Neuroimaging, the sense of self and the sense of God

Andrew Wood

Andrew Wood is a Biophysicist who currently chairs the department of Biomedical and Health Sciences at Swinburne University in Melbourne. He has taught many aspects of Biomedical Instrumentation over several years. He worships at St Stephen's Anglican Church in Greythorn, North Balwyn.

Abstract

Recent advances in imaging methods have allowed controlled studies of brain processes associated with religious beliefs and practices. Now that imaging and other techniques can follow the way that nerve cells interconnect, there is a fresh interest in what constitutes consciousness. There is a related question of whether, if religious experience is uniquely human, some neural firing pattern or connectivity differences between humans and non-humans might be expected. There is now quite a large number of experimental investigations both of religious experience (or practice) and religious belief. This article reviews this recent work and highlights some of the limitations to these methods. In particular, the evidence for a particular region within the brain responsible for religious experience (a so-called 'God spot') is found to be virtually non-existent and many of the brain networks involved in manifestations of religious practice or belief are shared by other aspects of social interaction and belief formation.

Key words

Biomedical imaging, neurotheology, identity, mind-brain problem, consciousness.

Introduction

Medical imaging systems have shown remarkable advances in recent years, particularly regarding the interpretation of functional responses to complex stimuli. The ability to image the workings of the brain while a person, for example, makes moral and ethical decisions or contemplates works of art, has extended the range of investigations from purely diagnosing illness to fundamental studies of the ways different people think. It has meant that topics which were previously thought to be 'off-

limits' to science (beliefs, emotions, moral reasoning) are now increasingly the objects of systematic experimentation. Bluntly, neuroscientists are seeking to find if there are characteristic brain regions which can be associated with the sense of what it is to be 'me'. Further, experiments have been done to investigate where in the brain, people 'do' religion, both in terms of religious beliefs and religious behaviours.

What makes all this possible? Briefly, the trillions of nerve cells within the brain communicate by passing tiny electrical currents around themselves. If a particular part of the brain is engaging in a task (i.e. 'thinking') then the currents may be a little higher in that region. In this region there is greater 'activation'. Thus, by measuring the effects these currents produce on the scalp, a 'map' of brain activation can be recorded by using a grid of electrodes. This forms the basis of Electroencephalographic (EEG) mapping. Since nerves expend energy after producing these currents, there is a local consumption of such 'fuels' as dissolved oxygen and glucose (or sugar). Other techniques build up a three-dimensional map of the brain, sensing those regions where more than average amounts of oxygen or glucose are being consumed. The names of these techniques are: functional Magnetic Resonance Imaging (fMRI) for oxygen and Positron Emission Tomography (PET) for glucose. EEG does have an advantage over these newer techniques, because very small differences in time between brain events can be recorded using it, but, on the other hand, it is poor at localising events (the newer techniques being superior in this regard). There is a related technique, Magnetoencephalography (or MEG) which does have better localising ability, but is limited to a few specialist centres. Returning for a moment to MRI methods, recent advances in fast computing have given rise to Diffusion Tensor Imaging (or DTI). This technique has the capacity to identify which particular regions interconnect via nervous connections within the brain, hence a name tractography, or the imaging of nervous tracts. The ambitious Human Connectome Project (http://neuroscienceblueprint.nih.gov/connectome/index.htm), which has been in progress for 5 years, aims to produce a complete 'wiring diagram' of the human brain, in a similar manner to those of primitive worms (such as *C elegans*) and earlier this year of a mouse (Oh, Harris et al. 2014). Much of this information is publicly available (http://www.openconnectomeproject.org).

When applying these neuroimaging techniques, precision is improved by comparing two images, taken when the person is responding to two different types of task. The differences between the two brain images can then be connected to the differences in the tasks. The tasks can be responding to statements, flashed on a computer screen, such as 'The Biblical God really exists' or 'Santa Claus really exists'. The reaction of a believer to these two statements is expected to be different, whereas for a non-believer might be the same. From the brain maps, the regions of the brain associated with religious, and maybe specifically Christian beliefs can be identified, by noting the local strength of differences between believers and non-believers. Investigators use previous findings to discover what other traits or behaviours are associated with the same

regions. They then use this knowledge to link religious behaviour with other behaviour. For example, more than one study has identified a brain region associated with 'sense of self' with acceptance or rejection of religious statements. However, by the nature of the questions, people who are religious may take longer to evaluate religious compared to non-religious statements, because these beliefs are important to them. Thus it may not be a fundamental difference in brain architecture (a 'God spot') giving rise to these differences. (The evidence points to the same brain processes being involved in deciding on whether to believe or disbelieve in religious propositions as are used for *general* propositions).

