Chapter 9.
Quantifying Spirituality through Neuroimaging – 4065

Neuroimaging is a suite of technologies used to observe brain structure or function. These technologies are incredibly exciting because being able to quantify brain activity is new in the history of our species. Partly because it is so exciting, people can get carried away with it so I want to begin with a caveat stated clearly enough that I don’t need to repeat it throughout this chapter.

Any serious neuroscientist will tell you that we really don’t know much about how the brain does what it does. We have little glimpses, thanks to data from biochemistry, from neuroimaging, and from people suffering from neurological conditions such as traumatic brain injury, stroke, brain tumors, or psychiatric illness. We have some truly promising neural models of a few processes of special interest, such as vision. But we lack compelling models of the integration of virtually endless, intricate complexity into unified states of consciousness sufficient to support the potent sense of self-awareness with which we are all familiar. We also have only the elementary beginnings of models of spiritual experiences. We have to approach neuroimaging technologies with caution as well as appreciation.

Sobering caveat in place, let’s allow ourselves to get just a little excited. Neuroimaging technologies are really cool! And they are only going to get more useful and more interesting with time. In what follows, I’ll explain how they work, how they contribute to technologies of spiritual enhancement, and how they can help us deepen our understanding of human religiosity and spirituality.

Just two hundred years ago, the most influential intellectual of the European Enlightenment, German philosopher Immanuel Kant, rebooted his already successful philosophical career with a trilogy of extraordinary books on human reason. These analyses of human reason display a rare capacity for introspection: Kant reflected on the workings of his own mind as an exemplar of all human minds. Of course, he didn’t write it the books that way; in the books it reads as though he is objectively analyzing the human mind—everyone’s minds!—as if these minds were somehow publicly available for inspection. They’re not. Yet generation after generation of philosophers have found Kant’s analyses insightful, and the careful way he built up a sophisticated understanding of human reason and its limits has impacted virtually every philosopher since his time.

Here’s the kicker: Kant didn’t discuss the seat of human reason, the brain. In fact, he seems to have conceived human reason entirely separately from whatever is going on inside our heads. It is tempting to give him a pass on this oversight, given that he wouldn’t have had a lot to say about the brain anyway. But the problem runs deeper than this. By treating the human mind as universally accessible through introspection, unrooted in brains, Kant neglected the bodily characteristics of reason that underlie cultural and individual differences in human cognition and emotion. He was also able to pretend that we could be certain about the conditions for the possibility of our reasoning activities, greatly
exaggerating the amount of confidence possible. These two mistakes—neglecting variation and exaggerating confidence—have been the focus of many critics’ attention. A more embodied, brain-focused approach would have helped, or at least couldn’t have hurt.

The same goes for spiritual experiences. When we think of human spirituality independently of our bodies, we set ourselves up for disappointment. Reason, emotion, experience, spirituality—these are all bodily functions. And this is precisely why the brain sciences are so important. Kant was sort of correct in assuming that there are approximately species-wide features of human reason. But how far do apparent patterns in human cognition extend given the obvious differences among us in regard to culture, gender, language, stages of development, and personality type? Careful attention to the way brain and behavior fit with one another—staying alert for demographic, life-stage, cultural, and individual differences—can help identify the extent of shared characteristics.

More important, to my way of thinking, is the puzzle of the centered self. We all operate with a conception of self as the subject of our experiences and the source of our decisions and actions. The experience of a unified self, albeit it one capable of cognitive errors, is precisely what led Kant to make the mistakes he made. He was seduced by the powerful sense of self he personally possessed, and which he inferred that others possess also, and simply assumed that it was somehow guaranteed to be unified and conceptually coherent.

The picture of the brain-self relationship that this suggests is the self as a distinct reality from the body to which the brain permits connection, like a radio antenna picking up some invisible signal. So we might say Kant was really analyzing the non-bodily part of human life and could afford to neglect the antenna’s brain-based reception and transmission functions.

