered eagerness to live a life of committed fidelity to cherished values" (p. 157, McGregor et al., 2010). It is assessed using a brief (8-item) scale that includes items such as, "I aspire to live and act according to my religious beliefs" and "My religious beliefs are grounded in objective truth". (McGregor et al., 2010). Early work on religious zeal showed that components of religious zeal – i.e., conviction of one's own beliefs and derogation of others' beliefs – increased when individuals were faced with personal uncertainty threats (McGregor et al., 2008). In subsequent work, the tendency to employ religious zeal in times of uncertainty was found to be most evident for individuals high in dispositional approach motivation (McGregor et al., 2010), suggesting that work examining associations with religious zeal might want to control for behavioral approach motivation in their analyses. Though religious zeal has been associated with religious extremism and anger, it has also been associated with love (Tietjen, 2021) and its utility as a means of coping with uncertainty has been emphasized (McGregor & Little, 1998). Along these lines, religious zeal has been distinguished from anxious religious conviction anxiety that revolves around vigilant, superstitious belief, and instead has been characterized as an idealistic (yet potentially defensive) belief system that leads to feelings of empowerment and insulation against anxiety motivation (McGregor et al., 2010). In other words, religious zeal might be a coping mechanism that helps individuals deal with uncertainty and conflict, including internal 'conflict' detection that is part of error monitoring.

In both studies by Inzlicht and colleagues (2009), participants completed the religious zeal scale, as well as a color-naming Stroop task during an EEG recording. Results showed that individuals higher in self-reported religious zeal [$r(27) = .43$] and with stronger self-reported belief in God, [$r(21) = .63$] had smaller (less negative) ERNs as elicited using the Stroop task. Religious zeal was also associated with more accurate and slower responding on incongruent Stroop trials. The association between religious zeal and the ERN remained significant even after controlling for Stroop behavior, as well as a variety of individual difference measures (i.e., need for cognitive closure, behavioral activation and inhibition, and self-esteem), some of which are known correlates of the religious zeal or the ERN (Amodio et al., 2007; Hall et al., 2007; McDonald et al., 2021; Nelson et al., 2011; Yang et al., 2019). With these findings, Inzlicht and colleagues (2009) proposed that religion might reduce anxiety by providing individuals with clear guidelines for how to behave, think, and interact with their environment. These standards might in turn reduce conflict monitoring and processing, especially in uncertain situations and when individuals are pulled in multiple directions at once via conflicting response tendencies.

Inzlicht and colleagues' (2009) novel findings spawned many subsequent studies. Several of these studies have failed to support Inzlicht and colleagues' (2009) findings. For instance, Senderecka and colleagues (2019) found larger ERNs in participants who reported higher levels of religious fundamentalism, as well as no association between religious fundamentalism and behavior (i.e., response time, inhibitory performance, and post-error slowing). In line with this, a conceptual replication using functional magnetic resonance imaging (fMRI) found no significant association between individual differences in religiosity and ACC activation or Stroop task performance (Hoogeveen et al., 2020).

Still other work has examined how priming of certain aspects of religiosity can interact with overall belief in God to affect the ERN. For example, Inzlicht and colleagues (2010) found that believers presented with religious primes that emphasized God's love had smaller ERNs compared to believers presented with primes emphasizing God's wrath. Similarly, when believers were primed with reminders of God's love, they had smaller ERNs in a Go/No-Go task. Nonetheless, these participants also made more errors than those primed with stimuli of religious wrath, and there was no overall difference in task performance between believers and non-believers (Good et al., 2015). Overall, while these results tend to support Inzlicht and colleagues' (2009) original findings, they also suggest that religiosity might interact with other state factors to affect the size of the ERN. In sum, since the Inzlicht and colleagues' (2009) study, evidence has been inconclusive regarding whether religion is associated with smaller ERNs.

Though several studies have performed investigations similar to that of Inzlicht and colleagues (2009), there has been no direct replication of either study in the paper. As part of the #EEGManyLabs initiative (Pavlov et al., 2021) we will be the first to attempt a direct replication of Study 1. In line with Inzlicht and colleagues (2009, 2020), we hypothesize that greater religious zeal will be associated with smaller (more positive) ERNs.

Our replication will stay as true as possible to the methods and paradigm design used in the original study. Data will be collected at labs in Delaware, Texas, Indiana, and Krakow, Poland. Therefore, a successful replication would speak to the robustness of Inzlicht and colleagues' (2009) findings across geographically and socio-politically diverse locations.