Some of the specific studies will be reviewed below, but before embarking on this, I would like to introduce a related question: where does intelligent, conscious thought come from? Or, what does it mean to have a *mind*? As has been pointed out by numerous writers, consciousness (or the 'hard problem' as it has been called (Chalmers 1995)) appeared rather late on the scene. As the earth has evolved, non-life has given rise to life, life to sentience, sentience to consciousness and, some would argue, consciousness to the complex web of thought and social interaction (mainly through language) which distinguishes human-kind from all other mammals. Just as living systems can be distinguished from non-living by their capacity to reproduce, self-assemble and self-repair, so too can an animal that is able to self-contemplate, generate imaginary future scenarios and have a sense of 'ought-ness' be distinguished from those (like the worm *C elegans*) possessing a network of neurons constituting a brain but apparently unable to carry out these functions. So why is it that in two organisms, both possessing a mass of neurons, one is able to design experiments to elucidate its own inner workings and the other seems only interested in finding its next meal? Is it purely a matter of extra connections (humans have 500 billion connections as opposed to around 1000 in the worm) or is there more to it than that? Humans have only slightly more cortical neurons than the elephant (see http://en.wikipedia.org/wiki/List_of_animals_by_number_of_neurons) and yet seem capable of producing far greater novelty. In a major contribution to the question of where mind comes from, TW Deacon (Deacon 2011) argues that *consciousness* has the following features (my summary):

1. It is constituted by dynamical organisation, not 'matter' (such as neurochemical signals or electrophysiological events);
2. It has hierarchical 'levels' which are separate but nested (these are levels in the sense of atoms, molecules, cells, organs, integrated organism systems and so on; as studied by physics, chemistry, cell biology, physiology, psychology, as relevant for a particular level);
3. That the emotions can partly be considered as a comparison of what *is* with what *could be* – and the tension involved in experiencing emotion has features of both inertia & momentum (which should manifest itself as physical energy);
4. Specifically: it has inertia; metabolic boost; work; not all-or-none emergence of awareness; shifts in mental focus because of neural refractoriness;

5. That where, or precisely how, mental experiences are interpreted has still to be identified;
6. That the human ability to envision a better world (interior model-building) gives rise to aspects of moral interpretation.
7. That looking for mental information in individual firing patterns is looking at the wrong 'level'.

Further, Deacon argues that 'self' is itself an emergent phenomenon: 'self-generating – emerging each moment from what is not there' (Deacon 2011 p. 535). Deacon devotes an entire chapter in the book to emergence: there is also a definition in the glossary. The central idea is that global patterns and regularities produced by interactions in a higher order system cannot be reduced to the properties of the lower order system. This brings us back to the main question of this essay: can neuroimaging identify where 'the self' and moreover where the sense of 'higher powers' (the numinous or the self-transcendence) might reside? Would we see this in humans but not animals? It would appear from Deacon's perspective that this is probably asking the wrong question. Nevertheless, this has not impeded neuroscientists from looking for manifestations of belief in God in their high-tech images, an activity graced with the name 'neurotheology'. I will now attempt to summarise some of the findings.

Neurotheology

Religious *experience* rather than religious *belief* has also been investigated using these methods. For example, brain images obtained while religious people have been reciting prayers (Schjodt, Stodkilde-Jorgensen et al. 2008), 'speaking in tongues' (Newberg, Wintering et al. 2006) or during religious contemplation (Wiech, Farias et al. 2008) have been compared against more mundane activities. In general, these are less than satisfactory in relation to making a valid comparison. The MRI machine, for example, is noisy and claustrophobic and not the environment naturally conducive to a sense of closeness to God. Even EEG mapping involves the attachment of maybe over 100 electrodes to the scalp. Nevertheless, comparisons were made with a group of Carmelite nuns who were asked to recall, within the MRI machine, the most intense religious experience they had ever had (Beauregard and Paquette 2006). Their brain activity whilst they were doing this was compared to that when recalling an intense personal relationship. Not unexpectedly, the regions which were differently affected, were those to do with 'sense of self'. Our religious sense is thus at the very centre of how we perceive who we are.

