Brain Science and the Non-Human Animal Mind

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Introduction

With the realization that the brain is responsible for what we think of as the "mind" (for readable accounts of brain science along these lines, see, for example, Eagleman, 2012; Ramachandran, 2012; Churchland 2013; Dehaene, 2014), modern brain science has helped us humans re-frame the questions we ask about *other* animals. Instead of asking intractable questions like "do other animals have souls," brain science allows us to ask whether other animals have conscious minds, and if so, to ask what those minds are like. But since the mind is a function of the brain, in order to better understand the non-human animal mind, you actually have to get in there and look at the brain. Modern neuroimaging, and brain science in general, has allowed us to do just that.

In this brief report, I aim to accomplish two main goals. First, I will describe some research from the field of brain science that I consider to be important for an understanding of the non-human animal mind. I certainly won't cover everything, and even the material I do cover will be covered with broad strokes. Still, I hope to describe the science in a plain-spoken, even-handed and accurate way. My second goal is to describe future directions that brain science might take, in order to deepen our understanding of the non-human animal mind. Unfortunately, work that helps us understand other animals' minds can come at a cost—and the price is often the well-being of the non-human animal being studied. However, this is not always the case, and "animal-centered" brain science may be gaining some steam. I'll more directly address these issues later. For now, I'll say this: my hope is that a better understanding of non-human animal minds can lead to a better life for all of us in the animal kingdom, not just humans. In part, I hope this shift occurs as the evidence continues to mount: we are not the only creatures with complex, conscious, active minds. In fact, in this author's opinion, the available evidence suggests that a human is not the only animal who can be understood to be a "person".

This project was borne from a desire to connect my scientific experience to efforts that advocate for the well-being of non-human animals. I consider such efforts to be important for reasons that are supported by a great deal of evidence. I hope those reasons become clear shortly.

Finally, a brief note about terminology. In this report, I use the loose term "brain science" to refer to scientific research that yields insights into the structure and/or function of brains. Such research spans multiple academic fields, and it utilizes objective brain measures, such as neuroimaging. Hopefully, the broader term "brain science" will make for easier reading.

Research Highlights

Memory

Tucked away near the bottom of the human brain, and toward the midline, is a structure called the hippocampus. Among other things, the hippocampus is very involved in creating our memories. More specifically, it's necessary for creating our long-term autobiographical (also called "episodic") memories. These are memories that can be consciously recalled, and that contain *who, what, when* and *where* information. My childhood memory of hiking in the Franklin Mountains in Texas with my father is, for example, an autobiographical memory. The hippocampus is a structure that is present, in remarkably consistent form, across mammals in general. But in some animals, the hippocampus and associated brain structures are especially complex; the elephant hippocampus, for example, is likely capable of supporting episodic memory capabilities comparable to those of humans (Patzke et al., 2014). This makes sense—the complex social behavior that elephants display probably necessitates sophisticated episodic memory (e.g., Bates et al., 2007; Byrne, Bates & Moss, 2009). It's not just large mammals that show neurobiological evidence of episodic memory, though; monkeys do (e.g., Ninokura, Mushiake, & Tanji, 2004) and rats do too (e.g., Crystal, Alford, Zhou & Hohmann, 2013; DeVito & Eichenbaum, 2011). Given the presence of the hippocampus and related structures in all mammals, it's likely that most or even all mammals have memories of this type (see Allen & Fortin, 2013; Templer & Hampton, 2013 for reviews), though the exact nature of episodic memory varies by species (e.g., Patzke et al., 2015). The capacity to remember aspects of personal experiences is probably not even confined to mammals, as it is likely present in birds, as well (Allen & Fortin, 2013). The remarkable conclusion that many species likely have the ability for some degree of autobiographical memory is illustrative, and it foreshadows many lessons to come.

Communication

Like autobiographical memory, language was once thought to be an obviously unique human capacity. And, it is possible that the capacity for symbolic, syntactic language is indeed particularly developed in the human brain (e.g., Rilling et al., 2008; although keep in mind that the language capacities of cetaceans, for example, are not perfectly understood and may be substantial; Janik, 2014). Still, whether you slap the label "language" on it or not, other animals are clearly capable of complex vocal communication and vocal learning—consider, for example, the well-documented complex communication abilities of non-human primates, songbirds, parrots, elephants and cetaceans (for partial discussions, see Rendall, Owren & Ryan, 2009; Janik, 2014).

