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Rewarding prayers

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ABSTRACT

We report a highly significant regional increase of the BOLD response in the caudate nucleus in a group of Danish Christians while performing silent religious prayers. The effect was found in a main-effect analysis of high-structured and low-structured religious recitals relative to comparable secular recitals and to a non-narrative baseline. This supports the hypothesis that religious prayer as a form of frequently recurring behavior is capable of stimulating the dopaminergic reward system in practicing individuals. It extends recent research which demonstrates a relation between interpersonal trust and activation in the dopaminergic system to also encompass relations to abstract entities.

The principal relation between science and religion has recently created a stir [3,5,9]. To most empirical researchers of religious practices, however, "religion" is not primarily an abstract ideological framework. Rather, it is important in motivating a range of frequently repeated behaviors. Repetition of rituals and prayers is central to all five world religions and pervades the lives of billions around the world [7,14]. Often sanctioned by dogma, such practices are constitutive of most religions. To many believers, praying, in particular, forms a recurring daily practice that requires the devotion of considerable time and energy (e.g. devoted Muslims prostrate while praying five times every day [21]). It has been argued that the actual practice of praying is central rather than epiphenomenal to its cognitive function in practicing individuals [1], and therefore cannot be separated from its other putative functions, e.g. dealing with epistemological questions [14] or coping with concrete challenges [7,11,14]. Praying as behavioral practice, however, has received much less attention in the cognitive literature.

Previous neuroimaging studies of religious practice have mainly attempted to identify neural correlates of practitioner's subjective experiences in phenomena like meditation [17,18] and mystical experiences [2,20]. In this study, we considered forms of praying as elaborate examples of (religiously inspired) repeated behaviors, and we examined the effects they elicited in the central nervous system. Briefly, we used functional magnetic resonance imaging (fMRI) to investigate how performing religious prayers changed the evoked BOLD response in a group of Danish Christians, who belonged to a fraction (Inner Mission) within the Protestant Danish Christian Church. We hypothesized that, like other forms of repeated habits, praying would activate the human striatal reward system [4,8].

The striatum is a subcortical brain region, which plays a crucial role in motor function and in forming behavioral habits [8]. Studies on addictive behavior in relation to drug usage show that the striatum may be involved in the formation of both early and advanced stages of addiction [6,8]. However, striatal activations have also been reported in oddball paradigms of reward evaluation, implying that the human striatum is also involved in reward-related learning [23]. It is not yet clear how forming behavioral habits and reward-related learning relate to each other in the striatum. They may be intrinsically related as habitual behaviors are motivated by reward, and reward is induced by habitual behaviors. Recent research on the human striatum suggests that the ventral and dorsal striatum form anatomical subdivisions that serve different functions with respect to goal-directed behavior [6] and conditioning [19]. The ventral striatum (in particular nucleus accumbens), which has extensive connections to ventral frontal regions and the limbic system, appears to be activated when processing immediate reward evaluation, a necessary capacity in both Pavlovian and instrumental conditioning. The dorsal striatum (e.g. caudate nucleus), which receives extensive input from the dorsolateral prefrontal cortex and other surrounding frontal regions, seems by contrast to be more

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	Religious	Non-religious
High Structure	The Lord's Prayer	Rhyme
Minimal Structure	Personal Prayer	Wishing to Santa Claus

