

Highly religious participants recruit areas of social cognition in personal prayer

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We used functional magnetic resonance imaging (fMRI) to investigate how performing formalized and improvised forms of praying changed the evoked BOLD response in a group of Danish Christians. Distinct from formalized praying and secular controls, improvised praying activated a strong response in the temporopolar region, the medial prefrontal cortex, the temporo-parietal junction and precuneus. This finding supports our hypothesis that religious subjects, who consider their God to be 'real' and capable of reciprocating requests, recruit areas of social cognition when they pray. We argue that praying to God is an intersubjective experience comparable to 'normal' interpersonal interaction.

Keywords: social cognition; theory of mind; belief; reciprocity; prayer

INTRODUCTION

In the comparative study of religion, it is a general finding that religious practice and experience encompass an enormous variety of diverse thoughts and behaviors. Since the early 20th century, massive efforts to categorise this diversity by psychologists, sociologists, anthropologists and scholars of religion have produced numerous typologies on different forms of religious expression (James, 1902; Weber, 1904; Durkheim, 1912; Berger, 1967; Geertz, 1973; Waardenburg, 1973; Whaling, 1983, 1984; Braun and McCutcheon, 2000; Antes *et al.*, 2004).

This finding that religion varies substantially within and between individuals and cultures is hardly acknowledged in the emerging experimental neuroscience literature on religious experience. In fact most studies on the relation between brain function and religion assume the hypothesis that religious experience is fundamentally a uniform category of human experience (Persinger, 1987; d'Aquili and Newberg, 1999; Azari *et al.*, 2001; Previc, 2006). Even though each line of research proposes different hypotheses on the neural substrates of religious experience, they generally agree on the uniformity of this broad phenomenon. Thus, it has been claimed that the felt presence of a supernatural being, and perhaps even the origin of religion, is caused by a specific pattern of transient electrical impulses

in the temporal lobe (Persinger, 1987, 2001), and that the transcendental experience of 'absolute unitary being' is caused by specific neural processes in the fronto-parietal networks (d'Aquili and Newberg, 1999, 2001).

Recently, however, work in the cognitive science of religion has attempted to integrate insights from the broader study of religion into the cognitive neurosciences (Geertz, 2004). In this line of research the underlying assumption is, in accordance with the broader framework of simulation and re-enactment theories, that religion is a product of complex interactions between cultural systems and basic human brain function. Akin to the idea that cognitive processing relies on the same neural regions as perception and action (Barsalou, 1999; Damasio, 1994, 1999; Fuster, 2003; Rizzolatti and Craighero, 2004), it is assumed that complex cultural phenomena such as religious practices are subserved by the basic processing of our biologically evolved dispositions, e.g. sensory-motor systems, reward processing and social cognition (Boyer, 2003; Schjoedt, 2007). Thus, the goal with this approach is not to map the neural correlates of the mystical or transcendental in religious experience, but to describe the basic cognitive processing employed by religious subjects in various religious practices.

To achieve this ambitious goal of describing cultural phenomena in terms of cognitive processes and brain function, insights from the social cognitive and affective neurosciences represent a particularly valuable source of data. Relating to social concepts and interacting with other persons is precisely where biological dispositions meet cultural systems. Indeed, this holds true for religion. Many religious subjects devote considerable time and energy on culturally transmitted beliefs and practices, e.g. gods, myths and rituals. A particularly striking example of such practices, in which social cognition and religious beliefs

Received 1 February 2008; Accepted 4 December 2008

Advance Access publication 25 February 2009

In this study participant consent was obtained according to the Declaration of Helsinki, and the study has been approved by the Ethical Committee of Aarhus Amt (journal nr. 20060038).

This work was done in collaboration with the MR Research Centre and the Center of Functionally Integrative Neuroscience (CFIN), Aarhus University Hospital, and the Department of the Study of Religion, University of Aarhus. Andreas Roepstorff was supported by grants from the Danish National Research Foundation and the Danish Research Council for Culture and Communication. Thanks to Gry Sjøqvist Sørensen and Kaare Schjødt for practical assistance and to Chris Frith for important comments and advice.