In humans, the structures that support language-use and comprehension are more pronounced in the left hemisphere of the brain than in the right. And at least one of those structures is also more pronounced in the left hemispheres of chimpanzees, orangutans, gorillas and bonobos (Hopkins, Marino, Rilling & MacGregor, 1998; Preuss, 2004). So, it is likely that the organization of these structures in the brain preceded or coincided with the last common ancestor of humans and other great apes (Riling, 2014). This is interesting, because even if it's true that language is especially developed in the human animal, structures that are related to language in the human are also present in the brains of our primate relatives. Language structures in humans are not "more evolved" than they are in other primates. Rather, human language structures and the analogous structures in other primates evolved *differently*, both from the same starting point: our last common ancestor.

What's more, non-human primates don't only have the structures associated with complex communication, they really do *use* them when they communicate with other members of their species (e.g., Petkov et al., 2008; Taglialatela, 2008). It's not just primates that use similar brain regions for vocal communication though, dogs do too (Andics et al., 2014). Communication areas of the dog brain respond to both human and other dog vocalizations, and they can even tell the dog about the emotional tone of those sounds (Andics et al., 2014).

As suggested at the start of this section, complex communication-enabling brain structures aren't exclusively a mammal thing. Behavioral research shows that vocal communication and vocal learning in birds can be extraordinarily sophisticated (Jarvis et al., 2005). But additionally, the brain structures that support those abilities in the bird brain are quite different from those that support it in primates. Fascinatingly, although the structures are different in the songbird brain compared to the primate brain, the connectivity between those structures is very complex, and can even change across the seasons—within a single songbird brain (De Groof et al., 2006)! This particular kind of brain plasticity is not known to exist in primates! Here's the main lesson: there are multiple ways for evolution to create an animal brain capable of complex vocal communication (Jarvis et al., 2005). The human primate—primates in general—represent one such way, but there are others.

Social Cognition

Communication is, of course, social. And indeed humans are deeply social animals. In addition to our language abilities, we have many sophisticated brain networks to support our sociality. But we're certainly not alone. Most of the great apes are also deeply social, although other ape brains develop more rapidly than our own and so are structured somewhat differently (Sakai et al., 2012; 2013; for a fascinating account of why humans evolved this developmental luxury, see Falk, 2016). As a result of all this complex brain structure devoted to sociality, thinking and feeling in social ways (i.e., "social cognition") takes many forms. It can include, for example, trying to infer what another's intentions and goals are. When monkeys think in this way, the brain structures and networks they rely on might not be that different from the ones we use to make similar inferences (Iacoboni, 2005; Ferrari, Bonini & Fogassi, 2009; Sliwa & Freiwald, 2017). Social cognition is complex stuff, but the brain structures to support it are not unique to us.

Social cognition also includes, for example, knowing when you've made a social faux paus, as well as the capacity for deception and empathy. The long-range cellular networks in the brain that likely support these functions in humans are common across all the great apes (Allman et al., 2010; perhaps especially developed in the bonobo, Rilling et al., 2012). In some form or another, they're also present in monkeys (Evrard, Forro, Logothetis, 2012), elephants (Hakeem et al., 2009), raccoons, (Lambert et al., 2014), and cetaceans (Hof & Van der Gucht, 2007; Butti et al., 2009).

Here's another example of significant overlap in social cognition. For humans, a huge part of being social includes seeing the faces of other people. Really, much of a given day involves looking at the faces of other people, whether in a conversation, on TV or a computer or just in a public crowd. Faces are very important objects for social primates like us because they carry a lot of social information. Who's attractive, who's not? Is that person paying attention to me or someone else? How is that person feeling, are they angry? It's no surprise then, that portions of our own brains, especially in an area called the temporal lobe, are devoted to extracting helpful social information from faces. But it's not just us humans that have brain regions like this. Other primates do (e.g., Tsao, Moeller & Freiwald, 2008), dogs do (Dilks et al., 2015), and sheep do (Kendrick & Baldwin, 1987), and they rely on them for decoding face information, just like we do. Having said that, it's important to note that not all species use their faces to communicate with each other to the same degree. As a result, we shouldn't necessarily expect face-specialization in every animal brain. But for many of the species that *do* heavily rely on social face information, similar brain regions handle it. Evolution seems to have re-used the solution to some problems (i.e., extracting useful social information from expressive faces) in a similar way across many mammals.