The brain sciences cannot settle such metaphysical questions decisively. But neurological disorders of the self, as when people fail to recognize parts of their own bodies, or support more than one distinct personality, can impact the decision about whether the brain is the seat of the self or merely an antenna connecting us to a disembodied self. Processes of conversion and personal change have an impact here, too, as they are all about transforming functional conceptions of self. I think these considerations make the antenna theory of brain-self connection less persuasive than the full-embodiment theory of the brain as the seat of the self—much less persuasive. There are no knock-down proofs here—constructing such proofs was one of Kant’s favorite intellectual pastimes—but thoroughgoing embodiment of the self in the brain makes a lot of sense. I’ll be assuming that as I move ahead.

I wish Kant had known about this. It would have been amazing to have seen his splendid mind applied to a more plausible conception of the human person. In any event, if this is the way things are for human beings, then there is a lot at stake for us in studying the structure and function of brains.
Our very sense of self is at stake, as well as the way that sense of self is (or is not) free in making decisions, how the self changes through the stages of life, and the very meaning of being a spiritual self.

Enter the neurosciences. Let’s begin with neuropsychology and then turn to neuroimaging. Neuropsychologists have produced an amazing array of physiological and survey-type tests that can tell us about brain function based solely on behavior. So, if you bang your head hard, a neuroscientist will run you through a series of tests based on bodily experiences and chat with you to diagnose what’s happening. Someone who suffered a stroke might have vision problems and neuropsychological testing can assess the extent and severity of the damage. Or the survivor of a car accident may have severe behavioral problems and the neuropsychologist can often figure out which functions of the brain have been affected. These tests are very good at isolating functional problems. Neuropsychologists devise treatment plans based on such tests and those treatment plans really help people heal faster.

Part of the reason this works is because brain function is sometimes associated with brain location. Vision is processed in parts of the brain at the back of the head so impairment in that function suggests damage in that part of the brain. The connection between function and location in the brain is incredibly useful for trying to understand what’s happening inside our heads. It’s also one of the reasons most interpreters find the full embodiment theory of the brain-self relation more convincing than the antenna theory: an antenna wouldn’t seem to require that kind of degree of organization.

Of course, just because some brain functions are localized does not mean that all brain functions are localized. Most brain functions, especially more complex cognitive functions, are widely distributed in the brain and employ networks with many key localized nodes. We have to be careful not to associate a complex brain network that supports a function of interest with one of its key localized nodes. It is always a mistake to underestimate the complexity of human brains! Nevertheless, when we find function-localization patterns, we can use neuropsychological testing to generate insight into brain structure and function.

Function-localization patterns are the key to meaningful neuroimaging of the functional type. These are the neuroimaging techniques that track brain activity over time. By contrast, structural neuroimaging is more like a photograph: it is most useful for detecting structural abnormalities or damage. We’ll begin with structural neuroimaging.

The coarsest type of structural neuroimaging employs x-rays. An x-ray machine shines high-frequency light through the body to take a kind of photograph showing more versus less dense tissues. Experts can detect structural abnormalities from x-ray images because they carry in their own minds a vivid awareness of how normal brains should appear.
Computerized application of x-rays yields a technique for imaging known as X-ray computed tomography, or CT. By sending x-rays through a part of the body from many directions and combining the results, a CT scan computes a three- dimensional image of the area in question. X-rays and CT scans work on the brain as they do any other part of the body but they use high-energy radiation so their use carries a (very) small risk of damage to DNA.

A more refined method for structural neuroimaging is the MRI, which is short for magnetic-resonance imaging. This technology depends on a difficult-to-believe detail about the way a subatomic particle called a proton interacts with magnetic fields. Every molecule of water contains two hydrogen nuclei, which are simply protons in the ordinary isotope of hydrogen, and our bodies are full of water—about 70%. That means there are a lot of relatively isolated protons in the human body that interact with magnetic fields in the way the MRI requires, which can yield a lot of structural information about whatever part of the body we examine, including brains.

