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Ten Principles for Interpreting Neuroscientific Pronouncements Regarding Human Nature

By A.C. Weissenbacher

Abstract: As the field of brain research continues to advance, much is being discovered about the various aspects of the brain that are associated with certain feelings, thoughts, and behaviors. However, certain studies, or popularized accounts thereof, overreach in their pronouncements, drawing unwarranted conclusions regarding human nature. There are ten principles that will assist the non-specialist in critically assessing both now and future discoveries reported from the neurosciences, with a focus on helping theologians using neuroscientific data in multidisciplinary work regarding human nature.

Key Terms: brain scan limitations, critique of neuroscience, fMRI, free will, neurotheology

Unreliable Pronouncements and Shaky Science

As the neurosciences continue to probe into the neural correlates of human behavior, one sees this reflected in news items regarding human nature. Various items declare that the "God spot" causing religious belief has been located in the brain; that criminals have unique brain formations that cause them to commit crimes and thus are not responsible for their actions; or that the mystery surrounding various mental activities has been solved due to finding their neural correlates. But how reliable are these pronouncements and can they be considered definitive? What should a person know when approaching these studies? And if one is incorporating neuroscientific data into theological or philosophical examinations of human nature, such as developing a theological anthropology, how can this be done well?

In this *Dialog* article I provide ten principles that will enable one to assess critically the conclusions presented in neurological studies. As brain science becomes fashionable in many domains, including theology, it is important to be literate in reading neurological pronouncements, especially as one sees them being practically applied, such as brain scans being used in court cases, marketing development, or to advance "brain-based" pedagogical techniques. Many of these practical applications turn out to stand on a shaky use of science. And when theologians wish to use science in their work, as when using neuroscience in doctrines of human nature, one should know how to discern the best science.

This article is not meant to diminish or devalue the neuroscientific study of human nature or the search for neural correlates of human behaviors. Such studies are valuable, informative, and should be pursued. Instead, it is meant to enable those not trained in the relevant sciences to critically interact with the pronouncements or popularized accounts coming from the field of brain research. At the

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same time, it should serve as a caution to the scientists themselves not to overreach in drawing conclusions from their research. To be fair, most scientists do judicious research.[1] It is often the various popularizers of science who then take pronouncements regarding activations on a scan, making declarations such as that these activations are what make you believe in God, or to be immoral, or what force you do the varied things that you "erroneously" believe are your free choices.

A Neural Correlate of an Experience Reveals Little

It should not be surprising when a discovery finds that an aspect of experience, behavior, emotion, or perception lights up an area of the brain on a scan. Our bodies and brains are what we use to interact with the world, and it should be obvious that the various mental aspects of human existence will involve the brain in some manner. Finding the neural correlates of a behavior or experience, while informative, essentially does not mean all that much. One would expect to find nothing less. As stated by Thomas Aquinas, "Grace builds upon nature,"[2] so any neuroscientific study, even discovering brain correlates of religious experience, should not threaten theology.

The problem with the science comes when the physical process is used to reductively explain away the experience. A prime example is the hype surrounding studies claiming to discover areas of the brain that control religious experience and belief. Studies of Tibetan monks during meditation and Carmelite nuns in prayer revealed that both evidenced similar changes in brain activity.[3] This helped spur the idea of a particular spot in the brain responsible for spiritual experiences. Barbara Haggerty, religion reporter for National Public Radio, relates how such a discovery led some to declare that this proved God as being nothing more than a quirk of the brain and that belief in God or spiritual experiences are nothing but a physical process.[4]

However, reading this article, petting a cat, or talking to a friend, also activate areas in the brain discoverable by a scan, and this does not mean the cat, friend, or article are mere illusions. One could just as easily conclude that an active area on a brain scan is where God is interacting with a person instead of reducing God to a mere brain quirk. Science might explain the biology of a spiritual experience but this does not explain the experience away. Knowing the neural correlates of human experience is not enough, one must go beyond this using anthropology, metaphysics, philosophy, and theology as the science alone cannot fully capture what it means to be human.