Often, social cognition doesn't just require specific brain regions, but a whole network of interconnected regions. At some locations in the brain, a large number of such connections all converge at dense "hubs"; think of them as miniature central processing stations. In humans, one such hub is associated with aspects of consciousness, social memories, and thinking about the self (Margulies et al., 2009; Vogt & Laureys, 2005). This hub is present in macaques and chimpanzees as well as humans, and likely supports similar functions in those species (Li et al., 2013). Other hubs present in all three primates may support directing attention outward to the external world, or inward, to the self (Li et al., 2013). The ability to attend to and think about the self is a sensible thing for a social animal to be able to do; complex sociality likely entails both the ability to think about others, *and* ability to think about the self (Mars et al., 2012)! This seems to be the case, at the very least, for many primates (Rilling et al., 2007; Mantini et al., 2011) and other mammals (Zhang et al., 2010).

All this is not to say that the species we've talked about in this section think and feel socially in exactly the same way. They do not (see, for example, Bliss-Moreau, 2017). Take empathy again, for example. Empathy in some form is likely present in most or even all mammals, and as I've said, it is probably supported in part by similar (but not identical) brain structures (Butti & Hof, 2010; de Waal & Preston, 2017). The presence of empathy (as well as other emotions, see Panksepp, 1998) across mammals shouldn't be surprising, since most care-giving mammals exist in interdependent social groups, so they're affected by the thoughts and feelings of others. They have good reason to be capable of identifying with those mental states. Nonetheless, the precise form that empathy takes can vary across species (de Waal & Preston, 2017), because the structures that support empathy—while having important similarities—are not identical. Remember, the similarity of animal minds is informative, but the differences matter too. Each species has a unique mind, even if there is significant overlap across multiple species.

Summary of Research Highlights

Mental capacities that were once thought to be uniquely human are simply not so. The commonalities among the minds of humans and the minds of other animals are remarkable. After all, some degree of complex vocal communication and vocal learning, conscious autobiographical memory, sophisticated social cognition and social emotion, and even self-related cognition are all present in multiple other species—and this isn't even an exhaustive list of the complex mental functions we share with other animals. The brain structures that support those functions can be quite similar across multiple species, as well. Modern brain science is telling us that we are probably not as unique as we'd like to think we are. Instead, the human animal is firmly rooted in the animal kingdom, and we represent just one version of a mind among many. The evidence that other animals also have complex, deep and conscious minds is overwhelming; I've reviewed a small sliver of that evidence here. Minds—perhaps the most beautiful and precious of Nature's creations—are much more ubiquitous than we once thought. We are surrounded by them.

Importantly, this does not mean that every species' mind is the *same.* They are not. The minds of different species *cannot* be the same, because at the big-picture level, their brains are different (e.g., Van Essen & Dierker, 2007), and the mind is a function of the brain. Although different, it is a big mistake to think of one mind as "better" or "worse" or "higher" or "lower" than another. Instead, each species' mind is adapted to flourish in the environment they evolved in, and so each species' brain is complex in its own, well-adapted, way (Hof, Chanis & Marino, 2005). Brain science cannot tell us which brain is the best, because that is a useless and foolish question to ask. What brain science can do is refine our understanding of what a species' mind is *like*. This is an important goal, since it's now clear that despite many commonalities, there is no such thing as *the* animal mind. Instead, there are many versions of animal minds: monkey minds, elephant minds, parrot minds, human minds, whale minds, and so on.

Since minds are so ubiquitous in the animal kingdom, we humans have good reason to re-think our concept of a "person". Various current, common definitions of "person" ultimately boil down to this: *a person is a human being*. But, I see no reason to restrict the term "person" to apply to only one species. What on Earth could be the justification for doing that, other than simple favoritism? After all, we already have a word that refers exclusively to our species, which is of course simply "human". Instead, I propose a more reasoned alternative for the definition of "person", informed by modern science and more free of anthropocentrism: *A person is an organism with a complex conscious mind, including functions such as perception and sensation, memory, emotion or affect, and/or self-regulated behavior.* Good evidence suggests that many non-humans are persons, under this more reasonable definition of personhood. Now, instead of using non-humans to better understand ourselves, or to serve our own needs, brain science allows us to look at them and ask, "*who, exactly, are you?*"

Future Directions and Future Applications

Understanding the minds of other animals more deeply—on their own terms and for their own sake—is an open and exciting frontier for brain science. All that potential for discovery and understanding comes with a qualification, though. Since the available evidence tells us that other animals have complex, conscious minds, the study of those minds must be done with compassion, care and a critical eye toward the well-being of all involved. We do so when we study the human animal mind. We should certainly do the same when we study non-human individuals.