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interact, is the act of praying, which generally consists of a direct communication between the individual and a culturally transmitted entity.

One central categorization in the study of religion, which has survived scientific scrutiny for more than a century, is a distinction between formalized and improvised modes of religious expression (Weber, 1904, Turner, 1969). This typology has become a central topic in the cognitive science of religion, where anthropologists and philosophers apply cognitive and neurobiological theories on the ethnographic material to explain this widespread division (Whitehouse, 2000, 2004; McCauley and Lawson, 2002; Boyer and Liénard, 2006).

We used functional magnetic resonance imaging (fMRI) to investigate how performing formalized and improvised forms of praying changed the evoked BOLD response in a group of Danish Christians. Because the practice of praying comprises multiple subgenres and varies tremendously in form and content (mantra, petition, worship, thanksgiving etc.) (Geertz, 2008), we expect that praying, like other forms of mental practice, differ widely in both cognitive content and corresponding neural correlates. Specifically, we hypothesize that social cognition and its neural substrates are active in improvised prayers where religious subjects converse with a personal god, who they believe is real and capable of reciprocating requests. By neural substrates of social cognition we mean the three classic 'theory of mind' areas, namely, the anterior medial prefrontal cortex, the temporopolar region, and the temporo-parietal junction (Gallagher and Frith, 2003). We also hypothesize that these areas are less active in formalized prayers, because this form of praying typically consists of abstracted recitations with mainly non-personal content.

METHODS

Participants

Twenty young healthy male ($n=6$) and female ($n=14$) volunteers (mean age 25.4, range 21–32 years) participated in the study. We used the DASS self report instrument (<http://www.psy.unsw.edu.au/dass/>) to screen for depression, anxiety and stress, and found no cases of pathology. All participants reported that they had no history of neurological or psychiatric illness.

The participants belonged to a fraction within the Danish Lutheran Church called the Inner Mission, which is known for its orthodox views on Christian conduct. One example of this orthodoxy is their frequent and sometimes even exclusive use of orthodox prayers like the Lord's Prayer, which, according to Christian tradition, is sanctioned by Jesus as encompassing all important aspects of life. However, while the older generation of IM has remained faithful to a doctrinal mode of religious practice and still opposes new charismatic influences such as healing practices through personal and intercessory prayer, young IM adults in addition tend to integrate charismatic features both

collectively and in private. One example of this turn towards charismatic practice is an increasing number of young IMs attending churches with overlapping attendance of Pentecostals. In private, young IMs are now practicing improvised forms of praying in addition to recitations of highly formalized prayers.

Conditions and procedure

We introduced two different forms of praying, which correspond to the above-mentioned typology of religious practice (Weber, 1904; Lawson and McCauley, 2002; Whitehouse, 2004). According to this typology, religious practice can be divided into two different categories depending on their structure: a highly formalized institutional mode of religion, which consists of frequently rehearsed and rigidly performed actions and speech acts, and a non-institutional mode consisting of improvised actions and speech acts. We used The Lord's Prayer as a highly formalized 'Speech act', and Personal Praying as an improvised 'Speech act' (see supplementary data for examples of personal prayer written by participants of this study) (Austin, 1962; Searle, 1969; Jensen, 2003). We used two corresponding speech acts from the secular domain as control (Table 1), namely a well-known Nursery Rhyme of participants' own choice to control for the effects of formalization, and wishes to Santa Claus to control for the effect of improvisation. We then contrasted the four conditions in a two-by-two design and further introduced a linguistic, non-semantic base line (counting backwards from 100).

After 10 min of structural scanning, which habituated the participants to the MR environment, they were asked to perform the five tasks in a semi-randomized order. Tasks were prompted by auditory stimuli in the headphones between tasks (discarded in analysis). Each of the five conditions lasted 30 s and was repeated six times. Tasks were performed silently as internal speech with eyes closed, and participants were asked to concentrate on the task and to repeat it if they finished within a 30 s block. Questionnaires on self-reported belief in God, confidence in God's reciprocity and frequency of praying were provided post-scan.