Neurotheology

The recently developing field of neurotheology has trouble with this issue. While the term *neurotheology* can be applied to any interdisciplinary work involving religion and the neurosciences, it is most often invoked in research seeking to explain religious behavior and experience using neuroscience. Again, discovering that there are neural correlates of religious experience should not be surprising, the issue is when neurotheology becomes a means to reduce religious experience to nothing but brain function.

Closely related to this is when it is assumed that a brain scan is required to provide validity to an experience, as if illusionary experiences would not also find neural representation. In a pioneering work of the field, neurotheologian Andrew Newberg claims that discovering brain areas active during religious experiences finally demonstrate that spiritual experiences exist or are real.[5] Must a specific area of the brain light up for an experience to be real? What if spiritual experiences are neurally realizable in a multitude of ways? For an experience to count as spiritual, must it have a common pattern of brain activity and those people without that common pattern be dismissed as having pseudo-experiences? I would say no. A larger issue, however, relates to defining what exactly is being measured in these neurotheological studies.

A Definition Should be Specific

In 2000, neuroscientists Andreas Bartles and Semir Zeki studied 17 subjects who reported to be in love, showing them pictures of romantic partners and compared brain activity with that from viewing pictures of non-romantic partners.[6] Viewing romantic partners resulted in activity changes in certain brain areas. Bartles and Zeki then claimed to have found the neural basis of romantic love, or as some may describe it, the area of the brain that causes someone to love another.

This raises the question, however, of what exactly romantic love is and whether it can be said to be the same for everyone. How does one define love, its various components and expressions, so as to claim that a particular region of the brain is associated with it? For example, is it commitment, sexual attraction, trust, familiarity, or some mixture thereof?

When one is attempting to research mental phenomena, it is important to define what one is attempting to locate as specifically as possible. If one is trying to scan for mystical or religious experience, as found in the neurotheological work of Andrew Newberg, is one measuring a mystical experience where a person senses a oneness with ultimate reality, a numinous experience where one feels insignificant before God's majesty, a regenerative experience where one feels one is receiving strength, comfort, or joy, a revelatory experience of insight, a vision, an interpretive experience where everyday experience or coincidences are given religious interpretation or meaning, or some combination of the previous?[7]

A large variety of religious experience seems to be conflated into a single type in some neurotheological work. Careful theological reflection is needed to define the object of experimentation as well as for interpreting the results. Discovering the brain areas involved in varieties of religious experience is informative, but declaring that brain scans on individuals reveal the core of religious experience is problematic in that it fails to capture community experience throughout history, and any study that claims to understand religion based on a scan is failing to distinguish the fact that it is the religious experience of individuals under study and not religion itself.

Returning to the issue of defining one's experimental subject, to quote William Uttal, professor of psychology and researcher into neural/psychological human-computer interactions, "Hypothetical psychological constructs are invented ad lib and ad hoc without adequate consideration of the fundamental issue of the very plausibility of precise definition."[8] Is what is under investigation real or a "convenient means of emphasizing how we are organizing our experiments?"[9] How one measures often can determine what is discovered. Using memory as an example, even the acceptance of dividing memory into short-term, working, and long-term memory depends on the methods used to study information retention, and as new methods develop, other types of memory are being suggested.[10] There is no agreed upon taxonomy of mental components. Each researcher defines what they are looking for in their own research, and some are better than others.

Definitions can also change through time. I do not know of any researcher trying to locate what Sigmund Freud called the "Id" or "Super-ego." These are now out of fashion as concepts. However, even if the consensus is that such concepts do not exist given a change in prevalent theory, I imagine some location in the brain could be seen activating in relation to these if one looked hard enough for them without being careful with one's research methods. The reason for this can be seen in the limits faced by brain scans.

Brain Scans Have Limitations

While brain scans have captured the public's imagination and often are touted as direct windows into the human mind, there are sources of error and limitations of which one should be aware. I will focus on Functional Magnetic Resonance Imaging (fMRI) studies, as these are currently common and produce colorful pictures for public consumption.