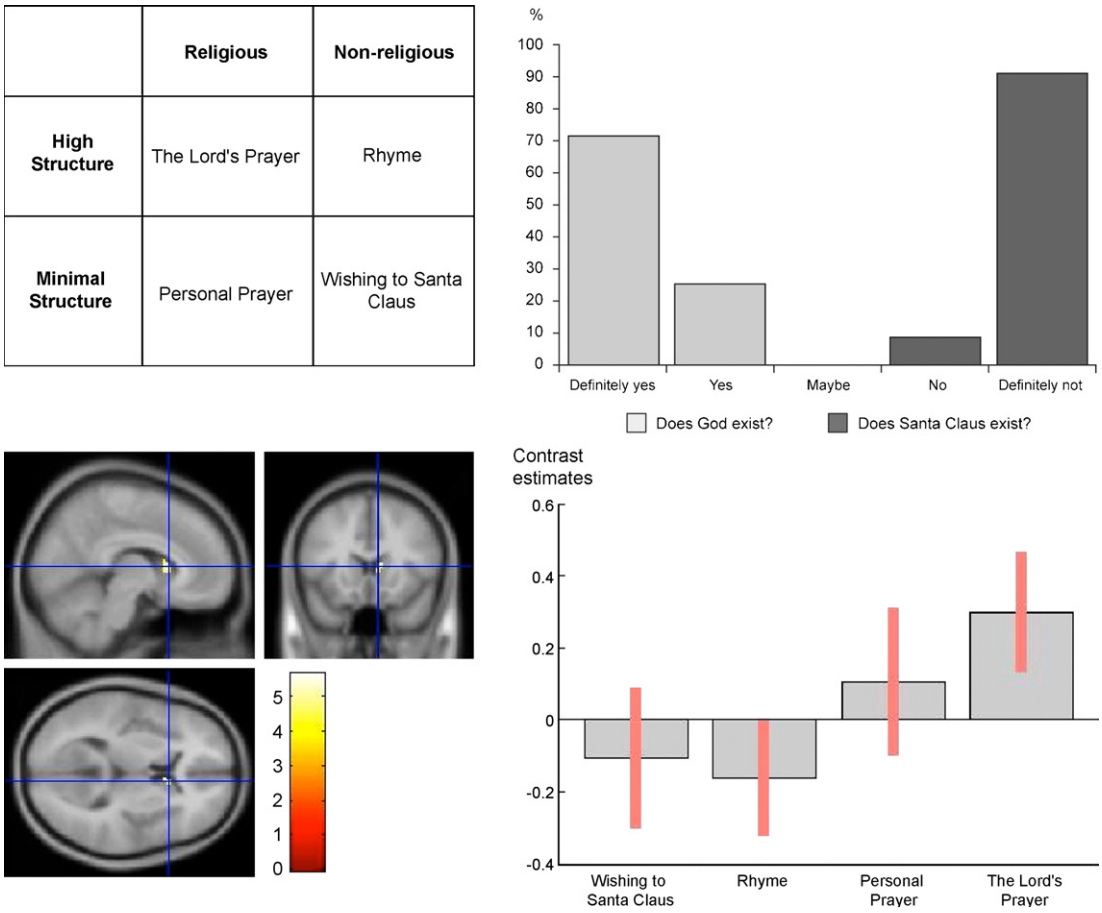

Fig. 1. (A) Experimental design. (B) Participants' self-reported belief in the existence of God and of Santa Claus. (C) Main effect of prayer in a Region of Interest (ROI) analysis of the caudate nucleus observed at $p < 0.003$ FWE, corrected for multiple comparisons. (D) Contrast estimates in right caudate nucleus in individual conditions relative to baseline (90% C.I.).

involved in instrumental conditioning, that is, learning, updating and reinforcing actions that lead to expected rewards in the future [4,23]. Recently, this idea has gained further support from economic exchange games extending the function of the dorsal striatum to the social domain [10]. In these reciprocity games participants learned about their partner's trustworthiness through trial and error, which made them able to optimize and predict monetary reward. Rather interestingly, this learning to trust partners was predicted and mirrored by activation of the dorsal striatum. This suggests that the caudate nucleus is also actively involved in evaluating future rewards dependent on interpersonal reciprocity.

Because of the central aspect of repetition in habitual praying, we assumed a main effect of praying in the striatum. Within the striatum, we hypothesized a main effect in the caudate nucleus of the dorsal striatum because praying is mainly about affecting future outcomes rather than immediate rewards. This relation between the dorsal striatum and instrumental conditioning becomes particularly interesting in studies on interpersonal reciprocity because reward evaluation in praying depends on the practitioner's confidence in a reciprocating God.

The subjects of our study were twenty young healthy male ($n = 6$) and female ($n = 14$) volunteers (mean age 25.4, range 21–32 years) with no known history of neurological or psychiatric illness. As we were equally interested in the general effects of praying and the differences between forms of praying, we introduced two different prayers, which correspond to a well-established typology of religious practice [15,24,25]. According to this typology, religious practice can be divided into two different categories depending on their structure: a highly formalized mode of religion, which consists of rigidly performed rituals and prayers, and a non-institutional mode consisting of low-structured and improvised practices. We used the Lord's Prayer as a highly formalized prayer, and Personal Prayer as an improvised prayer (see Supporting online material for examples of personal prayer written by participants of this study). We used a well-known rhyme of own choice to control for the effects of formalization, and a wishful praying to Santa Claus to control for the effect of improvisation. We then contrasted the four conditions in a two-by-two design (Fig. 1A) 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 (single recording with mixed 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 6 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.

The functional magnetic resonance imaging was carried out by using echo planar imaging (EPI) and was performed on a 1.5 T GE Signa using the standard head coil for radiofrequency transmission and 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. A scout

image and a T1-weighted image of each participant were obtained before the fMRI sessions. Image processing and statistical analysis were done using SPM 5 (Statistical Parametrical Mapping) implemented in MATLAB 2006a. The image series was realigned and spatially normalized to the MNI Talairach stereotactic space [22] and smoothed with a Gausian kernel of $8 \times 8 \times 8$ at FWHM. Low-frequency drifts in signal changes were removed by a high pass filter. Group data were analyzed in a simple one-sample *t*-test. We analyzed the region of interest (ROI) using the WFU PickAtlas Version 2.3 [12,13] to isolate the anatomical structure of the caudate nucleus.