Image acquisition and data analysis

The fMRI was carried out by using echo planar imaging (EPI) and was performed on a 1.5 Tesla GE Signa using the standard head coil for radiofrequency transmission and

Table 1 Two-by-two factorial design; 'Domain' and 'Speech act'

Two-by-two factorial design	Domain	
	Religious	Secular
Speech act		
Formalized	The Lord's prayer	Nursery rhyme
Improvised	Personal praying	Making wishes to Santa Claus

signal reception. For whole brain coverage, 30 axial slices (1.0 mm slice spacing, 3.0 mm slice thickness) were positioned with a 64×64 voxel size and a repetition time (TR) of 3000 ms. Scout image and T1-weighted image of each participant were obtained before the fMRI sessions. Image processing and statistical analysis were done using SPM 5 (Statistical Parametric Mapping; Wellcome Department of Imaging Neuroscience) implemented in MATLAB 2006a. The image series was realigned and spatially normalized to the MNI Talairach stereotactic space (Talairach and Tournoux, 1988) and smoothed with a Gaussian kernel of $8 \times 8 \times 8$ at FWHM. Low-frequency drifts in signal changes were removed by high pass filter. Anatomical localizations of local maxima were assessed neurologically by reference to the WFU PickAtlas 2.3 (Maldjian *et al.*, 2003; 2004). The second-level analysis was analyzed in a two-by-two factorial design. Tables showing the results include anatomical regions, mni-talairach coordinates and Z-value. All results discussed in this report are thresholded at $P < 0.05$ corrected for multiple comparisons (False Discovery Rate, Genovese *et al.*, 2002) with a minimum extent threshold of 15 voxels to accommodate for statistical noise from FDR limitations.

RESULTS

The participants all reported that they believed in God but not in Santa Claus. To the question 'do you believe that God exists?' all participants answered 'yes' or 'definitely yes', while answers to the same question for Santa Claus were either 'no' or 'definitely not'. They reported to be practicing the Lord's Prayer and Personal Prayer on a weekly basis (The Lord's Prayer, mean 4.75 times, range 1–14 times, and Personal Prayer, mean 19.75 times, range 7–50), and expressed a strong confidence in God's reciprocity. On a scale of 1–10, where 10 was 'I am absolutely sure God reacts to my prayer', all answers rated 9 (27%) or 10 (73%). Devoted Christians generally assume it to be self-evident that God answers all prayers in one way or another. This confidence correlates with their belief in an omnipresent, omniscient, and omnipotent God.

In recorded post-scan interviews, participants were asked to compare praying inside the scanner to praying in private. All participants reported that praying in the scanner was indeed comparable to praying in other settings outside the scanner (one situation, in which almost all participants reported to be praying, was while riding a bike). The participants reported that they were generally able to concentrate on all of the tasks in spite of the noise from the scanner. Asking them which condition was the hardest to perform of the five (baseline included) answers differed widely from subject to subject. Some reported that the Lord's Prayer and the Rhyme were the most difficult, because of their rigid structure, others judged Personal Prayer and Wishing to Santa Claus to be the most difficult, because they ran out of wishes and things to pray for (they had to perform each task six times for 30 s each). One reported that making wishes to Santa Claus was difficult because of her religious beliefs, i.e. 'praying' to Santa Claus simply felt wrong.

Main effects

In order to identify the general effects of 'religious speech acts', we performed a main effect analysis on the two prayers relative to their secular contrasts. In this whole brain analysis, we did not find any suprathreshold voxels corrected for multiple comparisons. Based on a prior hypothesis on reward processing in habitual praying we did, however, find a main effect in the caudate nucleus in a ROI analysis of the dorsal striatum, which was mainly activated by the Lord's Prayer. This finding is discussed separately elsewhere (Schjoedt *et al.*, 2008). In the opposite condition, which probed the main effect of 'secular speech acts,' we observed a strong response bilaterally in the lateral prefrontal cortex and in the right superior temporal cortex (Table 2). The bilateral activation of the lateral prefrontal cortex may point to an effect on the executive and attentional network, which may be a function of the participants' different levels of familiarity with the two domains (Fuster, 2003, 167). Because of our special interest in the social cognitive aspects