Without going into technical detail, the fMRI scan measures the difference between oxygenated blood and deoxygenated blood. The assumption is that the most active brain areas will be using the most energy and will need more blood and more oxygen, and that is what the scan detects.

Using this in research, usually someone will be told to engage in a task where their brain is scanned, then this is compared with a scan made while the person is at "rest." The rest state is then subtracted from the active scan. The areas of difference are then assumed to be what is related to performance of the task with the locus of a particular cognitive activity being where the activity measure is greatest. The final scan results revealed in studies then tend to be the average of all participants in the study.

Individual Differences

Because final scan results are an average composite, it is difficult to state that the final results reveal the location of a mental process. Brains are not the same in every individual. Scans on different subjects do not produce the same results and considering that many of those who participate in these studies are university students, it is not self-evidence that studies on this specific population translate to wider society. Scans can look very different from subject to subject and one must do correcting, noise reduction, standardizing and averaging, which introduce error and can produce an illusion of a localized process where one may not be.

To illustrate this problem, before brain surgery a neurosurgeon maps the locations of various brain regions in every patient, every time. She doesn't rely on a standard map to perform her work—much to the relief of those undergoing the surgery. The fact that brains are different is also why it is problematic to assign an abnormal status to a brain scan. Is the result a standard deviation of normal or truly "abnormal?"

Additionally, not only are results often not reproducible from subject to subject, the same can be true in the same subject at different points in time. A trained task can activate a different region of the brain than when it was novel, and areas responsible for that task can become less active as the brain has become more efficient at the process in what is called "practice-suppression" or the "training effect." The brain becomes more efficient at performing a task the more it repeats it.

Another source of uncertainty comes from the determination of what level of activation is significant. Assignment of colors to various levels of activity is arbitrary. It is the responsibility of the experimenter to decide what levels of activation are significant, what they should be colored, and what significance should be attached to the different scores. If one is too conservative, some activity could be missed, yet if one is not conservative enough, false alarms could register as significant. Setting the appropriate criterion threshold is an art and varying it will make a major difference in areas shown to be active in a scan. If one is not careful in setting activity thresholds, it is possible to find whatever one wishes.

In an experiment designed to illustrate this problem, neuroscientist Craig Bennett performed multiple scans on a dead salmon while showing it pictures of people in social situations, asking it to determine what they were feeling (the same social perspective task administered to humans). After analyzing the data, Bennett found an area of the dead salmon's brain that lit up in response and declared it to be the dead salmon's brain area for human emotional determination.[11] The decisions he made in data analysis and setting activity thresholds produced rather silly results and revealed how others must be very careful when they do the same. Proper studies should explain how they correct for false positives.

Looking at the method of subtracting a rest state from the experimental state, a key assumption is that when one scan involves an action and the other does not, any difference in the two should indicate the region involved in that action, all else being equal. Imaged responses, however, can be quite context dependent. According to Uttal, "Slight changes in the procedure, stimulus materials, or methodology often produce dramatic changes in the rules of perception."[12] To use the love study mentioned earlier, situations of viewing a picture of a loved

one, others, and a blank picture are not likely to differ in only a single way. Even having certain emotions during a scan, clenching one's teeth, or tapping one finger can produce false localizations on brain scans, introducing error.[13]

Another source of error can occur in attempting to obtain a true rest state in a scanning experiment. If the experimenter tells a person to think of "x" then not think of "x," can the person truly not think of what was mentioned, and how can that be verified? At some point a researcher in a human study has to rely on verbal reporting of her subject, and is the subject self-aware enough to relate what exactly he or she is feeling? This is in addition to the fact that it is likely that a person introduces additional error through extraneous mental activities that can co-occur during experiments.

One also assumes that if a region's function did not change significantly between the resting state and experimental state, then the region was uninvolved. However, there is a substantial amount of activity continually across the entire brain. It is possible that minor levels of activation that were zeroed could also be involved.