Similar experiments have been carried out during the activity of praying, with studies carried out in a number of places, including Denmark, where again fMRI techniques were used with participants engaged in formal praying and improvised praying compared against reciting nursery rhymes and making wishes to Santa Claus, respectively (Schjodt, Stodkilde-Jorgensen et al. 2008, Schjoedt, Stodkilde-Jorgensen et al. 2009). Whilst it could be argued that the comparison tasks could have been better selected, the improvised prayer was found to be comparable to a more

ordinary personal conversation. Again, this may not seem surprising. More recently, the same group has studied Christian versus secular participants who were in receipt of (pre-recorded) intercessory prayer (Schjoedt, Stodkilde-Jorgensen et al. 2009). The participants were told that six of the prayers were read by non-Christians, six by Christians and six by a Christian known for his healing abilities. In fact, all 18 prayers had been pre-recorded by 'ordinary' Christians, so there was some deception involved. The slightly surprising finding was that when the Christian participants believed that the prayer was spoken by someone with well-known healing ability, they behaved in a way similar to people being hypnotised, 'handing over' decision-making processes. In other words, the implicit trust in charismatic leaders (in this case imagined) led to a certain 'switching off' of critical faculties. This is perhaps something that has long been suspected, but now techniques of neuroscience mean that it can be quantified. 'Speaking in tongues' or glossolalia in Christian experience has long been controversial, some regarding it as a uniquely Christian phenomenon and the mark of the indwelling of the Holy Spirit. It is not the place in this article to enter into a debate on the necessity of this phenomenon to be manifest in a 'live' church, nor whether it is an exclusively Christian one. Like other religious behaviours, this too has been subject to scientific investigation (Schjoedt, Stodkilde-Jorgensen et al. 2010). Some have examined the phenomenon of ecstatic utterances for similarities with and differences from conventional languages. These investigators have noted that it is not a language with syntax or grammar, nor is it a language for conversation, but that it nevertheless leads to personal benefits in terms of measurable improvement in mood and social integration (Spanos, Cross et al. 1986, Pattison and Casey 1969). They have also noted that people become better at it with practice and thus it is perhaps a result of social learning rather than a semi-miraculous event (Johnson 2010). A study, with just five individuals, studied brain activation patterns during glossolalia compared with during singing (Newberg, Wintering et al. 2006). As in the study of the attitude to charismatic healers' prayers, glossolalia was associated with a reduction in the amount of intentional control, which is consistent with the notion of 'letting go' during speaking in tongues.

The study of religious phenomena by neuroimaging methods has not been limited to Christian groups. Two such studies have been of Buddhist monks, the first in China (Wu, Wang et al. 2010), the second in Italy (Manna, Raffone et al. 2010). The first is interesting in that the two groups, Tibetan monks and Han Chinese, represent two groups with very different world views. In particular, the monks have a view that the 'self' as experienced in the physical world is illusory, thus a minimal subjective sense of 'I-ness'. This was reflected in different brain activation patterns in relation to tasks involving contemplating the 'self' compared with contemplating other people. The second was of two different meditative tasks, focused attention versus open monitoring. This showed that not all meditative activities are associated with 'switching off' the will and that certain meditative activities show a great discipline of the mind.

So to summarise so far: mapping brain activity during religious and specifically Christian contemplation is now possible through advanced imaging techniques. Although there are deficiencies in the design of some experiments, the findings seem to confirm pre-conceived notions. However, the approach also assumes that nervous activity is all there is to 'thinking' and that regional brain activity can be tied rather rigidly to particular thought processes, neither of which assumptions are now thought to be valid.