Every proton is a mini-magnet and reacts to magnetic fields in its environment. An MRI scanning machine creates a magnetic field that passes through the body of the person inside the scanner, causing all of the relatively unconstrained protons (such as those in hydrogen atoms of water molecules) to process, which means that the north pole of the mini-magnet proton rotates at a specific frequency related to the applied magnetic field. That’s the “resonance” bit in the MRI name.

The application of a second magnetic field of a smaller strength forces this processional rotation to line up with the weaker magnetic field lines. Turn the weaker magnetic field off and the mini-magnet proton jumps back to its original mode of procession, emitting electromagnetic radiation as it does so. It is difficult to pick up the tiny magnetic field of this elastic rebounding of the mini-magnet proton because it is swamped by the large magnetic field that gets the procession started in the first place. But if the secondary magnetic field is lined up perfectly perpendicular to the primary magnetic field, even tiny electro-magnetic signals can be detected. It’s all about angles.

MRI signals would be an uninformative mess, with no localization information at all, if it weren’t for two other considerations. First, the primary magnetic field is actually a gradient, with high field strength at some places in a three- dimensional space (say, at top of the head, thinking of a person lying in an MRI scanner) and a steady gradient down from there to low field strength at the base of the feet. Different field strengths change the characteristic resonance frequency of mini-magnet-proton procession.

Second, the second magnetic field will only influence processing protons if the electromagnetic frequency perfectly matches the characteristics of those particular protons. This property of quantum particles has been understood for more than a century but it is still surprising to people today because folk-physics intuitions tell us that degree of influence should be based on strength of the force applied, leaving no room for all-or-nothing influence based on the compatibility of electromagnetic field frequencies.
The upshot of these remarkable quantum characteristics of sub-atomic particles is that an MRI machine can employ sophisticated computers to disturb mini-magnet protons in quite precise locations within the body, and measure emitted electromagnetic radiation specifically from those locations. And that’s how we get spatially specific information from MRI machines in three dimensions, down to a couple of millimeters of resolution. The amount of water changes with tissue type, which produces contrast in MRI images and makes them useful for detecting structure, and therefore structural abnormalities.

MRI machines can be tweaked to measure things other than electromagnetic pulses from mini-magnet protons. For example, if someone suddenly reports powerful migraines, a neurologist might want to check blood flow in the head to rule out aneurysm or stroke. One way to do this is to inject a radioactive substance into the blood, which will then go wherever blood flows in the head. Sensors pick up radioactive particles as they decay and locate those signals within the three-dimensional MRI map of the brain. A brain bleed or a bulging blood vessel will show up as an extra bright patch in a place where blood has no business being.

Let’s move to functional neuroimaging. These are the brain-measurement technologies that matter most for understanding spiritual experiences. Already understanding something about structural neuroimaging will help speed our way to grasping how functional neuroimaging works.

The oldest functional imaging technique was actually invented in the late nineteenth century by an extraordinarily clever and careful Italian physiologist called Angelo Mosso. He reasoned that the brain would require more blood when it is busy with some activity in order to meet the metabolic needs of working brain cells. At the time this hypothesis was a bit of a shot in the dark and it wasn’t at all clear that changes in blood flow could be measured. But Mosso devised a sensitive balance to get the job done. A subject would lie down on Mosso’s so-called “human circulation balance” and stay very still and relaxed. Mosso found ways to adjust for bodily processes such as breathing that shift a person’s center of gravity and disturb the balance in a cyclical way. He was then able to measure increased blood flow to the brain associated with intense thought, or even emotions.

Mosso’s discoveries were not very useful clinically because the level of detail required for clinical neurological use is much higher than the balance could provide. But they were quite pointed philosophically in that they located the processing of cognition and emotion in the brain and drove home the embodied character of mental activity in all of its forms. Those discoveries were forgotten for over a century but they marked the birth technologies to measure brain function that would eventually yield a host of functional neuroimaging techniques.