An important distinction should be made here. Sometimes, non-humans are used in research that has the potential to serve the well-being of humans. For example, non-human research can inform the treatment of human diseases or medical conditions, at the expense of non-humans. I will not comment on the ethics of that practice here, except to say that all possible efforts should be made to avoid, eliminate or minimize the suffering of research subjects. Other times though, non-humans are used in research that is clearly unnecessary and hurtful (e.g., "Car Companies Under Fire for Animal Testing", The Bottom Line, 2018). While condemnable, I am also not talking about that kind of research here. Instead, I am specifically discussing brain science that aims to understand the minds of non-humans, for their own sake. *That* is the program of research that has so much potential, and that I am directly recommending be done with careful attention to the well-being of research participants.

Unfortunately, that doesn't always happen. The guidelines in place for non-human animal research (Dunbar, Higa, Jones, Kaminski & Panicker, 2012; also see "Lab Animal Welfare", and "Guidelines for Ethical Conduct in the Care and Use of Nonhuman Animals in Research", American Psychological Association) are arguably insufficient, and not all research in the US abides them to the same degree, nor do all research labs experience equivalent levels of federal oversight. Even if welfare guidelines and requirements are roughly followed, some neuroimaging methods require the head to remain almost perfectly still for minutes at a time. This requirement means that studying a non-human brain can entail the surgical instillation of head-stabilization devices. This is always life-altering, likely painful, and sometimes terminal. Some other methods are particularly hurtful and invasive, and all research can entail less-than-ideal or harmful living conditions. Clearly, plenty of room for improvement exists.

Developments and Challenges in "Animal-Centered" Brain Science

Can we increase our understanding of non-human minds in ways that place emphasis on the well-being of the individuals involved? In ways that we might call "animal-centered"? Some laudable methods have already been implemented. For example, a lot can be learned about brain structure (as opposed to brain function) from post-mortem non-humans who did not die as a result of the researchers' actions (e.g., Hof, Chanis & Marino, 2005; Berns et al., 2015). Although this method alone cannot tell us about how that animal's brain functions, if it is combined with behavioral research, the result can be very powerful. Other times, researchers can investigate the brain structure of living non-humans, assuming the individual can fit in an MRI machine. In many of these cases, a combination of drugs are injected to immobilize and anesthetize the non-human participant. Although not completely non-invasive and certainly not voluntary, at least this method doesn't require surgery and is not life-threatening. In general, an "animal-centered" approach is feasible for research into brain structure, and can be paired with behavioral work to yield insightful results.

Here is an idealized example of combining behavioral research with ethical structural brain research. Careful behavioral and observational research can establish that elephants act in sophisticated social ways that seem to involve autobiographical memory (e.g., Bates et al., 2007; Byrne et al., 2009). Post-mortem scans could then reveal the elephant brain's particularly complex hippocampus, which tells us that the brain structure to support autobiographical memory is also present. So, convincing converging evidence suggests that elephants have autobiographical memory, and all that evidence can, in principle, be gathered without impinging on anyone's welfare.

Methodological improvements for studying how the brains of awake and behaving animals *function* show promise, too. Recall that, in order to scan the brains of awake animals, modern methods require the participant's head to be almost perfectly still. As a result, non-human participants often undergo invasive surgery. Recently, researchers have devised methods to reduce the amount of stress experienced by rats who participate in brain scanning experiments like these (King et al., 2005). This is important progress, since rats can experience pain and discomfort during traditional experimentation (e.g., Borsook & Bacerra, 2011). But more importantly, researchers have recently devised methods for restraining rats in a way that is completely non-invasive and surgery-free (Madularu et al., 2017). If these improvements are combined, the result is brain scanning research on awake, conscious rats who likely experience less stress than they would in more traditional brain research, and who are physically unharmed in the process. This is a simple but profound improvement, and one that can and should be applied broadly in future animal-centered brain science. Of course, more resources (e.g., time) are required for research like this, compared to invasive methodologies. This will often be true of "animal-centered" brain science, and represents one potential challenge.