2. Method

The overall study design, research question, sampling and statistical procedures for this replication are outlined in Table 1. Details concerning data collection, processing and participant recruitment, shown separately for each site, can be found in Table 2.

2.1. Sample recruitment

In line with the #EEGManyLabs protocol (Pavlov et al., 2021), our sample size will be powered to counteract potential overestimation of effect size in the original study. Sample size was computed (with G*Power 3.1; Faul et al., 2009) using the reported correlation of r = 0.43 between religious zeal and the ERN (Inzlicht et al., 2009), which was selected based on its importance relative to other findings reported by Inzlicht and colleagues (2009). We assumed the original effect size (r = 0.43) to be inflated, as evidence suggests that the effect size in pre-registered studies is about half the size of that in studies without pre-registration (Schäfer & Schwarz, 2019). Therefore, to counteract potential overestimation of the true effect size, we selected a sample size that would provide 90% power to detect 50% of the original effect size – i.e., r = 0.215. Further, in line with Cortex's requirements for Registered Reports, we selected a p = .02 (one-tailed) significance level for a one-sided test (Camerer et al., 2018; Lewis et al., 2020; Schäfer & Schwarz, 2019). Assuming both an alpha level of 0.02 and a 0.5 decrease in the effect of interest to account for shrinkage effects (Pavlov et al., 2021), the total sample size will be N = 236.

Methods for participant recruitment will vary across replicating labs. Texas A&M, University of Delaware, and Purdue University will recruit via institutional subject pools, through which participants will receive course credit for their time. At Jagiellonian University, participants will be recruited from the general community via internet advertisements and financially compensated according to local policies. To yield a sample consistent with that of the original study (Inzlicht et al., 2009) only right-handed participants will be included. Further exclusion of participants will occur during pre-processing of EEG data. In the absence of explicit parameters for exclusion in the original study, we will employ standard approaches to ensure reliable ERNs and acceptable data quality. Participants with fewer than six errors (Olvet &

Hajcak, 2009) or with less than 50% artifact-free trials will be excluded from the final sample. Replicating labs will receive study approval from their respective Institutional Review Boards or ethical committees.

2.2. Overall Procedure

Study 1 in Inzlicht and colleagues (2009) will serve as a model for the current study's procedures. Participants will begin their involvement by providing informed consent. Next, they will complete questionnaires and then the Stroop task, while EEG is recorded.

Some of the labs involved in this #EEGManylabs project will collect additional EEG task data and select self-report measures, for contribution to individual lab projects. Data collected for this purpose will not be included in analyses or discussion of results from this replication.

2.3. Questionnaires

Questionnaires used to assess various psychological dimensions will be the same as used in the original Inzlicht and colleagues (2009) study and are described below.

The Religious Zeal Scale (McGregor et al., 2008) assesses ardent religious conviction. Participants are asked to identify the religious belief system they most identify with (e.g., Jewish, Muslim, Christian, atheist, agnostic, other etc), prior to rating eight items on a scale from 1 = strongly disagree to 5 = strongly agree. Responses are averaged, yielding a range from 1 to 5, with higher scores indicating greater religious zeal.

The Need for Cognitive Closure scale (Webster & Kruglanski, 1994) assesses the desire for an answer in order to end further information processing and judgment, regardless of whether that answer is the best or most correct answer. The scale consists of 42 items that are rated on a scale from 1 = strongly disagree to 6 = strongly agree. Responses are summed after reverse-scoring of some items. Higher scores indicate greater need for cognitive closure.

The Behavioral Inhibition and Behavioral Activation scales (Carver & White, 1994) assess two motivational systems: a behavioral activation system (BAS) that is thought to regulate approach behaviors and a behavioral inhibition system (BIS), which is thought to regulate withdrawal behaviors. The scale consists of 24 items, only 20 of which are scored (4 items are filler items) that are rated on a scale from 1 = very true for me to 4 = very false for me. All but 2 items are reverse scored; following this, responses are summed, yielding separate BIS and BAS scores. Higher scores indicate greater BIS and BAS.

The Rosenberg Self-Esteem scale (Rosenberg, 1965) assesses self-esteem. The scale consists of 10 items that are rated on a scale from 1= strongly agree to 4 = strongly disagree. Responses are summed after reverse-scoring of some items. Higher scores indicate greater self-esteem.

Demographic information such as race, ethnicity, gender, age, and religious affiliation will be collected using a variety of inclusive demographic questions based on those created by Hughes and colleagues (2022). Handedness will also be self-reported using a single-item question.