The participants all reported that they were strong believers in God's existence, and they demonstrated no overlapping beliefs in God and Santa Claus. To the question "do you believe in God?" all participants answered "yes" or "definitely yes", while answers to the same question for Santa Claus were either "no" or "definitely not" (Fig. 1B). 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 from 1 to 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.

Based on our prior hypothesis, we made a Region of Interest (ROI) analysis of the caudate nucleus bilaterally. The regional analysis revealed a significant main effect of religious praying in the right caudate with peak activation in the head (Fig. 1C). Plots of the individual conditions relative to control showed comparable activations for the two religious conditions (Fig. 1D).

The activation of the caudate nucleus supports the hypothesis that religious prayer is capable of stimulating the dopaminergic system of the dorsal striatum in practicing individuals. This is in accordance with recent research on the human striatum suggesting that repeated behaviors which are expected to elicit future rewards evoke activity in the dorsal striatum [4,6,8,23]. We note that the present study cannot disambiguate between an effect of praying in actually changing outcomes (Math. 7:7; Luke 11:9) and an effect mainly in the reward system of the practitioners (Marx, 1843). Indeed, extensive studies of addictive behavior have claimed that the striatum, perhaps via extrinsic activation of the dopaminergic system, decoupled from learning, is involved in the formation (ventral) and maintenance (dorsal) of addiction [6,8].

King-Casas et al. [10] have demonstrated that caudate activity in reward conditioning extends to the social domain. Learning to trust partners in economic exchange games was predicted and mirrored by caudate activation. Our results suggest that intrinsic belief in God and a high confidence that God reacts to one's prayer may have similar effects on the dorsal striatum in praying subjects. This finding may provide valuable insight on how praying is reinforced at a neuronal level, and it could be a significant step towards understanding why devoted believers succeed in motivating a range of repeated behaviors. Habitual praying, however, might divert from social reinforcement learning as reported in [10] because subject–God reciprocity exclusively relies on the anticipation of future outcomes and interpretation of past events rather than on concrete monetary rewards. Praying offers no immediate feedback, and trusting God does not depend on trivial trial and error learning.

It is impossible to distinguish in this experiment whether the observed caudate activity is a function of repetitive behavior [4,8] or of trust [10] in God. Rather, in repeated behaviors like praying, which are motivated by interpersonal reciprocity, these levels are tightly interlinked, and the reward evaluation in the dorsal striatum will in effect be a function of both. The effect size of the caudate activation does not correspond directly to frequency of practice, because The Lord's prayer, which is less frequently practiced, showed a stronger response (Fig. 1D) than the more frequently practiced Personal prayer. This suggests that the observed caudate activity cannot be reduced to a function of the frequency of repetition. One putative explanation of the stronger caudate response to the Lord's Prayer could be that it is usually strongly associated with specific, habitualized situations, e.g. at bedtime or during congregational meetings or church services. Another possible explanation is that the Lord's Prayer, according to Christian tradition, is sanctioned by Jesus as encompassing all important aspects of life. This God-given authorization may reinforce practitioner's expectations of reciprocity in comparison with the often more idiosyncratic and individual requests in personal prayers. These explanations do not exclude each other, as The Lord's Prayer seems to optimally combine the aspect of habitual behavior and trust in God's reciprocity.

In a related study, we found no significant caudate activation in a group of self-reported religious persons, who did not pray regularly (see Supporting online text). This suggests that a regular practice of praying may be key to a cognitive effect of religious prayer. Whether such practice is mainly a matter of repetition or primarily of confidence in God's reciprocity is a question for future study. We believe that in this group these aspects are inseparable because repetition of praying is motivated by a strong confidence in God, and a strong confidence in God is supported by frequent repetition of praying.

A relevant approach to further examine the relation between the dorsal striatum and religious practice would be to study patients with infarctions or hemorrhages of caudate nucleus. However, this approach requires a detailed battery of religiosity measures to separate habitual behaviors from socially dependant practices. To our knowledge this has not yet been attempted. Another interesting approach is the study of religiosity in patients with Parkinson's disease in order to examine how decreased dopamine levels affect religious practice. A pioneering study on this particular relation reported a significant difference between PD patients and a matched control group revealing a decrease in frequency of private practices like praying and meditation [16]. This finding supports our hypothesis that the motivational systems of the dorsal striatum may play an important role in motivating frequently repeated religious behaviors.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.neulet.2008.07.068.

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