Physiologists had known that animal brains involve electrical activity since 1875, just before Mosso built his balance. In those early days, this research was done on animals such as...
rabbits, dogs, and monkeys and not on human beings because electrical activity had to be measured using electrodes on the surface of the brain. German physiologist Hans Berger recorded the first human electro-encephalogram (EEG) in 1924 using electrodes inserted inside the skull. Eventually electrical signal detection became sensitive enough to measure activity on the surface of the brain from outside the head using electrodes on the scalp, and the technology hasn’t looked back since. There were steady improvements in sensitivity to electrical activity, recording methods, and insight into how EEG could be used to assess clinical conditions.

Neurologists have been captivated by two basic facts about the brain disclosed by EEGs. The first is that the electrical activity at the surface of the brain is periodic, with waves of signaling sweeping across the outside part of the brain (the top part of the cortex) several times a second. Even today neuroscientists don’t have a clear understanding of why the cortical parts of the brain work this way. The second basic fact is that cognitive states are correlated with particular frequencies of periodic brain activity. Neuroscientists don’t know why that’s the case, either. Despite our current ignorance, these two basic facts about the brain make EEGs medically useful, both for research and clinical applications.

EEGs are routinely used to detect seizures and rapid-eye-movement (REM) sleep, making them especially useful for diagnosing and treating potentially debilitating seizure and sleep disorders. But EEGs can also be used to study a variety of other brain activities, too. In an earlier chapter, I described how quantitative analysis of EEG data produces characteristic electrical patterns for a range of conditions for which regular EEGs are too coarse. The key to so-called quantitative EEG (qEEG) is analysis of the EEG signal into component frequencies, measuring the strength of each frequency. This is how digital sound recording works, as well, and the procedure depends on mathematical tricks and technology capable of performing those mathematical conversions rapidly.

When we can generate data for many individual frequencies from many positions on the scalp, we have a tool that is far more sensitive than the ordinary EEG and far more useful for clinical applications. Indeed, qEEG is routinely used to diagnose disorders such as attention-deficit hyperactivity disorder (ADHD) and post-traumatic stress disorder (PTSD). We also have qEEG characterizations of a variety of meditation states. Using such standard characterizations, qEEG can be used to create neurofeedback systems that compare a subject’s brain activity with standard norms on the fly. That’s how neurofeedback-guided meditation works, as described in an earlier chapter. These qEEG neurofeedback systems are effective brain-computer interfaces because of their power to discriminate a host of large number of subjectively quite different mental states.

An alternative technique for functional neuroimaging focuses on the metabolic needs of brain cells rather than electrical activity. The metabolic focus is an extension of Mosso’s original insight. The new element is radioactivity. Attach radioactive tracers to a chemical that brain cells need to function, inject those tagged chemicals into the blood stream, wait a few minutes for the chemicals to be metabolically absorbed by the brain, then image the brain to see where the tagged chemicals are in abundance.
processed, and the radioactive tracers get fixed in the places where their host molecules were metabolized. After that, the brain lights up like a Christmas tree, displaying where the most functional brain activity was occurring a few minutes prior to the scan. There are many radioactive tracers in use today and the development of each of them required great cleverness and a profound understanding of metabolic processes in cells.

The most common way to produce an image from decaying radioactive tracers fixed in the brain depends on an effect of subatomic particles known to us from quantum physics. We can’t safely use radioactive decay of the alpha type because those types of decay emit helium nuclei, which are heavy enough to damage DNA. So we use radioactive decay of the beta type instead, which is much safer because the particles produced are much smaller. There are two types of beta decay and the key to the type that matters here is the spontaneous transition of an up quark into a down quark, effectively transforming a positively charged proton into an electrically neutral neutron. Through a brief cascade of particle emissions, this type of beta decay emits a positron. Those positrons, being anti-matter, interact strongly with nearby electrons after no more than a millimeter or two of travel. The positron and electron annihilate one another into another brief particle cascade. The result is a pair of photons that don’t interact much with anything in the human body so they pass through the brain to be measured by sensors. The fact that the emitted photons always move in precisely opposite directions from one another means that the location of all that sub-atomic action can be inferred from the places where the particles are detected, and that location will be within a couple of millimeters of the place where the metabolic action we are really interested in took place. Using clever computer programs, the result is a three-dimensional image, a bit like a CT scans, but produced using radioactivity.