Some might find the whole notion of Christian faith and practice being reduced to certain localised nervous activation patterns confronting, especially where there is a suggestion that similar patterns could be produced by implanted stimulating electrodes, or could be obliterated or created by a local injury (Urgesi, Aglioti et al. 2010). However, the evidence does not support this extreme reductionist view. It should be emphasized that there is a good deal of inconsistency between findings and a realization among many that there is a great deal more complexity to brain processing than is identified in these types of experiments. Meanwhile even some of the most sceptical have to admit that rather than religion withering in the light of modernity, 'religion remains one of the most prominent features of human life in the 21st century' (Harris, Kaplan et al. 2009). Three articles have been significant in pushing forward the endeavour of identifying the nature of the phenomena of religious belief and experience. These are from the laboratory of Kapogiannis et al. at the National Institute of Aging in Baltimore (Kapogiannis, Barbey et al. 2009A, Kapogiannis, Barbey et al. 2009B, Kapogiannis, Deshpande et al. 2014). The first two of these identified three 'dimensions' of religious belief:

1. involvement of God (or gods);
2. love (or anger) of God and
3. processing of doctrinal statements or religious imagery.

Various brain regions were shown to have different activation patterns between religious and non-religious persons, with the first two being related to activation of the right side and the third the left side of the brain. The more recent of these studies (Kapogiannis, Deshpande et al. 2014) concentrated on networks rather than regions, and I will come back to this later.

There have been several other publications which add to the state of knowledge of imaging and other neurophysiological methods to investigate the phenomena of religious experience. In particular, the second study of Sam Harris and others, already referred to (Harris, Kaplan et al. 2009), reaches some important conclusions on the differences between religious and nonreligious belief, specifically the tendency for the involvement of the emotion and self-representation in the former and memory retrieval in the latter. In addition, a recent review (Seitz and Angel 2012) points to some other relevant studies (Azari, Nickel et al. 2001, Rothmayr, Sodian et al. 2011, Sommer, Dohnel et al. 2007, Sommer, Meinhardt et al. 2010). Eleven studies were identified in this review as being relevant to the representation of belief processes, using various types of image methods. The authors noted a large variation in regions activated by the various aspects of religious and non-religious

belief and indeed between study participants engaged in similar tasks. An important conclusion of this review is that although the process of believing involves many distinct facets and associated brain regions, the medial frontal cortex is crucial to the cognition-based and emotion-based perspective taking (subjective appraisal) that the process of religious believing involves. This is the closest we can get to a 'God spot'. However, it appears that the same regions are involved in the process of secular believing, so it is likely that we are dealing with a '*belief*' spot rather than a 'God spot' per se. The distinction identified in the Harris et al. study may have more to do with the type of questions used in the questionnaire rather than there being a fundamental difference between religious and secular belief.

A recent series of studies series of studies has examined the nature of unbelief, as opposed to belief (Gervais and Norenzayan 2012, Norenzayan, Gervais et al. 2012, Norenzayan and Gervais 2013). These studies focus on the nature of atheism as well as its perceived 'hard sell', in the sense that over the history of human-kind religion has been the 'default position' and that 'daring to disbelieve' is a relatively recent phenomenon. They explore what appears to be reduced rates of religious belief in men (compared to women), in analytic-style thinkers and in those scoring high on measures of autistic tendency. The authors contend that the brain regions associated with 'mentalizing' are essential for belief in God 'without being a sufficient cause' (Norenzayan, Gervais et al. 2012). In relation to styles of analytic thinking, Pennycook, Cheyne et al. (2012) contend that this links more to the *type* of religious belief, rather than mere acceptance or rejection. However, none of these studies has included neuroimaging techniques and so there is clearly the possibility of further work in this area.

Regarding neuroimaging studies per se, along with developments on decision-making processes (Bogler, Bode et al. 2011, Chen, Namburi et al. 2011,(Haynes 2011 , Kahnt, Heinzle et al. 2011), including predicting what decisions we will make ahead of our being aware that we have made a decision, there has been a growing interest in following the process of moral reasoning using MRI (Sommer, Dohnel et al. 2007), with consideration of honesty versus dishonesty (Greene and Paxton 2009). Although it appears premature to regard fMRI techniques as producing a modern lie detector, these methods have further pushed back the interface between subjective experience and objective measurement of behaviour, with important implications on our sense of right and wrong and ultimately of God's nature. The question of using MRI techniques as a lie detector is a separate topic in itself, but those wanting a useful review of some of the issues are referred to Rusconi and Mitchener-Nissen (2013).

Summary of neurotheology findings.