Table 2 Main effect of domains

Anatomical region (Brodmann areas)	Cluster size (functional voxels)	x	y	z	Z-value
Main effect of religious domain [(the Lord's prayer + personal praying) – (nursery rhyme + making wishes to Santa Claus)]					
No suprathreshold voxels					
Main effect of secular domain [(nursery rhyme + making wishes to Santa Claus) – (the Lord's prayer + personal praying)]					
Right lateral prefrontal cortex (BA 10)	481	48	34	30	5.73
Right superior temporal cortex (BA 22)	91	66	–36	12	5.57
Left lateral prefrontal cortex (BA 46)	395	–48	38	14	4.59
Left parieto-occipital cortex (BA 7)	152	–28	–70	32	3.97
Right suppl. premotor cortex (BA 60)	25	8	20	50	3.94
Right parietal cortex (BA 40)	43	40	–58	44	3.90
Right Occipital cortex (BA 18)	19	20	–72	14	3.66

Region (nearest Brodmann's areas)/mni-talairach (x, y, z)/Z-value. Results are thresholded at $P < 0.05$ corrected for multiple comparisons (FDR) with an extended threshold of 15 voxels.

Table 3 Interactions

Anatomical region (Brodmann areas)	Cluster size (functional voxels)	x	y	z	Z-value
[(Personal praying + nursery rhyme) – (making wishes to Santa Claus + the Lord's prayer)]					
Right precuneus (BA 7)	950	8	–66	34	4.88
Left temporopolar region (BA 21)	144	–46	4	–40	4.74
Left temporo-parietal junction (BA 39)	803	–38	–54	22	4.46
Right premotor cortex (BA 6)	27	16	–16	62	4.11
Right superior temporal cortex (BA 22)	41	58	–30	2	4.00
Right temporopolar region (BA 21) ^a	13	50	10	–32	3.68
[(Making wishes to Santa Claus + the Lord's prayer) – (personal praying + nursery rhyme)]					
Right dorsomedial prefrontal cortex (BA 8)	836	2	18	54	4.64
Right cerebellum posterior lobe	146	8	–80	–24	4.62
Left premotor cortex (BA 6)	220	–32	2	58	4.41
Posterior cingulate cortex (BA 31)	129	–4	–68	12	4.41
Left parietal cortex (BA 19)	135	–28	–74	38	4.10
Right occipital cortex (BA 18)	56	6	–98	–2	4.09
Right lateral prefrontal cortex (BA 10)	43	–44	42	14	3.69
Left lateral prefrontal cortex (BA 10)	39	48	38	26	3.64

Region (nearest Brodmann's areas)/mni-talairach (x, y, z)/Z-value. Results are thresholded at $P < 0.05$ corrected for multiple comparisons (FDR) with an extended threshold of 15 voxels.

^aClusters of interest below 15 voxels.

of prayer, however, we shall not discuss these observations further.

Interactions

We then performed an interaction analysis on the presumption that our two factors of 'Speech Act' and 'Domain' interact in praying, particularly in the regions involved with 'theory of mind' processing. In the first contrast [(Personal Praying + Nursery Rhyme) – (Making Wishes to Santa Claus + The Lord's Prayer)], we observed increased activity in, among others, the right precuneus, left temporopolar region and the left temporo-parietal junction (Table 3). In the opposite contrast [(Making Wishes to Santa Claus + The Lord's Prayer) – (Personal Praying + Nursery Rhyme)] we observed activity in, among others, right dorsomedial prefrontal cortex, right cerebellum and left premotor cortex (Table 3). This interaction indicates that 'Speech Act' and 'Domain' are not independent factors.

Individual contrasts

We explored this interaction by contrasting the individual conditions. First, we contrasted Personal Praying relative to Making Wishes to Santa Claus. In this contrast Personal Praying revealed increased neural activity in the left precuneus, the left temporo-parietal junction, the left temporopolar region and in the left medial prefrontal cortex (MPFC) (Figure 1 and Table 4). In the opposite contrast, Making Wishes to Santa Claus revealed, among others, bilateral activations in the dorsolateral prefrontal cortex, the right supplementary motor area (SMA), the right posterior limbic lobe and bilaterally in the precuneus.

