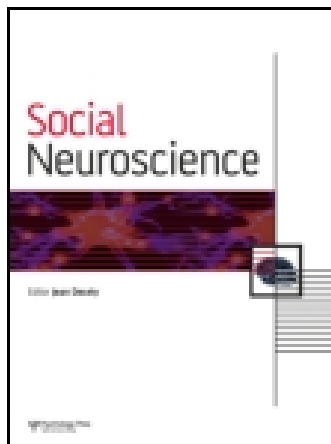


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## Social Neuroscience

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/psns20>

### The sacred and the absurd--an electrophysiological study of counterintuitive ideas (at sentence level)

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Accepted author version posted online: 17 Nov 2011. Published online: 06 Dec 2011.

To cite this article: Sabela Fondevila, Manuel Martín-Loeches, Laura Jiménez-Ortega, Pilar Casado, Alejandra Sel, Anabel Fernández-Hernández & Werner Sommer (2012) The sacred and the absurd--an electrophysiological study of counterintuitive ideas (at sentence level), *Social Neuroscience*, 7:5, 445-457, DOI: [10.1080/17470919.2011.641228](https://doi.org/10.1080/17470919.2011.641228)

To link to this article: <http://dx.doi.org/10.1080/17470919.2011.641228>

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## The sacred and the absurd—an electrophysiological study of counterintuitive ideas (at sentence level)

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Religious beliefs are both catchy and durable: They exhibit a high degree of adherence to our cognitive system, given their success of transmission and spreading throughout history. A prominent explanation for religion's cultural success comes from the "MCI hypothesis," according to which religious beliefs are both easy to recall and desirable to transmit because they are minimally counterintuitive (MCI). This hypothesis has been empirically tested at concept and narrative levels by recall measures. However, the neural correlates of MCI concepts remain poorly understood. We used the N400 component of the event-related brain potential as a measure of counterintuitiveness of violations comparing religious and non-religious sentences, both counterintuitive, when presented in isolation. Around 80% in either condition were core-knowledge violations. We found smaller N400 amplitudes for religious as compared to non-religious counterintuitive ideas, suggesting that religious ideas are less semantically anomalous. Moreover, behavioral measures revealed that religious ideas are not readily detected as unacceptable. Finally, systematic analyses of our materials, according to conceptual features proposed in cognitive models of religion, did not reveal any outstanding variable significantly contributing to these differences. Refinements of cognitive models of religion should elucidate which combination of factors renders an anomaly less counterintuitive and thus more suitable for recall and transmission.

**Keywords:** Religion; N400; Core knowledge; Semantics; Minimally counterintuitive.

The cognitive science of religion constitutes a new orientation in science in which religion is considered a natural phenomenon. Evidence for the practice of religion has been reported in archeology since prehistoric periods (Wade, 2006), constituting what appears to be a uniquely human social and psychological condition (Boyer & Bergstrom, 2008; Bulbulia, 2004). There is no culture that lacks some form of supernatural commitment and practice, and despite continuous cultural changes throughout history, core elements of religious cultures survive with remarkable fidelity (Bulbulia, 2009). Moreover, religious commitments

exert substantial influence in both the private and public decision-making processes of individuals the world over. Despite the central and enduring prominence of religion in the human way of life, relatively little is known about the evolutionary and proximate causes of religious conservation and persistent expression in human experience.

Scholars have made several proposals in order to account for religion's success from an evolutionary perspective. Some authors, for example, explain it as a specific adaptation for cooperation within groups for between-group competition (Wilson, 2005).

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This work was funded by grant SEJ2007-60485/PSI of the Spanish Ministry of Science and Innovation and by project PSI 2010-19619 of the same Ministry.

According to this view, different cognitive systems implicated in social relationships might have been subject to natural selection, creating an adaptive system—that is, religion, designed to improve cooperation (Pyysiäinen & Hauser, 2010). However, several authors have pointed out that the same advantages for social bonding can be obtained without any specific support from religious beliefs (Dennett, 2006).

According to an alternative viewpoint, religious ideas are by-products of our normal cognition. Thus, cognitive resources and processes involved in religious concepts belong to the basic “inference machinery” that humans have evolved for dealing with social relationships in ordinary life (Atran, 2002; Barrett, 2000; Boyer, 2003; Pyysiäinen, 2003). In this regard, the emergence of religion would be related to the development of novel cognitive processes during human evolution such as agent detection, theory of mind, fear of contagion, or social exchange (Boyer & Bergstrom, 2008). Consequently, together with the expansion of specific brain regions (such as the temporal lobes and prefrontal cortex) related to these cognitive processes, religious thinking might have arisen (Boyer, 2003).

Suggestive evidence for this line of thought comes from some fMRI studies reporting that the neural networks involved in religious cognition are also implicated in many other non-religious—mainly social—cognitive processes (Harris et al., 2009; Kapogiannis et al., 2009; Kapogiannis, Barbey, Su, Krueger, & Grafman, 2009). These cognitive processes, could have arisen as systems devoted to define the relationships between human beings, thereafter being used for, or giving rise to, relationships between human beings and religious entities (such as gods, spirits, etc).

Nevertheless, even if there is a large overlap between religious and non-religious cognitive processes and concepts, the successful cultural transmission of religious beliefs and their historical and geographical spread require explanation. To fill this gap, Boyer (Boyer, 1994b, 2001, 2003) has suggested that at least part of the success of religious belief systems relates to the way religious concepts are constructed. Boyer classifies domain concepts as ontological categories, such as persons, natural objects, plants, animals, and artifactual objects, each related to physical, biological, or psychological properties that are intuitively attributed to those categories. For instance, the concept of a cat implies that it is an animal that can run, needs food, and so on, but also that it neither thinks like us nor speaks our language. For Boyer, as for most authors in the cognitive science of religion, counterintuitiveness in the strict sense only applies to violations of expectations

derived from core knowledge—intuitive ontologies about biological, physical, or psychological properties associated with different domains of information, organized along specific sets of principles and based on specific neural structures. Consequently, other types of counterintuitions or violations of intuitive knowledge about the world, such as bizarre ideas—not violating core knowledge but being extremely odd, such as a heavy butterfly—are disregarded.