Developing "animal-centered" methodologies presents other challenges for brain science, too. For instance, most modern brain imaging technology is bulky, finicky and certainly not portable. This makes studying non-human brains in relatively naturalistic, ethological valid, settings obviously difficult. But one technology (called *electroencephalography*, or *EEG*) may be able to help buck that trend. This technology has an established track record for yielding insights into the human brain (e.g., Dehaene 2014; Michele & Koenig, 2018). And already, portable or mobile versions of EEG devices exist and can be used to study the minds of unrestrained humans, via a tight-fitting cap or head-mounted device (e.g., De Vos, Gandras & Debener, 2014; Krigolson et al., 2017). Free-to-roam rats who underwent surgical instillation have also been studied with mobile EEG devices (e.g., Lapray et al., 2008; Zhang, Gao & Yu, 2011). But in order to apply these technologies non-invasively to non-humans who might forcefully object to EEG equipment being placed on their heads, researchers risk damage to costly resources. Still, it may be possible to overcome this challenge, perhaps by slowly acclimating the individual to the device (Madularu et al., 2017). Although time-consuming, this possibility is certainly worth exploring. And, EEG technology can even be fitted to non-humans whose bodies are very different from our own ("Developing Underwater EEG Electrodes For Octopus Research", 2018), meaning the technique could be applied to a wide array of different species. These techniques could, in principle, even be used to help us understand how the "neural signatures of conscious awareness" vary across multiple kinds of animal minds (for a thorough discussion of these signatures in the human, see Dehaene, 2014). To me, this makes overcoming the challenges involved with applying mobile EEG to other species worth tackling. In general, mobile EEG technology represents an exciting and promising avenue for future "animal-centered" brain science.

A final challenge is that funding "animal-centered" brain science could be, or could continue to be, quite difficult. Federal funding is tight, and without an obvious benefit to the human animal, the quest to understand the minds of other animals for their own sake could find itself strapped for cash. This challenge is particularly tough, for it may present a sort of "chicken-or-egg" problem. Funding agencies (and the public at large) might become more interested in granting resources to "animal-centered" brain science if it becomes increasingly clear that humans are not the only ones with complex, conscious minds. But developing and distributing the evidence that supports that conclusion takes resources, which are limited… and round and round we go. That is why, in my opinion, public educational outreach is so important. Relatedly, brain science education in our public schools and universities would greatly benefit from a less anthropocentric approach, and this provides another open avenue for significant improvement within the fields of brain science. Such improvements to education could ultimately lead to a public that more deeply appreciates the existence of and value of non-human minds, and the value of attempting to know them better.

So, there is a lot of room for exciting developments in "animal-centered" brain science and science education, even if the challenges are significant. Having said that, keep in mind that brain science is not the end-all-be-all. Importantly, brain science will likely continue to yield the most profound insights when it is paired with ethical behavioral and observational research (for an excellent example of eye-tracking technology used in this way, see Ryan et al., 2019). Even as "animal-centered" brain science overcomes challenges and develops further, behavioral work will always remain a critical piece of the puzzle.

Conclusion

Many animals, including but not limited to humans, have complex, conscious minds. This statement is supported by a great deal of evidence, including profound insights into the brain itself. Now, an important task for brain science is to better understand the minds of other animals, for their own sake and in a way that puts their well-being front and center. That task will require dedicated effort, technological developments, and of course, resources. But if our species values conscious minds in general to the same degree we value our own, the task is worth the effort.

Importantly, it's likely that "animal-centered" brain science will call attention to what is best for the species being investigated. I'll use our own species to explain what I mean. Research (and perhaps common sense) tells us that humans require, for example, reliable social connections, meaningful work, physical activity, and a sense of purpose and self-determination in order to really flourish (e.g., Haidt, 2006). So, understanding our own minds entails understanding what is best for an animal like us, and what circumstances can cause us to suffer. Likewise, as we come to know the brains and minds of the non-humans we share this planet with, we will likely begin to appreciate what is best for them, and what circumstances cause them to suffer.

In the process, an "animal-centered" approach to understanding brains and minds will likely cross paths with other important challenges and problems our world currently faces. For instance, we probably won't discover that environmental degradation and pollution, or habitat and biodiversity loss, is what's best for non-human minds. Nor will we discover that the minds of other animals thrive in the deprived conditions of factory farms. Instead, we'll probably find that—like us humans—other animal minds flourish when they have access to natural habitats, and can freely express the natural behaviors their brains are built to carry out. In the absence of those things, other animals—like us humans—suffer. In this way, "animal-centered" brain science will likely intersect with modern environmental and food-production challenges and issues.

Ultimately, "animal-centered" brain science is compatible with something very grand: a deep appreciation for the living world in general (see Kellert & Wilson, 1995). In my opinion, brain science—far from being cold and detached—has an emotionally resonant message, one that can even guide our future behavior as a species. The mind of the human animal is not the most precious and valuable of Nature's creations. No, that view is much too myopic and narrow, and I know of no objective reason to hold it. Rather, the whole of this Earth is covered in the rare phenomenon we call life. This biological system has led to something remarkable. At least some of the animals here, including but certainly not limited to humans, have complex, conscious minds. On the cosmic scale, that phenomenon appears to be vanishingly rare, and is thus immeasurably precious. If conscious minds—and the planet that supports them—are not worth preserving and stubbornly protecting, I do not know what is.

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