There are many aspects to religious experience and its practice, so it should be no surprise that several brain locations have been identified as being activated, including those regions associated with emotions, reward

systems and mysticism (loosely defined). Again, it is hardly surprising, since a person's Christian commitment is often the mainspring of that person's life and is often the defining quality of that person, that the related areas of brain function associated with 'sense of self' or essential 'me-ness' are those which are often implicated in these neuroimaging studies (the insular cortex and the associated areas cortical midline (Modinos, Ormel et al. 2009 , Northoff, Heinzel et al. 2006)). More recent studies have concentrated on networks and connectivity rather than regions. The recent study of Kapogiannis, Deshpande et al. (2014) demonstrated that in religious participants, regions involved in 'Theory of the Mind' (that is the ability to read others' intentions) were driving other brain regions, whereas for non-religious, the pathways were different, implying a difficulty to imagine how a supernatural agent might operate. It thus emphasises the reciprocal nature of social interaction, which is intrinsic to religious belief. It is also perhaps encouraging to have empirical confirmation that religiosity is not self-generated (Kapogiannis, Barbey et al. 2009) but rather is more a part of social network processes. It is also reassuring that religious experiences have been linked to general 'enjoyment' experiences (the Westminster Confession, after all, does state that 'Man's chief end is to glorify God, and to enjoy him for ever'). The neuroimaging studies of Beauregard and Paquette (2006, 2008) highlight the sense of subjective pleasantness and also of sense of purpose leading to contentment experienced by nuns in religious contemplation. The question is rather whether there are regions that are 'special' for religious experiences, such as the sense of mysticism termed 'self-transcendence' or 'at-one-ness'. However, this seems not to have been established by neuroimaging studies. In the light of the findings on 'sense of self' regarding religious convictions, the loss of 'sense of self' seems to be a characteristic of certain religious practices, including meditative states. These findings are not contradictory, but highlight the many aspects to religious faith, and the dangers of drawing false conclusions based on a poor understanding of what religious faith involves. It might also be emphasised that since the Christian faith is centred on acceptance or rejection of the redemptive significance of the earthly life of a person, Jesus Christ, and of his eternal significance as the 'Word made flesh', there is something specific here that has not, as yet, been captured in experimental designs.

Limits to the methodology

Before accepting these findings as representing firmly established science, it is well to bear in mind several methodological limitations of the whole neuroimaging approach. The first, and perhaps most obvious one, is that imaging methods primarily establish associations and not causations (although the more recent network analyses do give insights into the latter). Even those approaches that involve activation (via electrical stimulation or pharmacological agents for example) may not uncover the prime causative influences, which may well be a combination of exogenous and endogenous (including genetic) influences.

The second limitation, and again rather obvious, is of reproducing genuine religious behaviours in the environment of an imaging facility, which tends to be rather hostile to inward reflection and quiet contemplation. As may be well known, participants in MRI experiments wear ear mufflers, because of the high level of noise associated with the magnetic field gradient switching.

Thirdly, there still seems to be lacking a set of reliable, universally agreed categorisations of religious experience or activity (Seitz and Angel 2012) to clarify whether religious experiences or activities are somehow 'special' (Harris, Kaplan et al. 2009). It is nevertheless fair to say that ongoing belief patterns and convictions tend to be associated with the R frontal regions, whereas ecstatic religious experience associate more with the R temporal regions (Devinsky and Lai 2008). Beyond this, further refinement in phraseology needs to be applied.

Fourthly, there is still a great deal of debate on what neuroimaging methods actually measure. Logothetis (2008), for example, has questioned the assumption that the fMRI BOLD signal (which is essentially a measure of local blood flow) is actually a good measure of neuronal electrical activity, and indeed whether electrical activity is all there is to cognition. The same limitation also applies to other functional brain imaging methods.

Critics of the neurotheology approach maintain that all it can study are empirical aspects of religion or 'spirituality', and that it cannot properly investigate possible validity of spiritual experience with all of its subjectivity. Kapogiannis, Barbey et al. (2000B) (discussed earlier) make a very useful distinction between doctrinal and experiential knowledge of God in designing their experiments, noting that the former engage networks processing abstract semantics, whereas the latter networks for memory retrieval and imagery. Whereas doctrinal knowledge is perhaps the more important of the two in considering the question of whether in some way some individuals are more pre-disposed to belief on some genetic or personality basis, the question of the nature of experiential religious knowledge is also important to clarify. The apparent objective of extreme reductionism of 'explaining away' religious experience is similar to 'explaining away' sublime emotional moments in music, the visual arts or literature. The demonstration of characteristic brain signals in response to such stimuli would not invalidate the experience, but most of us would contend that the particular response recorded would only represent a small facet of the total experience. We would also want to contend that some responses to these moments in the arts can be inappropriate (and we would therefore judge invalid), thus some religious experiences would be by the same token invalid. Hence imaging studies, such as that by Urgesi, Aglioti et al. (2010) on the at times inappropriate mystical and religious experiences of those with brain lesions should not fill us with alarm. Of course, there is danger in using the fact that people report mystical experiences, including near-death or out of the body experiences as somehow 'proof' of 'other worlds' (Nelson 2011). As St John says, we should '…test the spirits to see whether they are from God…' (1 Jn 4:1).