According to Boyer, religious concepts are especially appealing to our cognitive system because some of their properties are counterintuitive while, at the same time, they retain most tacit assumptions of intuitive features or ideas associated with these concepts (Boyer, 1994b). For example, a “ghost” is a person that can violate some intuitive physical laws applying to solid objects by “passing through walls” or being invisible, while, at the same time, preserving most intuitive psychological properties pertaining to people, such as having emotional states, intentions, or even language (Boyer, 2001).

On the one hand, many religious concepts are surprising enough to be salient and interesting; on the other hand, they maintain enough cognitive constraints on tacit inferences according to ontological structures to allow for easy comprehension and processing (Boyer, 1994a, 1998). Consequently, religious concepts are not entirely but, rather, minimally counterintuitive. This feature might constitute a “cognitive optimum” explaining the successful adherence of religious concepts (such as ghosts, speaking animals, statues that cure diseases) to our cognitive system (Barrett, 2000) as well as other successful non-religious but appealing concepts.

Memorability has been invoked as a factor for successful cultural transmission (Sperber, 1996). In this regard, some authors have reported recall advantages for minimally counterintuitive concepts over intuitive and bizarre concepts embedded in narratives. These results were found in Western university students with Native American folk tales (Barrett & Nyhof, 2001) and for a tale used in samples from three different populations—specifically Tibetan Buddhist monks, West Africans, and French university students (Boyer & Ramble, 2001). Additional supportive evidence is found in a detailed analysis of the microstories of the Roman prodigies (Lisdorf, 2004). These studies suggest that core-knowledge violations operate in a similar way in different cultural contexts. Thus, the cultural success of religious beliefs might be a function of their minimal counterintuitiveness, rather than bizarreness (unusual features that do not violate core knowledge), or cultural unfamiliarity (Norenzayan & Atran, 2004).

Alternatively, other authors have proposed that the success of religious beliefs stems from the level of the narratives or tales involved in religious thinking. If cognitive optimality were operating at the level of concepts only, and if narratives in which they are embedded did not have any cognitive effect, it would be expected that the cultural success of a narrative would increase with the proportion of minimally counterintuitive concepts included. Norenzayan and colleagues (Norenzayan, Atran, Faulkner, & Schaller, 2006) examined the cognitive optimality of word pairs and narratives. Narratives that comprised mostly intuitive concepts combined with a minority of minimally counterintuitive ones had the highest rate of delayed recall and the lowest rate of degradation over time. This was true in comparison to both tales with a larger amount of counterintuitive concepts and totally intuitive ones. This cognitive template characterizes most popular folk tales and religious narratives, and appears to be the optimal balance for recall and transmission in cultural success.

In addition to the cognitive optimality hypotheses of minimally counterintuitive beliefs, some authors suggest that agency is a crucial aspect in the success of religious concepts. In a series of studies carried out by Pyysiäinen et al. (Pyysiäinen, Lindeman, & Hakela, 2003), counterintuitive statements involving some kind of agent were more likely to be judged as religious than statements involving no agent. In a similar vein, Guthrie (1993) stressed that our cognitive system is biased toward detecting human-like agency in our environment (a hypersensitive agent detection device), triggered whenever sensory data are ambiguous or incomplete. The hypersensitive agent detection device might have contributed to the prevalence of agents over non-agents in religious beliefs (Barrett, 2004).

However, there are numerous culturally successful, minimally counterintuitive concepts and narratives in which agency plays a relevant role that may have been recalled and transmitted in a similar way as religious ones, but which are clearly non-religious. This contradiction has been called the “Mickey Mouse problem” (Culotta, 2009). The Disney character Mickey Mouse is an agent that has supernatural powers—a speaking and thinking mouse that never ages or dies after devastating crashes—together with many intuitive features. However, Mickey Mouse is not worshipped, nor would anyone fight or die for him.

Though insufficient to distinguish religious concepts from all non-religious cultural concepts, the cognitive optimality of minimal counterintuitiveness appears as a well-established and important feature in accounts which try to explain religion’s success.

As reviewed above, minimal counterintuitiveness has been found in both religious concepts (i.e., entities or objects combining intuitive and counterintuitive properties such as “spirit”) and narratives with such features (Boyer, 1994b; Norenzayan et al., 2006). It seems possible, nevertheless, that minimal counterintuition might also apply at the level of single isolated ideas expressed in sentences that show violations of some properties of the categories described. That is, counterintuitive ideas might appear to be less anomalous or counterintuitive when used in religious contexts than non-religious counterintuitions, even if core physical, biological, or psychological features are violated in both cases. Compare, for example, the ideas of a thinking stone and a thinking peach. In both cases, we have a core violation by a psychological property, the former for a natural object and the latter for a plant. Whereas it appears easy to conceive the former idea as religious and somehow plausible—in fact, many religions attribute supernatural properties to stones—this is not the case for the peach. For some reason, still undefined, a thinking stone might be more religiously acceptable than a thinking peach—an idea that seems to be rather absurd.

In the current work, we test the hypothesis that religious counterintuitive ideas are less anomalous to the human cognitive system than non-religious counterintuitions. To investigate this hypothesis, we recorded event-related brain potentials (ERPs), focusing on the N400 component. The N400 component is a centroparietal negative wave around 400 ms after stimulus onset with higher amplitude when a word is semantically unexpected, as in “I like my coffee with cream and socks” (Kutas & Hillyard, 1980). The N400 is an index of semantic processing and seems to represent the amount of resources necessary for integrating the meaning of a word in an ongoing sentence (Molinaro, Conrad, Barber, & Carreiras, 2009). In addition to its sensitivity for the context, the amplitude of the N400 is larger for between-category semantic violations (like the appearance of the verb “to cry” when the one expected is “to eat”) than for violations occurring within a category (like “to drink” in the example) (Federmeier & Kutas, 1999). In this regard, the N400 seems to be sensitive to the access and organization of long-term semantic memory—that is, our world knowledge (Hagoort, Hald, Bastiaansen, & Petersson, 2004; Van Berkum, Hagoort, & Brown, 1999). On the other hand, such a violation can be mitigated when embedded in a context that makes it plausible (Hald, Steenbeek-Planting, & Hagoort, 2007; Nieuwland & Van Berkum, 2006).

The N400 is therefore sensitive to counterintuitiveness in a general sense (violations of intuitive

knowledge about the world) and, hence, should be also sensitive to counterintuitiveness in a more strict sense (core knowledge violations). Indeed, the N400 component has been used to analyze semantic processing of core knowledge violations in paranormal believers (Lindeman et al., 2008).