"X" does not Always Mark the Spot

A point of brain activation may not indicate a seat of a particular behavior. There are theories that attempt to localize complex mental activity to specific, singular, and local areas of the brain, however, this is challenged by the brain's systemic nature. Uttal notes that one must distinguish between a nonhomogeneous brain where different regions interact to influence different mental or behavioral processes, and the hypothesized role of these regions as the unique locations of the mechanisms underlying those processes. He blames the failure to make that distinction as fueling the imaginative theories of cognitive localization, calling this a type of phrenology, a pseudoscience that attempted to discern one's character traits based on skull morphology.[14] The localized brain region activated during a particular task should rather be considered as a specific region correlated with the task, not necessarily the locus where the processing for the task originates, and likely reflecting part of a more distributed processing network.

Specific brain areas can serve more than one function, yet it is assumed in some studies that once a piece of brain real estate has been identified with a particular cognitive process, it is assigned to only that process. For example, there is an area of the brain that has long been considered as being responsible for face recognition, yet now it seems to be involved with familiarity of all kinds.[15] Even areas typically thought of as dealing exclusively with sensory or motor tasks are being shown to have considerable overlap and are involved in other functions, even cognitive ones.[16] Finding a brain region that activates during the performance of a task does not mean that this area operates only to perform this function, and it is possible that in a different context or with a slightly varied task, the same operation could be correlated with an activation in a different brain region. Brains have many redundant systems for achieving the same tasks and a specific function may be activated by several locations.

The fact that areas can serve more than one function is why reverse inference is problematic at best. This is common in the popular literature, and it describes when someone reasons backward from brain activity to concluding that the subjects are experiencing certain thoughts or emotions. The amygdala may light up when one is afraid. So as was done in the recent elections, if a researcher sees the amygdala light up in scans of undecided voters in response to being shown a political candidate and then reasons backward that such means these voters fear the candidate, this ignores the fact that the amygdala also registers with other emotions, including sexual arousal, potentially producing a very different news report.

Or in another example, when branding consultant Martin Lindstrom declared that Apple users were in religious love with their iPhones due to having a similar activated insula as that in the brains of devoted Christians,[17] this ignores the fact that the insula mediates many other emotions as well. Reverse inference is the logical fallacy of

affirming the consequent, yet many studies promote their conclusions on such a fallacy.

It is also important to keep in mind regarding studies that purport to have found the brain locus for a particular behavior or experience, is whether this region is necessary or sufficient. Uttal gives an example regarding perceptual learning. One could remove an experimental animal's eyes, thus abolishing its ability to perceptually learn. The eyes are necessary for this learning to occur, but one would not declare them sufficient as the locus of perceptual learning. Yet, he describes how many brain studies do something similar when an aspect of the brain in blocked in some manner and an observed change in behavior is noted, then a declaration is made that the region is the locus of that behavior.[18]

Exercise Caution in Applying Animal Studies to Humans

Many brain studies are conducted on animals, yet it is important to realize that animal studies do not necessarily imply a similar conclusion in humans. An assumption in some neuroscientific studies is that the human mind and brain are qualitatively similar to those of other species, just more developed, and that the major features of organization are widely shared across animals with the differences being minor and unimportant. These assumptions have encouraged research using a few accessible nonhuman species as models and extrapolating those conclusions to humans. Injudicious studies appear to tacitly assume the idea of the great chain of being, where natural selection is seen as a means of improving species through the production of greater complexity. Species thus can be arranged along a linear scale from the simple to more complex, leading to the thought that the more complex beings have everything the simpler beings have, plus more.

However, there is no reason to hold that all aspects of the human mind or brain exist in a lesser form in other species.[19] Evolutionary biologists now understand that arranging species on a linear scale is misguided, and neuroscientists have documented that the way cortical areas are organized into functional networks can vary widely across species. Even among closely related mammals there can be marked differences.[20]

For example, Todd Preuss, professor of anthropology and neuroscience, ~~describes differences in various brain regions between hominids and monkeys and~~ relates that there is a class of neurons in humans that are absent in other primates but shared with some dolphin and whale species.[21] J. L. Rekhart, professor of education and psychology and researcher into the neurobiology of emotion in memory, describes how scientists should be cautious when extrapolating results from one mouse strain to another or from mice to rats.[22] How much more cautious should one be when jumping from mice to humans?