Returning to doctrinal knowledge, this gets to the important questions of where, in the brain, we do our choosing, committing, trusting or having faith. Further, it gets to why some individuals make decisions to follow Christ, while some actively choose not to and perhaps most make no firm decision at all. This type of choosing can be similar in intensity to choosing a life partner, a job change or where to live, thus experiments on making moral choices are relevant here. However, many experimental designs to date involve trivial or at least hypothetical rather than actual life-changing decision-making, thus may not be very relevant. For many, 'coming to faith' is a gradual rather than crisis process, which would be even more difficult to study experimentally.

So far, we have assumed a naturist, or at least a nonreductive physicalist approach. Is coming to faith something we do with our brains or our minds? This is a big question, but I think it can safely be said that coming to faith is not conditional on our having a separate mind from a brain. Neuroimaging is certainly dealing with brain and not mind. It is also dealing with very specific brain signals: blood flow and to a lesser extent electrical activity. I think most if not all neuroscientists would agree that this is not all there is, even in relation to brain function.

As Donald Mackay wrote many years ago:

> …I am suggesting that fears of mechanistic explanations of brain functions are groundless, not because we can be sure that the brain is not a machine, but because even if it were, the whole constellation of claims regarding our inner nature and significance and destiny expressed in our moral tradition and the Christian religion would remain unaffected.
>
> Mackay 1967

The beginning of John's Gospel ('In the beginning was the word…') reminds us that the capacity for *symbolic understanding* (which is the basis of religious experience) is probably the most recent (and most advanced) emergent phenomenon (in human terms), and a phenomenon in which humans become 'in the image of God'.

> But as many as received him, to them gave He power [right, *power to act*, εξουσιαν] to become the sons of God, even to them that believe on his name
>
> Jn 1:12

is a reminder that the capability to 'be in tune with eternal realities' is a God-given faculty, and one which is uniquely human. The vast majority of the world's population have some form of religious belief (86% according to some). Deacon and Cashman (2009) argue that the previous approaches produce 'impoverished accounts'. They conclude that in religion there is a synergy of synergies: that human language gives rise to a 'narrative predisposition'; that there is a bias towards discerning a 'pattern behind the pattern' (leading to a metaphysical dualism which is intuitively *natural* and that expansion and transformation of mammalian emotional repertoire in humans leads to unprecedented emotional

experiences. So there is something special (and we would argue God-given) about religious experience that no amount of neuroimaging or any other form of physical measurement is about to reduce to a mere epiphenomenon or 'parasitic meme' (Dawkins 1994).

Conclusions

This paper has been discussing an area where investigations of aspects of religion, both doctrinal and experiential, have been studied and will be continued to be studied using continually refined neuroimaging methods. At present, there is still a range of uncertainties regarding the appropriateness of the stimuli used, the specificity of the signals obtained and the interpretation of the data with regard to regions activated. There is also still insufficient cohesion in the literature to get a sense of consistency of results. The Seitz and Angel (2012) review has clarified definitions of aspects of religious faith and practice, and has attempted to identify brain regions associated with these aspects, but there is clearly much more which can be done. Thus far there have been no unpleasant surprises (for Christians, in my view) and the indications are there are none in store. On the contrary, there may be some important insights on how we form religious convictions and the nature of both genuine and spurious religious experience.

References

Azari, NP, Nickel, J, Wunderlich, G, Niedeggen, M, Hefter, H, Tellmann, L, Herzog, H, Stoerig, P, Birnbacher, D, Seitz, RJ, 2001 'Neural correlates of religious experience', *Eur J Neurosci* 13(8): 1649–1652.