The N400 component can be followed by a P600 component, a possible index of structural reanalysis, classically observed for syntactic violations (Osterhout & Holcomb, 1992) but sometimes also in response to semantic violations (Kim & Osterhout, 2005; Martin-Loeches, Nigbur, Casado, Hohlfeld, & Sommer, 2006).

In our experiment, we approached the question of counterintuitive religious ideas from an unbiased viewpoint, by using a collection of genuinely religious ideas extracted from religions and classical mythological corpora such as the Rig Veda, the Popol Vuh, or the Koljiki, all unfamiliar to the participants of the study. Following the proportions as they were found in the original texts, about 80% of counterintuitive religious ideas were core-knowledge violations, the remaining world-knowledge-violating ideas being bizarre or ambiguous in this regard. The proportions confirm that, while not all counterintuitions in real religious frames are core-knowledge violations, they predominate. All of them could be expressed in a single sentence. By altering the target word (last word) of the counterintuitive religious ideas, we created counterintuitive non-religious (also about 80% core-knowledge violations) and intuitive ideas, having three versions of sentences such as “*She was born from the foam/pan/womb.*”

We hypothesized that if counterintuitive religious ideas are less semantically anomalous (and therefore less counterintuitive to a certain degree) to the human cognitive system at the level of isolated sentences, a reduction in the amplitude of the N400 should appear to the last word of our religious sentences when compared to the non-religious counterintuitions. We controlled other factors known to affect the N400, such as word frequency, length, cloze probability, concreteness, or syntactic category (Hagoort, 2008; Lau, Phillips, & Poeppel, 2008).

## EXPERIMENTAL PROCEDURE

### Participants

Thirty native Spanish speakers (21 women, mean age: 23.83, *SD*: 5.24, range: 18–43) took part in the experiment. All were right-handed with average handedness scores (Oldfield, 1971) of +65.8, ranging from +20 to +100, and had normal or corrected to normal vision.

All participants grew up within the Western Spanish culture with different degrees of exposure to or familiarity with the predominant Catholic religious system. Their degree of religiosity was measured with a 25-item questionnaire developed by Kapogiannis et al. (2009) about current religious experience and behavior, their religious upbringing, and aspects of their worldview. In this questionnaire, it is assumed that religiosity patterns are based on clusters of personality traits that influence cognitive strategies and behavior over time. Although this questionnaire is not yet validated in large population samples, it is considered appropriate to exclude persons with outstanding levels of religiosity. On a Likert scale from 1 (disagreement with religiosity statements) to 7 (agreement), our participants obtained a mean of 1.96 (*SD* = 1.66) reflecting a low to moderate level of religiosity. Participants gave their written, informed consent prior to the study and received payment for participation.

The study was performed in accordance with the Declaration of Helsinki and had been approved by the ethics committee of the Complutense University of Madrid.

### Stimuli

A set of 180 religious ideas was collected from various mythologies and religious corpora other than Christian. The religions and mythologies employed were as follows: Hindu, Mesoamerican, Japanese, Egyptian, Greco-Roman, African, Australian, Chinese, Polynesian, and Inuit (Allen, 1975; Anonymous, 1982; Anonymous, 1981; Anonymous, 2008a; Anonymous, 2008b; García Noblejas, 2007; Knappert, 1988; Ovid., 2004; Poignant, 1967; Resenberg, 2001).

From the original set of religious ideas collected, a percentage of 78.4% explicitly constituted ontological, core-category violations according to the criteria outlined by Boyer (2001). In this regard, a violation is either a *breach* of expectations from a knowledge domain (psychological, biological, or physical) related to a given ontological category (person, animal, plant, natural object, or artifact) or a *transfer* from another domain of knowledge. The remaining 21.6% of violations could be considered bizarre ideas or ambiguous to some degree, such as related to abstractions, events, or substances that are excluded from theoretical frameworks (Barrett, 2008; Boyer, 2001). These figures follow the proportions found in the original texts.

To better adapt the material to an ERP study, the collected counterintuitive religious ideas were used to construct sentences where the violation was always determined by the very last word of the sentence. Two

other types of sentences, counterintuitive non-religious and intuitive sentences, were formed from these religious counterintuitive sentences by changing only the last word. This procedure is explained below.

On the one hand, non-religious counterintuitive sentences are core-knowledge and bizarre or ambiguous violations—to the same proportion as religious ideas (81.2% and 18.8%, respectively)—that are unacceptable as religious sentences, whereas intuitive sentences describe plausible situations of the real world. Finding the correct last word for the latter was relatively simple, as the preceding context in the sentence facilitated the construction of several plausible sentence endings. Acceptability of the last word as defining an acceptable or intuitive sentence was always unanimous among the present authors in a first step; thereafter, it was reinforced by the moderate degree of rated cloze probability (see below). The determination of non-religious counterintuitive sentences was more indirect, as it was based on the authors' unanimous subjective judgment that the resulting sentence or idea would be unacceptable as religious, while at the same time maintaining the criterion of violating world knowledge.

On the other hand, a strong constraint imposed on the material was that several linguistic and psycholinguistic variables that may affect N400 amplitude were controlled for the last (target) words. In this regard, the target words of the three conditions did not differ significantly in word frequency according to the "Lexico Informatizado del Español" (LEXESP) (Sebastián, 2000)—mean of religious condition: 364.25; non-religious: 323.06; intuitive: 293.30,  $F(2, 539) = .67$ ,  $p > .1$ —nor mean syllable length—religious: 2.61; non-religious: 2.57; intuitive: 2.62,  $F(2, 539) = .24$ ,  $p > .1$ . Cloze probability was assessed with a questionnaire presented to a group of 46 university students other than those participating in the study. The percentage of participants that predicted the actual target word was zero in both religious and non-religious counterintuitive sentences, but 15% in the intuitive sentences. The percentage of word categories of critical words was also matched; 85% nouns, 11.1% verbs, and 3.9% adjectives for both religious and non-religious conditions, and 83.88%, 11.1%, and 5%, respectively, for the intuitive condition. Finally, the percentages of abstract (non-imageable) and concrete (imageable) words were also matched for religious, non-religious, and intuitive conditions: 92.7%, 93.3%, and 93.8%, respectively, were concrete words. Table 1 displays examples of the three types of sentences.