One should hold reasonable suspicion toward studies that make too quick a leap from a nonhuman animal study to making a declaration regarding human nature. However, one should not be tempted to ignore all animal-model studies, as it is possible to do good research upon one species and make inferences regarding another. A judicious study will be careful to explain one's method and why a cross species inference has been made.[23]

Avoid Confusing Correlation with Causation

One should also be skeptical whenever one sees a report about human nature that states, "Brain Scans Show . . ." as they typically only show a correlation—what part of the brain is active when a person participates in a particular task. This does not mean it is the part of the brain that causes it.

The idea of the Mozart effect on the brain illustrates the fallacy of equating correlation with causation. Researchers reported that listening to only ten minutes of a Mozart sonata lead to significant increases on the Stanford Binet IQ spatial reasoning task, leading to popularized accounts that Mozart can improve IQ.[24] However, this was only

a correlation and the effect has subsequently been attributed to short-term arousal's effects on test taking. Some popular music, such as "Country House" by Blur, led to greater increases than Mozart.[25] Yet the idea that Mozart makes you smarter persists.

Head and Heart are Integrated

It is common in both neurological and theological writing to regard emotion and rationality as two contrasting forces involved in decision making. One is logical and deliberative and the other irrational and spontaneous. It seems self-evident that they are separate, as one can override emotional impulses with rationality, yet even performing that function relies on emotional motivators. While there is some debate as to the degree of integration between emotion and cognition, one finds a them not so easily divisible when examining the neural circuitry of emotion and decision making.[26]

As stated by the renowned psychologist of emotion Klaus Scherer, emotion is a much nuanced concept composed of a number of overlapping, indiscreet processes that are not represented by a single neural system.[27] While certain brain regions are associated with emotions, almost all these regions also have roles in cognitive and sensory processes. A primary role that emotions serve is to highlight what is important for "rational" deliberation as well as what memory should encode and retrieve.[28] Emotions are an implicit part of rationality, organizing and coordinating brain activity including where one focuses attention, even if one is unaware of it.[29]

One should be cautious of studies that make a sharp demarcation between emotion and reason. Affective neuroscientists have generally abandoned the idea that there is a single emotion system in the brain. Older brain studies advanced the concept of a limbic system responsible for emotional processing, yet there has never been a definitive criteria for inclusion therein.[30] According to neuroscientist Joseph Ledoux, the term has become more descriptively useful than scientifically informative, and some have advocated for abandoning it as a concept altogether. [31] Choices are not clearly led by the head or the heart, but rather both in an integrated fashion.

Brains Change

For the longest time, the brain has been viewed as a Newtonian machine with research being guided by the principle of *localizationism*, which holds that the machine brain consists of many modules that each perform a specialized mental function. The brain does not change, and, therefore, human nature which emerges from the brain is also unalterable. However, recent scientific discoveries have begun to reveal that the brain can change through the activities it performs, essentially rewiring itself through experience

The mechanism for brain change at the neuronal level is that neurons can be sensitized through repeated use and desensitized through neglect. Repeated stimulation of a neuron increases its ability to respond, called potentiation, and repeated neglect depresses its response ability, called depression. The neuron changes chemically and structurally through activity both in the short and long term. (This is how habits are created. Repeat an action long enough then the behavioral process becomes more "neurologically entrenched.") Each biological system and associated behavior is then unique, given how it has organized itself in response to unique details of its own history.

One can see the dichotomy between the fixed-brain theory and the idea that brains are malleable in developmental studies. According to cognitive neuroscientist Mark Johnson, many developmental studies assume what he terms the maturational view, where success in a new behavioral task during development is the result of a new brain region maturing and coming "online" with a one-to-one mapping of function to neural location. [32] The assumption is that the relationship between structure and cognitive function is unchanging and current structures continue to support the same function they always have. This static assumption is why it is common to study disorders in the adult brain and extrapolate back to early development.