2.4. Stroop task

Participants will receive instructions on a color-naming Stroop task. For details on the software used to administer the Stroop task, see Table 2. In this task, participants will be presented with a set of color words (e.g., “blue”, “red”, “green”), with font color selected to be congruent or incongruent with word meaning. Participants will be told to respond to each word to indicate the font color. Trials will begin with a fixation cross presented for 500 ms, followed by presentation of a stimulus word for 200 ms. Participants will have a maximum of 1000 ms to respond to each color word, including the 200 ms stimulus presentation (personal communication with M. Inlzicht, May 14, 2023[1]). Prior to task completion participants will complete a practice set including both congruent and incongruent pairings. Practice trials will be followed by five task blocks, in which responses will be recorded. Each block will consist of 24 color congruent words and 12 color incongruent words, presented in random order, for a total of 180 trials. The task will have an approximate duration of 10 minutes, not accounting for optional self-paced breaks.

2.5. EEG recording

For details pertaining to the setup and software employed in each replicating lab, see Table 2. Multiple sites will additionally capture electrooculogram data from four facial electrodes. Electrodes will be positioned as follows: two electrodes will be placed approximately 1 cm above and below the right eye, forming a bipolar channel to measure vertical eye movement and blinks (University of Delaware will use Fp1) and two electrodes placed approximately one cm beyond the outer edges of each eye, forming a bipolar channel to measure horizontal eye movements. Although the study of focus did not record horizontal eye movement, we will record these movements to facilitate correction for related artifacts.

2.6. EEG artifact removal and preprocessing

Data processing procedures will mirror those described in the original study. Data will be re-referenced offline to the average of both mastoids and filtered between 1 and 15 Hz (as in the original study). Data will be time-locked to responses and segmented 400 ms before and 800 ms after each response. Baseline correction will use the average voltage between 400 and 200 ms before participant response. We will correct for ocular artifacts using the method developed by Miller and colleagues (1988), which is the same procedure used in the original study. Though the original study provided few details on artifact rejection, we will also perform semi-automatic artifact rejection. Artifact analysis will be used to identify a voltage step of more than 50.0 μV between sample points, a voltage difference of 300.0 μV within a trial, and a maximum voltage difference of less than 0.50 μV within 100 ms intervals. Further artifact rejection through visual inspection and subsequent rejection of poor-quality channels will occur on a trial-by-trial basis. We will report the number of total participants excluded based on poor data quality (i.e., with over 50% of EEG trials rejected). ERPs will be averaged separately for incorrect and correct trials for each participant. Offline processing of all EEG data will be performed using BrainVision Analyzer software (Brain Products GmbH**)** and conducted by the lead replicating lab at Texas A&M University.

2.7. Outlier Handling

Outlier criteria were not specified in the original study. Nonetheless, for this replication, we will examine the distribution of the ERN and responses on the religious zeal scale and will exclude outliers on these measures as identified using Grubbs test (Grubbs, 1969), prior to performing analyses.

2.8. Quantification of ERPs

In line with the majority of the literature on the ERN and its counterpart for correct responses, the correct-related negativity (CRN), it will be quantified as the mean area amplitude between 50 ms before and 100 ms after participant response (e.g., Klawohn et al., 2020; Olvet &

Hajcak, 2008). We will follow recent recommendations to use a functional localizer approach (Luck & Gaspelin, 2017) to score the ERN at the sites in which the error versus correct response is maximal across labs.

2.9. Statistical analyses

Analyses will be performed by the lead replication site (Texas A&M University), using SPSS statistical software (IBM, Armonk, NY)**.** Before assessing associations between key study variables, we will evaluate their internal consistency. The results of this assessment will be treated as an outcome-neutral criterion, meaning that we do not expect internal consistency to reach a specific threshold for the results of our replication attempt to be considered informative.

2.10. Evaluation of the replication and robustness of effects

Lab datasets will be subjected to a random effects meta-analysis, in order to account for potential heterogeneity between sites, and as specified by the #EEGManyLabs pipeline (Pavlov et al., 2021). The lead replicating lab (Texas A&M) will conduct a random-effects meta-analysis using the R function ‘metacor’ from the ‘meta’ package (Schwarzer, 2007). Prior to entering effect sizes into our software, we will calculate a Pearson’s correlation coefficient between ERN amplitude and religious zeal – separately for each site – and then transform each value into a Fisher’s z-value. We will then employ a restricted maximum likelihood estimator method for estimating τ2 (a measure of variance in true effects). Combined median effect size, weighted and unweighted effect sizes (at 99 % confidence intervals), and individual site effects will be reported using forest plots. The number of labs that successfully reproduce the original effect will additionally be reported. The pooled association will be interpreted following Cohen’s convention (small: $r = 0.10$, medium: $r = 0.30$, large: $r = 0.50$; Cohen, 1988) and the significance level will be set at $p < .02$, one-tailed. Inter-lab heterogeneity will be classified using Higgins &