In application of these constraining criteria, the experimental materials displayed a number of features that are of interest for interpretation and discussion.

Initially, all the counterintuitive religious sentences had as the subject of the sentence a member of an ontological category, with proportions distributed as depicted in Table 2. In a number of sentences, the subject was ambiguous, in the sense that pronoun actually played this role, as in the example, "*She was born from the foam.*" In these cases it was considered that the ontological category was a person. As a result of constructing sentences in which the last (target) word entirely determined the counter-intuitiveness, however, a total of 64% of the experimental sentences had non-canonical orders. Consequently, in many cases, the subject of the sentence was actually also the last word. Table 2 gives the ontological categories of the last words of the sentences, regardless of whether they were the subject or agent of their corresponding sentence. The types of violations, in terms of properties of ontological categories in the counterintuitive sentences, are given in Table 3.

Experimental sentences varied in structure and length, ranging from 4 to 18 words. We also included 60 filler sentences (all intuitive) of 6 to 10 words, in order to equate the overall number of counterintuitive (both religious and non-religious) and intuitive (correct) sentences.

All sentences were presented word by word, with 300-ms duration per word and 600 ms of stimulus-onset asynchrony (SOA), white-on-black on an LCD screen and controlled by Presentation software (San Francisco, USA). Participants' eyes were 65 cm from the monitor. At that viewing distance, all stimuli were presented between 0.7° and 1.3° high and between 1.1° and 6° wide.

## Procedure

Participants were seated in a comfortable chair in a sound-attenuated, electromagnetically isolated room. Electroencephalographic activity was recorded while participants performed a semantic judgment task for each sentence. This task was explained at the beginning of the experiment as follows: "Do you think this is possible in the real world? It is important not to think metaphorically and just pay attention on how plausible are these ideas in the real world." Participants used a right (possible) or left (not possible) button press to indicate their judgment during the appearance of a question mark presented 1 s after the last word of each sentence. Correctness and incorrectness judgments were given with the index and middle finger of one hand. The assignment of finger to response type and usage of left or right hand was counter-balanced. Under these procedures, motor preparation artifacts should not affect the main ERP components

TABLE 1

Examples of the sentences taken from diverse mythologies used in the study (with literal English translations in parentheses):

1. Hindu, 2. Egyptian, 3. Greco-Roman, 4. Mesoamerican, 5. African, 6. Australian, 7. Japanese, 8. Polynesian, 9. Chinese, 10. African

<i>Counterintuitive religious</i>	<i>Counterintuitive non-religious</i>	<i>Intuitive</i>
1. De su mente surgió la <b>luna</b> . (From his mind emerged the moon.)	De su mente surgió la <b>casa</b> . (From his mind emerged the house.)	De su mente surgió la <b>idea</b> . (From his mind emerged the idea.)
2. Su ojo te <b>devora</b> . (Her eye devours you.)	Su ojo te <b>lava</b> . (Her eye washes you.)	Su ojo te <b>observa</b> . (Her eye observes you.)
3. Ella nació de la <b>espuma</b> . (She was born from the foam.)	Ella nació de la <b>sartén</b> . (She was born from the pan.)	Ella nació de la <b>barriga</b> . (She was born from the womb.)
4. Embarcó en una balsa de <b>serpientes</b> . (He embarked in a boat made of snakes.)	Embarcó en una balsa de <b>hormigón</b> . (He embarked in a boat made of cement.)	Embarcó en una balsa de <b>madera</b> . (He embarked in a boat made of wood.)
5. Debajo de la tierra vive el <b>viento</b> . (Under the Earth lives the wind.)	Debajo de la tierra vive el <b>comedor</b> . (Under the Earth lives the dining-room.)	Debajo de la tierra vive el <b>topo</b> . (Under the Earth lives the mole.)
6. El hombre se volvió <b>halcón</b> . (The man became a falcon.)	El hombre se volvió <b>pierna</b> . (The man became a leg.)	El hombre se volvió <b>viejo</b> . (The man became old.)
7. Estaba tejiendo la tela del <b>universo</b> . (She was hand-weaving the fabric of the universe.)	Estaban tejiendo la tela del <b>manzano</b> . (She was hand-weaving the fabric of the apple tree.)	Estaban tejiendo la tela del <b>vestido</b> . (She was hand-weaving the fabric of the dress.)
8. Con un anzuelo, del fondo del mar sacó las <b>islas</b> . (With a hook, from the bottom of the sea, he took out the islands.)	Con un anzuelo, del fondo del mar sacó las <b>preocupaciones</b> . (With a hook, from the bottom of the sea, he took out the problems.)	Con un anzuelo, del fondo del mar sacó las <b>lubinas</b> . (With a hook, from the bottom of the sea, he took out the sea bass.)
9. De su barba salieron <b>asteroides</b> . (From his beard came out asteroids.)	De su barba salieron <b>armarios</b> . (From his beard came out wardrobes.)	De su barba salieron <b>canas</b> . (From his beard came out gray hairs.)
10. Se casó con la hija de la <b>estrella</b> . (She got married to the daughter of the star.)	Se casó con la hija de la <b>máquina</b> . (She got married to the daughter of the machine.)	Se casó con la hija de la <b>vecina</b> . (She got married to the daughter of the neighbor.)

TABLE 2

Semantic features (ontological categories) of experimental materials

	<i>Subject of the sentence</i>			<i>Target word</i>		
	<i>Religious</i>	<i>Non-religious</i>	<i>Intuitive</i>	<i>Religious</i>	<i>Non-religious</i>	<i>Intuitive</i>
Person	51.7	49.5	52.8	9.9	0	23.1
Natural object	28.6	15.4	27.2	72.6	29.7	41.8
Animal	7.7	6.6	7.7	12.1	1.1	6.6
Artifact	6.6	22	7.7	0.5	68.2	25.2
Plant	5.5	6.6	4.4	5.5	1.1	3.3

TABLE 3

Types of violations expressed in the counterintuitive sentences

	<i>Religious</i>			<i>Non-religious</i>		
	<i>Biological</i>	<i>Physical</i>	<i>Psychological</i>	<i>Biological</i>	<i>Physical</i>	<i>Psychological</i>
Person	25.3	23.1	3.3	17.6	28.6	3.3
Natural object	9.8	18.7	0	2.7	11.6	1.1
Animal	0	4.4	3.3	2.2	4.4	0
Artifact	0	6.1	0.5	1.1	18.7	2.2
Plant	3.8	0.5	1.1	2.2	2.2	2.2

of interest— N400 and P600—as the participants had to respond only after the question mark appearing 1 s after the end of the last (target) word of the sentence. Additionally, responses were always performed with the same hand, and both religious and non-religious incongruencies were responded to with the same finger. In order to minimize movement and ocular artifacts, participants were asked to move as little as possible and to blink only after pressing the button response, in the interval between sentences.