However, brains can change and such studies may be flawed. Johnson suggests rather that one should view the developing brain as having areas of poorly defined function that sharpen in their specificity through experience, and having a mechanisms of malleability that continue life-long. Brains can respond to new training even in adulthood. When a new skill is acquired, there can be a reorganization between different structures and regional activity, a reorganization that can even change how prior functions are represented. The same behavior can be supported by different brain regions at different times of development.[33]

To use the example of criminal brains, one cannot easily say that a defendant's current brain formation is the way it always has been. It is highly problematic to scan a defendant in a criminal case and reason that the current scan represents his or her mental state at the time of the crime. The brain may have changed. Unless a study is accompanied by a longitudinal analysis of the brain throughout one's maturational development, one cannot simply assume that the way a brain is functioning currently was how it was at birth.

There have been brain damage studies in adolescents that result in anti-social behavior that may be described as psychopathic, yet these same lesions in adults, while producing some self-damaging behaviors, rarely produce psychopathic tendencies. The fact that the same lesions in adults may cause one to make poor choices but not become a psychopath reveals that a lifetime of moral influence and choices against such has a profound impact and raises the question of the possibility of intervention in adolescents with such brain damage. One need not speak of a "neural fate."

Nature and Nurture are Integrated

One often can find studies that attempt to figure out how much of a behavior is nature and how much is nurture. The very statement "nature or nurture" is disingenuous in that it seems to deny a physical substrate to nurture, or that once one discovers a natural element, there is no room for nurture. Neurological terms can often "suggest a rigid internal process that leads inexorably to only one behavior."[34] Biological does not automatically mean hardwired. If a person commits a crime and it is shown that the brain was involved, it is false to immediately jump to the idea that because such behavior was biological it could not be under one's control. The same can be said for addiction. Because there are neurobiological changes that accompany substance abuse, it does not automatically mean the person is unable to choose.

Choice is not an all-or-nothing concept, a completely neutral and rational space where all options can be equally considered. Choices can and often are impaired, emotionally weighted, or difficult. This should motivate compassion and care for those suffering from ill-advised choices, but it does not mean that a particular choice was inevitable.

Biological systems develop in close connection with the environment, and neither system functions without the other. As stated by developmental and clinical psychologist Willis Overton, "It is not a set of genes that causes behavior, nor a brain, nor a culture. Behavior emerges from the embodied person actively engaged in the world."[35] According to affective neuroscientist Jaak Panksepp, even speaking of something as inherited is shorthand for tendencies or dispositions being represented by brain and bodily constructions. Dispositions to think and act in certain ways can be directly inherited, but these promote or diminish possibilities and "do not necessarily dictate our destinies." "No specific thoughts or behaviors are directly inherited. Nature provides the potentials and nurture provides the opportunities for how these potentials can be manifested in diverse ways."[36] Such then leads one to consider the oft-debated topic of free will.

The Reports of the Death of Free Will are Premature

Scientists study what they can measure: the physical world, observable behavior, and efficient causes.

Everything is reduced to matter and to its simplest components. This is needed for effective experimentation, yet often this automatically excludes anything but strict determinism. While this is a sound methodological approach, to then insist, however, that the world consists of only matter and efficient causes is a metaphysical claim, not a scientific one. Experiments designed with a deterministic presumption only give conclusions that support that presumption. The data generated in brain studies that support denying free will are essentially irrelevant, as a deterministic universe is held before any experiment is conducted, and no contradictory data can emerge as the experiments themselves measure efficient causes. This does not denigrate science, but merely reveals it limits.

Conclusions that attempt to dictate reality outside of the boundaries of science are going beyond those that science is capable of truly making. There is a difference in being only able to measure physical causes to declaring that only the physical exists. While Christianity does not stand or fall on the existence of free will, there are strands that hold to determinism as well as libertarianism; science is not currently in a position to declare that free will does not exist regardless of how strongly some may say otherwise.