Second, we contrasted Personal Praying relative to The Lord's Prayer. Again, Personal Praying revealed increased neural activity along the MPFC, and minor

activations in the left temporopolar region, the left temporo-parietal junction, and in the left precuneus (Table 4). The Lord's Prayer showed massive activations in the right dorsolateral prefrontal cortex, the right parietal cortex, left cerebellum, and in the posterior part of the inferior temporal cortex. However, a main effect analysis of the formalized speech acts indicated that these activations may be a general effect of rehearsal and retrieval, which are distinctive aspects of both formalized prayers and nursery rhymes (see supplementary data for results of the main effects of formalized and improvised speech acts). Finally, we contrasted The Lord's Prayer with the Nursery Rhyme, but found no significant voxels in these contrasts.

DISCUSSION

We found no significant main effects of the two prayers relative to their secular controls in our 'whole brain' analysis, but we did find significant activations in the interaction analysis between the two factors, 'Domain' and 'Speech act'. These findings support the general assumption that different forms of religious praying are defined by diverse cognitive features and subserved by different networks of activation. Furthermore, our main hypothesis on the relation between social cognition and praying was supported by individual contrasts, which revealed a specific pattern of neural activity in Personal Praying relative to Making Wishes to Santa Claus consisting of the temporo-parietal junction, the temporopolar region, the anterior MPFC and the precuneus.

The temporo-parietal junction, the temporopolar region and the anterior MPFC have all been extensively reported in studies of social cognition (Castelli *et al.*, 2000; Rilling *et al.*, 2004; Amodio and Frith, 2006; Schilbach *et al.*, 2008), and together they have been referred to as the three