From the total of 600 sentences used in the experiment (180 each of counterintuitive religious, counterintuitive non-religious, and intuitive sentences and 60 fillers), three different sets of stimulus material were constructed. Each set contained non-overlapping 60 religious counterintuitive, 60 non-religious counterintuitive, and 60 intuitive sentences. In addition, the same 60 fillers were assigned to each set. None of the experimental sentences were repeated or presented in different versions within a given set; sentence presentation within each set was randomized. The same number of participants ( $n = 10$ ) was assigned to each of the three sets. The session started with a few practice trials that did not include any of the experimental sentences. Four short breaks were allowed during the recordings.

### Electroencephalogram (EEG) recordings analyses

The EEG was recorded from 27 tin electrodes embedded in an electrode cap (ElectroCap International, Ohio, USA) at sites Fp1, Fp2, F7, F3, Fz, F4, F8, FC3, FC4, T7, C3, Cz, C4, T8, TP7, CP3, CP4, TP8, P7, P3, Pz, P4, P8, O1, O2, FT7, and FT8 of the revised 10/20 International System (American Electroencephalographic Society, 1991). Additional external electrodes were placed on the mastoids (M1 and M2), and bipolar vertical and horizontal electrooculograms (VEOG and HEOG) were recorded from electrodes VEOG+, VEOG-, HEOG+, HEOG-. Electrodes were referenced online to the right mastoid and rereferenced off-line to the average of the left and right mastoids. Electrode impedances were kept under 3 k $\Omega$ . EEG signal was filtered with a band pass from 0.01 to 30 Hz and sampled at 250 Hz.

### Data analysis

Performance was measured in terms of reaction times (RTs) and error rates (i.e., counterintuitive religious and counterintuitive non-religious sentences judged as acceptable, and intuitive sentences judged as unacceptable).

From the continuous EEG record, epochs were selected time-locked to the target word presentation (–200 to 1000 ms). Artifact rejection was performed in two steps; first, eliminating those epochs which exceeded a range of  $\pm 100 \mu\text{V}$  in any of the channels, and second by visual inspection, rejecting those epochs that still presented artifacts. Ocular correction for blinks and eye movements was performed off-line by the method described by Gratton et al. (Gratton, Coles, & Donchin, 1983). Epochs with erroneous judgments were also eliminated. On average, 30.32% of the epochs were rejected (26.5% of counterintuitive non-religious, 29.73% of counterintuitive religious, and 34.73% of intuitive sentences).

## RESULTS

### Behavioral data

The mean percentage of judgment errors was highest for the intuitive sentences (21.2%), followed by religious (10.5%) and lastly by non-religious counterintuitive sentences (7.1%). The high rate of rejection, particularly for the intuitive sentences, may be due to our instruction that participants rate metaphors or ideas that do not belong to the real world as incorrect. Similarly, RTs were longer to intuitive sentences ( $M = 477.0$  ms,  $SD = 135.2$  ms) than to religious counterintuitive sentences ( $M: 433.9$  ms,  $SD: 118.8$  ms) or non-religious sentences ( $M: 415.93$  ms,  $SD: 113.3$  ms). Repeated-measures ANOVAs on error rates and RTs with the factor Counterintuitiveness (counterintuitive religious, counterintuitive non-religious, and intuitive) showed strong effects for both RTs,  $F(2, 29) = 23.3$ ,  $MSE = 1386.46$ ,  $p < .0001$ , and error rates,  $F(2, 29) = 33.8$ ,  $MSE = 24.99$ ,  $p < .0001$ . Pair-wise post-hoc analyses (Bonferroni corrected) showed that comparing intuitive with religious and non-religious counterintuitions yielded significant differences for RTs,  $t(29) = 4.3$ ,  $p < .01$  and  $t(29) = 6.2$ ,  $p < .01$ , respectively, and for error rates,  $t(29) = -3.2$ ,  $p < .0001$ , and  $t(29) = 7.7$ ,  $p < .0001$ , respectively. Comparisons between religious and non-religious sentences yielded significant effects for error rates,  $t(29) = 3.2$ ,  $p < .05$ , but only a trend for RTs,  $t(29) = 2.3$ ,  $p < .1$ .