Positron emission tomography (PET) works in exactly this way. By contrast, single photon emission computed tomography (SPECT) employs a kind of radioactive decay that emits a photon that can be measured directly. SPECT is cheaper because the radioactive tracers are less expensive to produce. But SPECT spatial resolution is around 10 millimeters compared to the 2-3 millimeters of PET scans.

Functional magnetic resonance imaging (fMRI) is another functional neuroimaging technique that depends on metabolism. By contrast with SPECT and PET scans, which focus on metabolized chemicals, fMRI focuses on blood flow, and particularly on the metabolic depletion of oxygen in the blood. We pondered the wonders of MRI earlier in this chapter. fMRI extends the basic MRI technology by means of a neat fact about the oxygen-carrying protein hemoglobin: oxygenated hemoglobin is magnetism-resistant, while de-oxygenated hemoglobin is a wonderful mini-magnet of just the kind that fMRI machines are good at detecting.

SPECT and PET techniques produce only a snapshot of brain activity due to the need for radioactive tracers but fMRI, like EEG, produces an ongoing map of brain activity. That makes fMRI both more expensive and a lot more useful.
resolution of a high-quality fMRI is a couple of millimeters (similar to PET) and temporal resolution can go as low as a tenth of a second. That’s nowhere near as good as EEG’s millisecond temporal resolution, but EEG’s are confined to the outer cortex while fMRI delivers both decent temporal and decent spatial resolution throughout most of the brain. In fact, the discriminating power of fMRI has become so refined that Shinji Nishimoto and colleagues were able to reconstruct the content of videos from fMRI recordings of brain activity. Think about that: fMRI measures of activity in the visual cortex actually permitted the coarse but recognizable reconstruction of video content seen and processed by participants in this experiment! Our impression of the potential for brain-computer interfaces only increases in the wake of such discoveries.

The final functional imaging technique I’ll discuss is magnetoencephalography (MEG). An MEG scanner uses incredibly sensitive instruments to measure the tiny magnetic fields created by ionic currents flowing within neurons near the surface of the brain. A bit like EEG, and unlike fMRI and PET, MEG can’t penetrate very deeply into the brain. But, thanks to some very clever computing tricks, and the fact that magnetic fields are less distorted than electric fields by skull and scalp, MEG has better spatial resolution than EEG, akin to fMRI and PET. The temporal resolution of MEG is much like EEG. The combination of these qualities makes MEG suited, like qEEG, to sensitive discrimination of mental states and neurological conditions, and also to neurofeedback applications. MEGs are more expensive than EEGs and qEEGs, by a lot, so it is qEEG that has been the main tool for neurofeedback to date. But that will change as MEG equipment becomes more affordable, and as neuroscientists discover the special advantages of the greater spatial resolution permitted by MEGs.

Several key technologies of spiritual experience depend on knowledge of brain activity, as indicated in Part I. This is especially true for neurofeedback where on-the-fly analysis of brain states facilitates spiritual self-realization and self-cultivation. It is also true for the emerging technologies of brain-computer interfaces, which promise eventually to transform options for corporate spiritual togetherness. Meanwhile, both psychometric and neuroimaging techniques advance the research task of understanding spirituality in relation to all types of spiritual experience, from postural meditation and prayer to the induction of spiritual states by means of entheogens or rTMS.

Recent developments in spirit tech would be impossible without the quantification of spiritual experiences, and of brain states more generally. Likewise, quantitative techniques are game-changers for researchers such as me who strive to understand the nature of human spirituality.

With this brief interlude on quantification in place, it is time to get practical. To that end, Part III attempts to evaluate spirit tech and to supply guidance to individuals, families, and groups who find themselves face to face with some intriguing high-tech product within the Scattered Supermarket of Specialized Spiritual Services.