Beauregard, M, Paquette, V 2006, 'Neural correlates of a mystical experience in Carmelite nuns', *Neurosci Lett* 405(3): 186–190.

Beauregard, M, Paquette, V 2008, 'EEG activity in Carmelite nuns during a mystical experience', *Neurosci Lett* 444(1): 1–4.

Bogler, C, Bode, S, Haynes, JD 2011, 'Decoding successive computational stages of saliency processing', *Curr Biol* 21(19): 1667–1671.

Chalmers, D 1995, 'Facing up to to the problem of consciousness', *Journal of Consciousness Studies* 2(3): 200-219.

Chen, Y, Namburi, P, Elliott, LT, Heinzle, J, Soon, CS, Chee, MW, Haynes, JD 2011, 'Cortical surface-based searchlight decoding', *Neuroimage* 56(2): 582–592.

Dawkins, R 1994, 'Viruses of the mind' in B Dahlbom (ed.), *Dennett and his critics: Demystifying mind*, Wiley, Hoboken, NJ: 13–27.

Deacon, T 2011, *Incomplete nature: How mind emerged from matter,* WW Norton & Co, NY.

Deacon, T, Cashman, T 2009, 'The role of symbolic capacity in the origins of religion', *Journal of religion, nature & culture,* 3: 490–517.

Devinsky, O, Lai, G, 2008, 'Spirituality and religion in epilepsy', *Epilepsy Behav.* 12(4): 636–643.

Gervais, WM, Norenzayan, A 2012, 'Analytic thinking promotes religious disbelief', *Science* 336(6080): 493–496.

Greene, JD, Paxton, JM 2009, 'Patterns of neural activity associated with honest and dishonest moral decisions', *Proc. Natl Acad. Sci. USA* 106(30): 12506–12511.

Harris, S, Kaplan, JT, Curiel, A, Bookheimer, SY, Iacoboni, M, Cohen, MS 2009, 'The neural correlates of religious and nonreligious belief', *PLoS One* 4(10): e0007272.

Haynes, JD 2011, 'Multivariate decoding and brain reading: introduction to the special issue', *Neuroimage* 56(2): 385–386.

Johnson, KD 2010, 'A neuropastoral care and counseling assessment of glossolalia: a theosocial cognitive study', *J Health Care Chaplain* 16(3–4): 161–171.

Kahnt, T, Heinzle, J, Park, SQHaynes, JD 2011, 'Decoding different roles for vmPFC and dlPFC in multi-attribute decision making', *Neuroimage* 56(2): 709–715.

Kapogiannis, D, Barbey, AK, Su, M, Krueger, F, Grafman, J 2009A, 'Neuroanatomical variability of religiosity', *PLoS One* 4(9): e7180.

Kapogiannis, D, Barbey, AK, Su, M, Zamboni, G, Krueger, FGrafman, J, 2009B, 'Cognitive and neural foundations of religious belief', *Proc. Natl Acad. Sci. USA* 106(12): 4876–4881.

Kapogiannis, D, Deshpande, G, Krueger, F, Thornburg, MP, Grafman, JH 2014, 'Brain networks shaping religious belief', *Brain Connect* 4(1): 70–79.

Logothetis, NK 2008, 'What we can do and what we cannot do with fMRI', *Nature* 453(7197): 869–878.

Mackay, D 1967, *Freedom of action in a mechanistic universe,* Cambridge University Press, Cambridge UK, 40 pp.

Manna, A, Raffone, A, Perrucci, MG, Nardo, D, Ferretti, A, Tartaro, A, Londei, A, Del Gratta, C, Belardinelli, MO, Romani, GL 2010, 'Neural correlates of focused attention and cognitive monitoring in meditation', *Brain Res. Bull.* 82(1–2): 46–56.

Modinos, G, Ormel, J, Aleman, A 2009, 'Activation of anterior insula during self-reflection', *PLoS One* 4(2): e4618.

Nelson, K 2011, *The God impulse - is religion hardwired into the brain?* Simon & Schuster, London.

Newberg, AB, Wintering, NA, Morgan, D, Waldman, MR 2006, 'The measurement of regional cerebral blood flow during glossolalia: a preliminary SPECT study', *Psychiatry Res.* 148(1): 67–71.