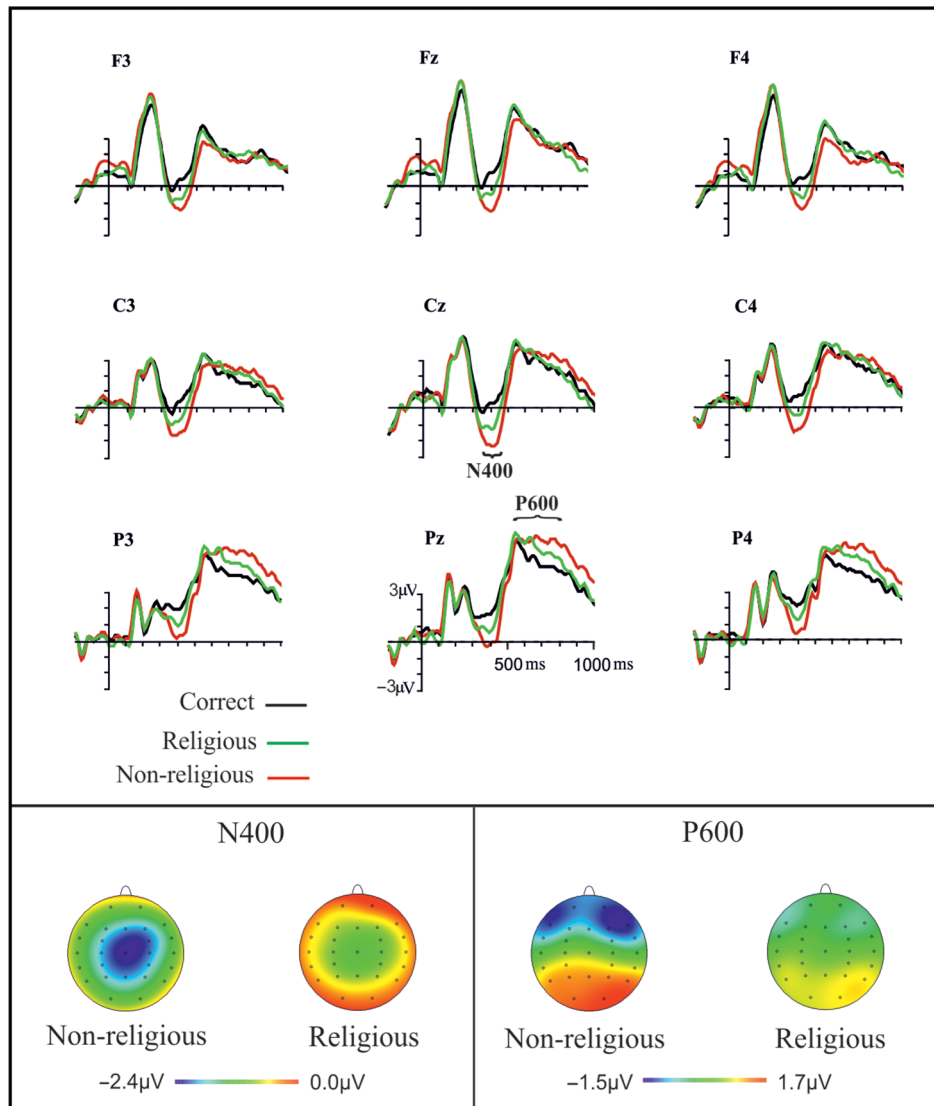
### ERP data

Visual inspection of the ERPs revealed a remarkable differential modulation of the N400 and P600 components by counterintuitive ideas. Both religious and non-religious counterintuitive sentences yielded a central N400. Although the standard

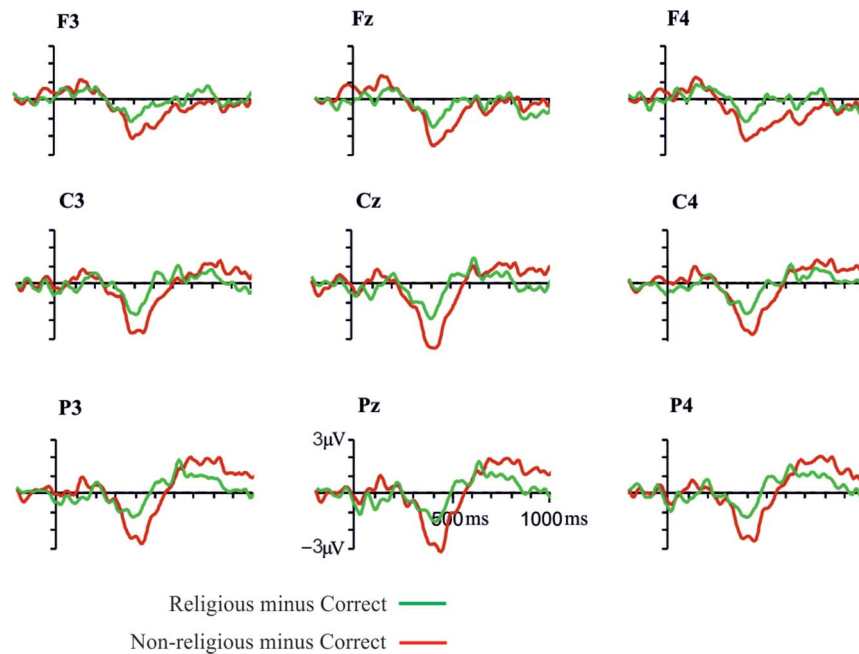


distribution of the N400 to visually presented words is centroparietal—displaying its maximum between Cz and Pz—small topographical deviations, such as the one found here, are not exceptional (Kutas & Federmeier, 2007). The N400 wave started at about 350 ms and peaked at about 400 ms after target stimulus onset, with the counterintuitive non-religious sentences exhibiting the largest amplitude. The N400 modulation was followed in both counterintuitive sentences by a small posterior positivity, or P600 effect, covering the time range from about 550 to 850 ms, and peaking around 750 ms. Again the non-religious counterintuitive sentences displayed the largest amplitude (Figures 1 and 2).

All of these observations were supported statistically, except for a difference in amplitude of the P600 component between religious and non-religious counterintuitive sentences that revealed no statistical differences. Overall repeated-measures ANOVAs were performed (Greenhouse–Geisser corrected) with the within-subjects factors Counterintuition (counterintuitive religious, counterintuitive non-religious, intuitive) and Electrode site (27 levels). The mean amplitude in the N400 latency window (350–450 ms) was strongly influenced by Counterintuition as main effect,  $F(2, 29) = 22.847$ ,  $MSE = 19.53$ ,  $p < .0001$ , as well as in interaction with Electrode,  $F(26, 52) = 2.8$ ,  $MSE = 5.22$ ,  $p < .01$ . In view of these results,



**Figure 1.** ERPs to intuitive (correct), religious and non-religious counterintuitive sentences. Top: ERP waveforms at a selection of electrodes for three types of sentence endings. Bottom: difference maps of the significant effects (non-religious minus intuitive on the right and religious minus intuitive on the left) for both N400 (left) and P600 (right) in 350–450-ms and 550–850-ms time windows, respectively.



**Figure 2.** Difference waves of results displayed in Figure 1. ERP waveforms at a selection of electrodes for the two counterintuitive sentence endings (religious and non-religious) after subtracting the activity to intuitive (correct) sentence endings.

pair-wise comparisons (Bonferroni corrected) were performed at the Cz electrode where the N400 was most conspicuous. Comparing intuitive with religious and non-religious counterintuitive sentences yielded significant effects,  $t(29) = 3.4$ ,  $p < .01$  and  $t(29) = 5.3$ ,  $p < .005$ , respectively. Importantly, the comparison between religious and non-religious counterintuitive sentences was also significant  $t(29) = 3.1$ ,  $p < .01$ , yielding an average voltage difference of  $1.1 \mu\text{V}$ .