The Importance of Neuroliteracy

Are those neuroscientists going to take away ~~our~~ faith in a transcendent God? ~~Can everything we believe as Christians be reduced to neuronal firings within our brain?~~ Will science step on ~~our~~ most precious religious beliefs and crush them into the ground like a cigarette butt?

No. Yet, it may appear that ~~our~~ faith is under threat if ~~we~~ fail to become neuroliterate. Neuroliteracy reveals that neuroscience—as is the case for science overall—must be viewed with a critical eye. A critical eye will discern the limits within which science works, and the limits to the capacity of neuroscience to explain just what makes us human in relationship to God.

Keeping the above listed ten principles in mind will enable one to be neuroliterate and to determine more accurately what pronouncements from the neurosciences are actually able to conclude. Neuroliteracy will help ~~us~~ filter out alleged findings that overreach in their determinations regarding human nature. As we have observed, first, the fact that one discovers neural correlates of human experience should be expected. The threat of reductionism comes when one uses these discoveries to advance a reductive and one-dimensional view of human nature, explaining away an aspect of human experience because it has a physical substrate.

Second, one should recognize when studies inadequately define the mental process for which they are searching. Definitions should be as specific as possible for phenomena as complex as mental processes. There is no agreed upon taxonomy of mental components and it is possible that definitions could be ad hoc and rather reflect one's ~~methodology~~ of experimentation.

Brain scans are also not infallible. They are processed and averaged representations of activity. Experimental design and how one analyzes data can have a significant impact on the final results. It is also important to note that FMRI scans do not literally read thoughts, they measure brain oxygen levels, revealing areas of the brain that have increased activity during the performance of a task. It is a huge leap to go from this to claiming that one is reading the subjective experience of mind.

Additionally, a point of brain activation may not indicate a seat of a particular behavior, as it could rather be distributed over several brain activity regions. Realistic conclusions regarding brain function and mental processes should incorporate the plastic nature of the brain as a non-linear, dynamic system with parallel processes and redundancy with brain regions that overlap and are multifunctional. For example, study tools that market that one can train part of the brain to enhance a particular skill ignore the brain's systemic nature. Even the traditional, popular concept of "right brain" or "left brain" people turns out to be largely mythical.[37] Brains that are not radically altered through surgery work as a systemic whole.

One also often does not know whether an area revealed in a scan is necessary or sufficient for the studied behavior and reverse inference, such as when one scans the brain to determine if one likes a product, is enamored of a political candidate, or is lying, is highly problematic and rests on a logical fallacy.

Studies should be cautious in making inferences to humans from animal studies, should reflect the integrated nature of emotion and reason as well as nature and nurture, and reflect the knowledge that brains change throughout life. One also should always remember that correlation does not imply causation. Finally, any study that dismisses free will on the grounds that matter and efficient causes are the totality of reality is based on certain metaphysical assumptions and is going beyond what science is capable of investigating.

Endnotes

1. Lest this article lead one to dismiss the field of neuroscience given its challenges and potential misinterpretations, it is important to realize there are many good researchers. Sally Satel and Scott Lilienfeld, authors of the book *Brainwashed: The Seductive Appeal of Mindless Neuroscience,* cite several researchers who are exemplars of judicious and rigorous scholarship who are thoughtful and circumspect in their use of imaging data: Steven Hyman, Hal Pashler, Eric Nestler, Danny Pine, Erin Tone, Angus MacDonald, Sohee Park, Helen Mayberg, and Greg Berns to name a few. (Personal communication, Oct. 1, 2013).

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11. Craig Bennett, Abigail Baird, Michael Miller, and George Wolford, "Neural Correlates of Interspecies Perspective Taking in the Post-Mortem Atlantic Salmon: An Argument for Multiple Comparisons Correction," *Journal of Serendipitous and Unexpected Results* 1, no. 1 (2010).

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