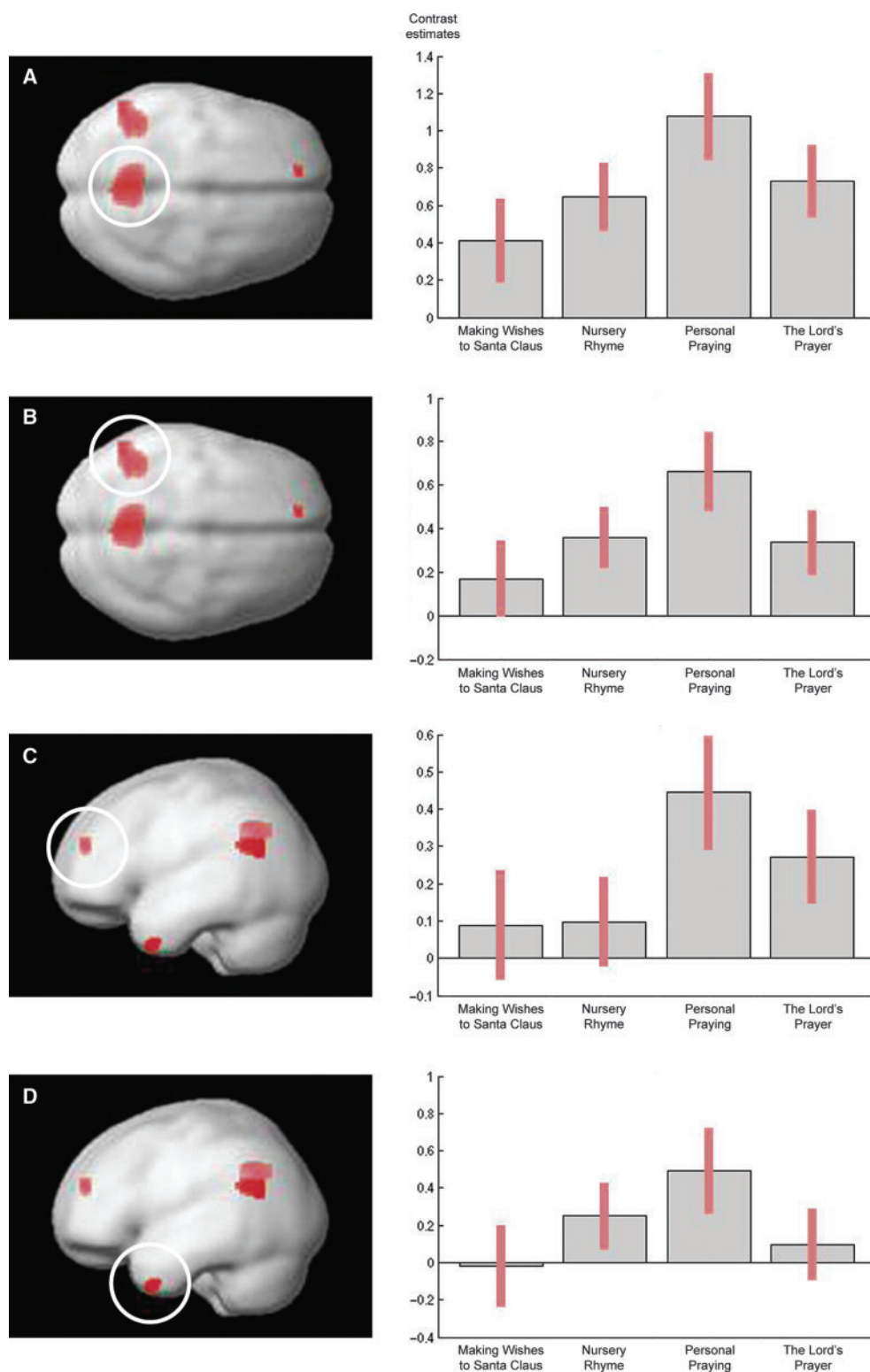


Fig. 1 To the left: Personal praying relative to making wishes to Santa Claus. Results are thresholded at $P < 0.05$ corrected for multiple comparisons (FDR) with an extended threshold of 15 voxels. To the right: effect size analysis of the regions of interest in the four conditions relative to baseline (90% CI). (A) Precuneus. (B) Temporo-parietal junction. (C) Anterior medial prefrontal cortex. (D) Temporopolar region.

Table 4 Individual contrasts

Anatomical region (Brodmann areas)	Cluster size (functional Voxels)	x	y	z	Z-value
Personal praying vs. making wishes to Santa Claus					
Left precuneus (BA 7)	527	−10	−60	32	4.71
Left temporo-parietal junction (BA 39)	286	−40	−54	24	4.68
Left temporopolar region (BA 21)	44	−46	6	−40	4.30
Left medial prefrontal cortex (BA 9)	31	−14	50	22	4.18
Making wishes to Santa Claus vs. personal praying					
Right dorsolateral prefrontal cortex (BA 46)	1336	46	38	26	5.53
Left dorsolateral prefrontal cortex (BA 46)	1399	−32	26	14	4.74
Right suppl. motor area (BA 6)	994	8	18	50	4.44
Right posterior limbic cortex (BA 30)	791	18	−70	8	4.37
Left precuneus (BA 19)	1080	−28	−74	38	4.36
Right occipital cortex (BA 17)	114	8	−98	0	4.34
Left motor cortex (BA 4)	57	−12	−36	64	4.05
Right precuneus (BA 19)	149	30	−70	38	3.55
Personal praying vs. the Lord's prayer					
Left dorsomedial prefrontal cortex (BA 6)	52	−8	10	64	4.85
Left anterior medial prefrontal cortex (BA 9)	145	−10	54	38	4.41
Left temporopolar region (BA 21) ^a	7	−46	4	−40	4.00
Left temporo-parietal junction (BA 39) ^a	12	−46	−62	24	3.92
Left precuneus (BA 7) ^a	4	−8	−56	36	3.84
The Lord's prayer vs. personal praying					
Right dorsolateral prefrontal cortex (BA 10)	13378	40	40	24	6.05
Right Parietal cortex (BA 40)	11530	48	−42	54	5.26
Left cerebellum	5156	−12	−84	−30	4.91
Right inferior temporal cortex (BA 20)	1333	62	−50	−16	4.65
Left dorsolateral prefrontal cortex (BA 46)	1113	−46	44	12	4.26
Right posterior cingulate cortex (BA 31)	3141	4	−30	42	4.24
Left superior parietal cortex (BA 5)	60	−12	−42	68	3.19
Right cerebellum	173	28	−64	−26	3.10
Left superior parietal cortex (BA 7)	51	−14	−50	56	2.97
The Lord's prayer vs. nursery rhyme					
No suprathreshold voxels					
Nursery rhyme vs. the Lord's prayer					
No suprathreshold voxels					

Region (nearest Brodmann's areas)/mni-talairach (x, y, z)/Z-value. Results are thresholded at $P < 0.05$ corrected for multiple comparisons (FDR) with an extended threshold of 15 voxels.