Concerning the P600 component, the mean amplitude in the 550–850-ms latency window was not influenced by Counterintuition as main effect ( $F < 1$ ), but it was in interaction with Electrode,  $F(26, 52) = 10.5$ ,  $p < .0001$ . Accordingly, we performed pair-wise comparisons (Bonferroni corrected) at the Pz electrode, where the P600 is usually largest. None of these comparisons yielded significant results,  $t(29)$  between 1.3 and 2.6,  $p$  always  $>.051$ , with the exception of the comparison between non-religious and intuitive conditions, which yielded a significant main effect,  $t(29) = 2.6$ ,  $p < .01$ . When these comparisons were made in the electrode displaying the largest differences in the present study, O2, the comparisons between the intuitive sentences and the religious and non-religious counterintuitions were significant,  $t(29) = 3.2$ ,  $p < .05$  and  $t(29) = 4.3$ ,  $p < .01$ , respectively. However, when both types of counterintuitive sentences were compared, the result was far from significant,  $t(2, 29) = 0.06$ ,  $p > .1$ , with an average voltage difference of  $0.783 \mu\text{V}$ . Accordingly, and in

contrast to the N400, the P600 component does not seem to be significantly modulated by the religious nature of the sentences.

## DISCUSSION

The main aim of our study was to investigate whether religious and non-religious counterintuitive ideas are processed differently even though both are counterintuitions (for the most part, core-knowledge violations) and, at the same time, are equated in linguistic variables affecting semantic processing, such as word frequency and cloze probability. Hence, the main feature that differed between both types of counterintuitive ideas was their religious versus non-religious nature. As a prime indicator for the way these ideas are processed, we used the N400 component of the ERP. In particular, we assumed that semantic processing of the critical word together with a sentence context describing a religious counterintuitive idea could be easier to process than a non-religious counterintuitive idea, reflected in a smaller N400 for the former. The results confirmed this hypothesis.

The P600 component was not significantly modulated by the religious nature of the sentences. This component has been traditionally related to reanalysis or repair processes of sentence structure when a syntactic anomaly takes place (Osterhout & Holcomb, 1992). However, the occasional observation of a

P600 to purely semantic violations—as was the case here—has motivated recent alternative proposals, according to which it might reflect the activity of a combinatorial system that integrates both semantic and syntactic information (Kuperberg, 2007) or a domain-general monitoring mechanism (Kolk & Chwilla, 2007). Under either interpretation, our results suggest that the two types of counterintuitive sentences do not differentially affect these later processing stages. If anything, differential effects on the P600 were weaker and mirrored those during the N400 window.

Our main finding was the observation of a reduced amplitude of the N400 component for religious compared to non-religious counterintuitive ideas. Thus, in a semantic judgment task, the mind/brain processes religious ideas as being more intuitive/plausible than non-religious ones. Behavioral data appeared to go in the same direction. Our participants found it more difficult to reject religious ideas as unacceptable, as they needed more time to respond and made more errors as compared to non-religious counterintuitive ideas.

According to these observations, religious ideas appeared more imaginable or plausible than non-religious ideas. To substantiate this assertion, we used a sample of 80 participants other than those participating in the ERP study. They were asked how plausible our counterintuitive experimental sentences (both religious and non-religious) would appear in non-religious cultural contexts. Specifically, the question was, “How easy is it for you to imagine a context (books, films, newspapers, etc.) in which these statements may appear?” As in the EEG study, participants were unaware of the interest of the study in religion and answered on a scale from 1 (very unimaginable) to 5 (very imaginable). Each participant saw only one version of each sentence. Interestingly, the degree of plausibility was considerably higher for religious ( $M = 3.7$ ,  $SD = 0.7$ ) than non-religious ( $M = 2.6$ ,  $SD = 0.6$ ) ideas,  $t(79) = 15.1$ ,  $p < .0001$ .

The N400 component has been widely investigated in different conceptual frameworks and cognitive tasks. However, what it exactly reflects is still a matter of debate, and at least two main interpretations emerge. On the one hand, the N400 has been characterized as an index of the access to long-term, multimodal, lexico-semantic memory (Kutas & Federmeier, 2000, 2011; Lau et al., 2008). In this framework, N400 amplitude reflects the efforts of activating long-term memory representations of features associated with a lexical item. Hence, the preceding words in a sentence pre-activate certain semantic features stored in long-term memory, rendering lexical access to the target word less effortful to the extent that

its meaning overlaps with the pre-activated circuits. The lexical access view assumes that N400 modulations are not always directly related to the degree of lexical associations between the preceding words; that is, it reflects a non-combinatorial process. In contrast, the N400 has been characterized as an index of integration of the critical word in the ongoing context. The N400 would reflect a “unification process” defined as the integration of lexically retrieved information into a representation of multi-word utterances, as well as the meaning extracted from non-linguistic modalities (Baggio & Hagoort, 2011; Hagoort et al., 2009). This unification process results in a representation that is not already represented in memory. Therefore, differences between congruent and incongruent context would yield an N400 effect: The more incongruent the context, the larger is the amplitude of the N400, and congruity is constructed by a combinatorial process.

How should we interpret the finding of modulation of the N400 component as a function of the religious origin of the material, such that larger amplitudes of the N400 were found for non-religious incongruous sentences as compared to religious sentences? Under the lexical-access view of the N400, and given that all conditions share the same preceding sentence, a possible interpretation is that religious targets might share some semantic similarities in long-term memory with the (content) words preceding the target, leading to a priming effect. Indeed, of the multiple causes that can give rise to expectations against the ending word (such as scenario-based world knowledge, sensory context mental representation, or metalinguistic representation of discourse; see Van Berkum, 2010), this appears to us the most plausible factor in our materials. Under the semantic integration view of the N400, and given that all conditions share the same preceding context, a possible interpretation is that religious targets might share some semantic similarities in long-term memory with the situation or context described prior to the target word, facilitating the integration with the context. Thus, it would seem that even if describing implausible situations (judged specifically as such by the participants), words used as targets in religious sentences are easier to process semantically either at the lexical access stage or at the post-lexical stage of integrating the meaning of the word into the preceding context. According to the ERP chronometry, this mitigation of anomaly by religiousness is fully developed by 400 ms after the appearance of the target word which the idea expressed in the sentence renders as counterintuitive because it violates the world knowledge (in most cases, core knowledge) about an ontological entity. This indicates that differences related to religious ideas occur relatively early in cognitive processing. This is

the case even in participants with a low to moderate degree of religiosity.