Norenzayan, A, Gervais, WM 2013, 'The origins of religious disbelief', *Trends Cogn. Sci.* 17(1): 20–25.

Norenzayan, A, Gervais, WM, Trzesniewski, KH 2012, 'Mentalizing deficits constrain belief in a personal God', *PLoS One* 7(5): e36880.

Northoff, G, Heinzel, A, de Greck, M, Bermpohl, F, Dobrowolny, H, Panksepp, J 2006, 'Self-referential processing in our brain—a meta-analysis of imaging studies on the self', *Neuroimage* 31(1): 440–457.

Oh, SW, Harris, JA, Ng, L, Winslow, B, Cain, N, Mihalas, S, Wang, Q, Lau, C, Kuan, L, Henry, AM, Mortrud, MT, Ouellette, B, Nguyen, TN, Sorensen, SA, Slaughterbeck, CR, Wakeman, W, Li, Y, Feng, D, Ho, A, Nicholas, E, Hirokawa, KE, Bohn, P, Joines, KM,

Peng, H, Hawrylycz, MJ, Phillips, JW, Hohmann, JG, Wohnoutka, P, Gerfen, CR, Koch, C, Bernard, A, Dang, C, Jones, AR, Zeng, H 2014, 'A mesoscale connectome of the mouse brain', *Nature* 508(7495): 207–214.

Pattison, EM, Casey, RL 1969, 'Glossolalia: a contemporary mystical experience', *Int. Psychiatry Clin.* 5(4): 133–148.

Pennycook, G, Cheyne, JA, Seli, P, Koehler, DJ, Fugelsang, JA 2012, 'Analytic cognitive style predicts religious and paranormal belief', *Cognition* 123(3): 335–346.

Rothmayr, C, Sodian, B, Hajak, G, Dohnel, K, Meinhardt, J, Sommer, M 2011, 'Common and distinct neural networks for false-belief reasoning and inhibitory control', *Neuroimage* 56(3): 1705–1713.

Rusconi, E, Mitchener-Nissen, T 2013, 'Prospects of functional magnetic resonance imaging as lie detector', *Front. Hum. Neurosci.* 7: 594.

Schjodt, U, Stodkilde-Jorgensen, H, Geertz, AW, Roepstorff, A 2008, 'Rewarding prayers', *Neurosci. Lett.* 443(3): 165–168.

Schjoedt, U, Stodkilde-Jorgensen, H, Geertz, AW, Lund, TE, Roepstorff, A 2010, 'The power of charisma—perceived charisma inhibits the frontal executive network of believers in intercessory prayer', *Soc. Cogn. Affect. Neurosci*.

Schjoedt, U, Stodkilde-Jorgensen, H, Geertz, AW, Roepstorff, A 2009, 'Highly religious participants recruit areas of social cognition in personal prayer', *Soc. Cogn. Affect. Neurosci.* 4(2): 199–207.

Seitz, RJ, Angel, HF 2012, 'Processes of believing—a review and conceptual account', *Rev. Neurosci.* 23(3): 303–309.

Sommer, M, Dohnel, K, Sodian, B, Meinhardt, J, Thoermer, C, Hajak, G 2007, 'Neural correlates of true and false belief reasoning', *Neuroimage* 35(3): 1378–1384.

Sommer, M, Meinhardt, J, Eichenmuller, K, Sodian, B, Dohnel, K, Hajak, G 2010, 'Modulation of the cortical false belief network during development', *Brain Res.* 1354: 123–131.

Spanos, NP, Cross, WP, Lepage, M, Coristine, M 1986, 'Glossolalia as learned behavior: an experimental demonstration', *J. Abnorm. Psychol.* 95(1): 21–23.

Urgesi, C, Aglioti, SM, Skrap, M, Fabbro, F 2010, 'The spiritual brain: selective cortical lesions modulate human self-transcendence', *Neuron* 65(3): 309–319.

Wiech, K, Farias, M, Kahane, G, Shackel, N, Tiede, W, Tracey, I 2008, 'An fMRI study measuring analgesia enhanced by religion as a belief system', *Pain* 139(2): 467–476.

Wu, Y, Wang, C, He, X, Mao, L, Zhang, L 2010, 'Religious beliefs influence neural substrates of self-reflection in Tibetans', *Soc. Cogn. Affect. Neurosci.* 5(2–3): 324–331.