^aClusters of interest below 15 voxels.

classic 'theory of mind' areas (Gallagher and Frith, 2003; Völlm *et al.*, 2006). We argue that this pattern of activation in Personal Praying suggests that talking to God, who is considered 'real' rather than 'fictitious' like Santa Claus (see Results section), is comparable to normal interpersonal interaction.

Imaging studies have shown that subjects playing reciprocity games against computers and humans recruit the anterior MPFC and the temporo-parietal junction specifically for 'human' interaction (McCabe *et al.*, 2001; Gallagher *et al.*, 2002; Rilling *et al.*, 2004). While the anterior MPFC in particular has been associated with mentalizing about the intentions of self and others (Brunet *et al.*, 2000; Gallagher and Frith, 2003; Amodio and Frith, 2006), it has been suggested that the temporo-parietal junction is more involved in analyzing behavior and processing social causation and goal attribution (Gallagher *et al.*, 2000; Brunet *et al.*, 2000; Gallagher and Frith, 2003). The observed activation of

these regions may suggest that praying to God is comparable to negotiating with a human partner in reciprocity games. Christian subjects generally understand God as an intentional agent with beliefs and desires, and they recognize God's agency as an effect of God's intentions. The participants of our study support this general finding. According to post-scan interviews, they all claimed that they visualize God as a human being rather than an abstract superhuman entity, and questionnaires revealed a high confidence that God reacts to their prayers (see Results section).

It is, however, uncertain whether the active areas of social cognition observed in Personal Praying point to an effect of the perceived 'reality' of God or the expected 'reciprocity' of God. One way to distinguish between these two factors would be to introduce a third condition between the 'fictitious' Santa Claus and the 'real' God in which participants were instructed to converse with an imagined significant other, e.g. a parent who is real but incapable of reacting to

the internal speech in the scanner. We hypothesize that the anterior MPFC is linked to the 'realness' of God and therefore would remain active, while the temporo-parietal junction, which may be linked to the expected 'reciprocity' of God, may prove less active in such a condition because it does not include processing of social causation. Thus, we argue that both aspects are likely contributors to the observed findings in personal praying.

Personal Praying also activated the temporopolar region, which has been associated with autobiographical memory and processing of social narratives in previous social cognitive studies (Fink *et al.*, 1996; Dolan *et al.*, 2000; Vogeley *et al.*, 2001; Olson *et al.*, 2007; Zahn *et al.*, 2007). The temporopolar region may subserve these functions in praying, because praying on a daily basis requires a constant updating of the subject-God relation (e.g. how God has responded to previous prayers). Our participants reported that they practiced personal praying 20 times a week (see Results section), and according to post-scan interviews, they claimed that God had always answered their prayers in one way or another, which is in line with their self-reported confidence that God generally reacts to their prayers (see Results section).

Note that we observed a strong response in the precuneus, although at different locations, in both Personal Praying and Making Wishes to Santa Claus. The function of precuneus in higher-order cognitive processing is still unclear, but the region has consistently been associated with self-referential activities (Cavanna and Trimble, 2006), e.g. in self-relevant information processing (Kircher *et al.*, 2000; Kjaer *et al.*, 2002). The activation of this region in both Personal Praying and Making Wishes to Santa Claus may be related to the fact that both conditions include self-relevant information processing, e.g. things you desire or problems you need to attend to. These aspects may not be influenced by the participant's belief or disbelief in God or Santa Claus.