The extent to which the N400 as an index of lexical access might apply to our data could be tested, at least concerning the presence of semantically priming words. Accordingly, we checked our materials regarding the content words preceding the targets in order to detect possible semantic relationships explaining differential priming effects on incongruous targets as a function of the type of counterintuition. An example of this situation can be found in the religious sentence no. 8 of Table 1, where “sea” could prime “island,” whereas no priming effects may be assumed in the non-religious sentence. However, we found this situation to be very rare in both conditions: Only 10 out of 180 religious sentences and 4 out of 180 non-religious sentences exhibited possible priming of preceding content words on the target word. Thus, the lexical access view of the N400 does not appear to substantially account for our data. Instead, the semantic integration view seems to be a more likely candidate. Our results suggest that religious sentences describe implausible situations as a result of combinatorial operations, which are nonetheless more acceptable for the human brain than other types of implausible situations. Therefore, a key unresolved puzzle emerging from our data is the question of which factor or set of factors renders some implausible combinations more acceptable than others.

It might be that the ontological categories and properties involved in the combinations play some causal role in such effects. When comparing our materials in terms of across-category types of counterintuitiveness (Table 3), the only noteworthy difference we found seems to be a threefold increase in violations of physical properties of artificial objects in non-religious counterintuitions over religious ones. When we consider the subject and the last word in the sentence (Table 2), differences are somewhat more conspicuous. In non-religious sentences, the subject was relatively often an artificial object when compared to the other two types of sentences. In contrast, in the latter two, natural objects occurred more as subjects than in non-religious sentences. Still, these differences appear to be relatively minor when we consider that about 50% of sentences of all three types contained persons as their subject. However, differences between sentence types appear clearly more remarkable when we consider the target word of the sentence. Most words terminating religious sentences and, therefore, converting the whole idea into a counterintuitive religious one, were natural objects. In contrast, non-religious counterintuitive sentences were mostly terminated by artificial objects.

Consequently, a critical variable in disentangling religious from non-religious counterintuitive ideas appears to be the ontological category of the target words. As the last word was the subject of the sentence in a number of occasions (16.6%), this means that religious ideas appear to be defined occasionally by either the violation of a biological, physical, or psychological property of a natural object or, alternatively, by attributing a property of natural objects to another ontological category. Considering that most subjects in either type of sentence belonged to the ontological category of person (Table 2), we suggest that the second alternative is more likely. By contrast, in non-religious counterintuitions, the violations occurred around artificial objects, at least in our materials. This type of counterintuition was apparently less intuitive and more difficult to integrate into the cognitive systems of the participants, yielding larger N400.

To test this hypothesis, ERP data were separated as a function of the specific category of the final word, within both the religious and non-religious counterintuitive materials. However, the results indicated that the distinction of natural versus artificial object is not a main explanation for our results. When both religious and non-religious counterintuitions containing only natural objects as targets were contrasted, the originally observed differences in the N400 remained very similar (an original average difference of 1.127  $\mu\text{V}$  at Cz changed into 1.081  $\mu\text{V}$  after this selection), even though differences dropped to a statistical trend,  $t(29) = 1.7$ ,  $p = .10$ . Furthermore, and critically, non-religious counterintuitions containing natural objects and artifacts as targets were compared, yielding nearly identical N400 amplitudes (average difference, 0.03  $\mu\text{V}$ ,  $t(29) = 0.6$ ,  $p = .54$ ), both being as conspicuous and large as in the original, pooled data. The same comparison could not be performed for the religious sentences, given the scarcity of artifacts as targets in this condition. Accordingly, a central role of natural objects as a critical category for religious ideas seems untenable. The underlying reason for religious sentences appearing as less anomalous than other world-knowledge violations remains unexplained.

Our results suggest some implications for cognitive models of religion. First, differences in N400 amplitude between intuitive and counterintuitive items indicate that the counterintuitive items (both religious and non-religious) were conceptually more anomalous and therefore processed differently than the intuitive items. Assuming this difference in anomaly relates to counterintuitiveness, these results demonstrate that counterintuitiveness is not necessarily the product of a larger narrative context, where the degree of counterintuitiveness depends upon the number of

world-knowledge violations included in the narrative. The same would apply to concepts and the number of violations included in their definition. Presumably, the advantages of being minimally counterintuitive shown for the narrative or concept levels (Boyer & Ramble, 2001; Norenzayan et al., 2006), such as better memorability or cognitive adherence, may also apply to isolated violations as used in the present study. Thus, cultural success of minimal counterintuitiveness—for example, in religious narratives or fiction in general—may be related also to the power of single ideas showing such properties and not only to the properties of the narrative as a whole. The high plausibility of counterintuitive religious ideas for our participants was therefore contextually independent.

A second implication is the necessity to further investigate the reasons why some world-knowledge violations are more acceptable than others to the human mind/brain. The systematic post-hoc analyses performed on our materials failed to engender salient explanations. However, these analyses were based on the distinctions suggested by Boyer (2001, 2003), whereas disagreements exist in the cognitive science of religion with respect to the types and number of ontological categories, “expectation sets” (i.e., types of violations), and even the type of phenomena belonging to a category (e.g., Barrett, 2008). Future work might take into consideration these conceptual differences.

Solving this question scientifically, in our view, would be of great interest in evolutionary terms. In approaching the human mind/brain as a product of natural selection, it is important to understand the reasons and evolutionary pressures resulting in some world-knowledge violations being more acceptable than others and hence more prone to be integrated in such complex cultural phenomena as religion.

In conclusion, religious ideas appear as less semantically anomalous for the human cognitive system than other types of world-knowledge violations. This seems to be an constitutional feature of certain ideas, which is even present when they are not embedded in a meaningful context. The present study highlights the importance of determining the evolutionary reasons why certain ideas are more acceptable to the human cognitive system than others and, thus, for their cultural success.

Original manuscript received 25 April 2011  
 Revised manuscript accepted 8 November 2011  
 First published online 2 December 2011

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