Thompson's I^2 statistic. $I^2 = 25\%$, $I^2 = 50\%$, and $I^2 = 75\%$ will represent low, moderate, and high heterogeneity for interpretation (Higgins & Thompson, 2002). For the replication to be deemed successful, the overall meta-analytic effect size will need to be 1) positive, per the direction seen by Inzlicht and colleagues (2009) and 2) significantly different from zero.

2.11. Data sharing

Data and study materials will be shared using the Open Science Framework (OSF, https://osf.io/9cbvn/).

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Footnotes

1. The original programming files for the task used in Inzlicht and colleagues (2009) could not be located.
2. The mean area amplitude was originally described as the "mean minimum deflection" (Inzlicht et al., 2009, p. 387).

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Table 1

Study Design

Question	Hypothesis	Sampling plan	Analysis Plan	Rationale for deciding the sensitivity of the test for confirming or disconfirming the hypothesis	Interpretation given different outcomes	Theory that could be shown wrong by the outcomes
Are study variables internally consistent?	Outcome neutral criterion (no hypothesis).	The entire sample will be used (see sample size justification below).	Split-half reliability for the ERN and Cronbach's alpha for self-reported religious zeal.	Outcome neutral criterion	Outcome neutral criterion	Outcome neutral criterion
Is greater religious zeal associated with smaller a ERN? (i.e., attempt to replicate Study 1 in Inzlicht et al., 2009)	Religious zeal will be positively associated with the ERN.	Sample size was computed (with G*Power 3.1; Faul et al., 2009) using the r = 0.215, which is 50% the size of the reported correlation between religious zeal and the ERN (Inzlicht et al., 2009) and 90%, with p = .02 (one-tailed).	Internal meta-analysis of the bivariate correlations between the ERN and religious zeal obtained from individual labs.	We assumed the original effect size (r = 0.43) to be inflated. Evidence suggests that the effect size in pre-registered studies is about half the size of that in studies without pre-registration (Schäfer & Schwarz, 2019).	For the replication to be deemed successful, the overall meta-analytic effect size will need to be 1) positive, per the direction seen by Inzlicht and colleagues (2009) and 2) significantly different from zero. Any other outcome will be taken as a replication failure of Inzlicht and colleagues (2009).	Failure to replicate Inzlicht and colleagues (2009) would work against the theory that religion functions to reduce psychological conflict and associated distress.

Table 2

Experimental Setup Across Replicating Labs

Site	Amplifier System	Electrode, Cap Model, Number EEG + External EOG Electrodes	Sampling Rate	Online Reference, Ground	Online Filter	OS, Recording Software	Screen Type, Size, Ratio, Refresh Rate	Stimulus Presentation, Language	Compensation
Texas A&M University	ActiCHamp (Brain Products, Gilching, Germany)	BrainProducts ActiCap slim, active, 32 + 4	1000 Hz	Fz, Afz	Low-pass 280 Hz	Windows 10, Brain Vision Recorder 1.21.0001	LED, 21.5 in. & 24.5 in., 1920 x 1080, 60 Hz & 59.90 Hz	Presentation (Vers. 21.1), English	Course Credit
Purdue University	ActiCHamp (Brain Products, Gilching, Germany)	BrainProducts ActiCap regular, active, 32 + 2	1000 Hz	None, Afz	Low-pass 280 Hz	Windows 11, Brain Vision Pycorder V.1.0.0	LED, 17 in, 1280 x 1024, 60 Hz	Presentation (Vers. 21.1), English	Course Credit
University of Delaware	ActiCHamp (Brain Products, Gilching, Germany)	BrainProducts ActiCap slim, active, 32 + 2	1000 Hz	Fz, Afz	Low-pass 280 Hz	Windows 10, Brain Vision Recorder 1.21.0001	LED, 21.5 in, 1920 x 1080, 59.90 Hz	Presentation (Vers. 21.1), English	Course Credit
Jagiellonian University	BioSemi (BioSemi, Amsterdam, Netherlands).	Biosemi, active, 64 + 4	1024 Hz	CMS, DRL	Low-pass 280 Hz	Windows 10, ActiView 812	LED, 24 in, 2560 x1440, 60 Hz	PsychoPy (Vers. 2022.1.3), Polish	Financial Compensation