Precuneus activity has also been reported in conjunction with activations of the MPFC and the temporo-parietal junction in both social cognitive and self-referential tasks (Gusnard and Raichle, 2001; Gusnard *et al.*, 2001; Vogeley and Fink, 2003; Schilbach *et al.*, 2006, 2008). One way to interpret the functional overlap of this network is to appreciate the close relationship between processing intentionality of self and others, especially in the light of simulation theories on empathy and social interaction (Barsalou, 1999; Damasio, 1999; Rizollati and Craighero, 2004; Singer *et al.*, 2006). Personal praying, which activated the network, serves as a particularly illustrative example of this functional overlap, because this form of praying is precisely about relating interpersonally to self-relevant subject matters.

The same network of activation is also commonly reported in effortless baseline conditions relative to demanding target conditions, and because of this, it is sometimes referred to as the brain's 'default system' or 'resting state'.

According to Schilbach *et al.*, these observations may reflect a human predisposition of social cognition as the default mode of cognizing (Schilbach *et al.*, 2008). It is unclear how the activation of the temporopolar region observed in Personal Praying relates to this 'default' system. We suggest that it may serve this network as a storage room of social narratives and autobiographical memories relevant for subject-God relations.

Activation of the MPFC, the temporopolar region, the temporo-parietal junction, and the precuneus was also found in Personal Praying relative to The Lord's Prayer. This finding indicates that, compared with formalized praying, improvised forms of praying are better capable of activating 'theory of mind' processing. We expected this because highly formalized prayers usually consist of frequently rehearsed, abstracted and non-personal content. Indeed, more than one of the IM participants warned us in pre-scan interviews that The Lord's Prayer had become so habituated that it probably would not give us any results at all. Contrary to reciting The Lord's Prayer, personal praying consists of improvised and direct conversations with God about personal problems and requests. In this form of praying mentalizing, social reciprocity, autobiographical memory and updating of social narratives are much more relevant features.

Reciting The Lord's Prayer did show major activations in a number of regions in the opposite contrast, e.g. in the dorsolateral prefrontal cortex, the parietal cortex, and the cerebellum. However, a main effect analysis of 'formalized speech acts' (The Lord's Prayer and Nursery Rhyme relative to Personal Praying and Making Wishes to Santa Claus) revealed that most of these activations may be a general effect of rehearsal and retrieval (supplementary data). Furthermore, analyses on these regional activations are necessary in order to explore d'Aquili and Newberg's hypothesis on the function of fronto-parietal networks in religious experience (d'Aquili and Newberg, 1999; Newberg *et al.*, 2001).

In conclusion, our results show that young Danish Christian Protestants of IM recruit areas of social cognition during personal prayer, which suggests that praying to God is an intersubjective experience comparable to 'normal' interpersonal interaction. This finding is not only interesting to social cognitive and affective neuroscience and the cognitive science of religion. It also offers important insights to the study of theology, in which Christian doctrine on God's nature includes abstract concepts like God's omnipresence, omniscience, omnipotence, the Trinity and the Holy Spirit. Interestingly, in terms of brain function, our results suggest that the IM participants mainly think of God as a person, rather than as an abstract entity. This observation supports previous cognitive studies which have demonstrated that religious subjects are generally incapable of keeping a strict doctrinal representation of God in online cognitive processing (Barrett and Keil, 1996).

However, praying, which lies at the center of all religions (Geertz, 2008), is a complex phenomenon that includes acts of individual prayer, collective prayer, intercessory prayer, ritual incantation and meditative prayer, and each have multiple subgenres (petition, hymns, worship, thanksgiving, confession, chanting, etc.) and demonstrate significant variance across cultural contexts (Mauss, 1909). Further studies of other religious groups and other types of prayer are needed to grasp the differences and commonalities of this broad category of religious practice. Our finding that personal praying and the Lord's Prayer activate different neural regions adds force to the general assumption in the comparative study of religion that religious practices and experiences are very diverse phenomena. We do not argue that these findings support the hypothesis that formalized and improvised modes of religious expression are essential categories with distinct and uniform neural correlates, but our results do support ethnographic and psychological evidence on this distinction. Finally, we urge future studies in the experimental neuroscience of religion to use conventional theories of brain function rather than novel hypotheses on specific neural mechanisms, and to take insights from the comparative study of religion seriously in order to give a realistic account of this complex and heterogeneous phenomenon.

SUPPLEMENTARY DATA

Supplementary data are available at SCAN online.

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