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Transcript of an oral presentation given at *The Science of Animal Thinking and Emotion* conference organized by HSISP, Washington, DC, March 17-18, 2014.

I am going to talk a little bit about the work that we have been doing in my lab with dogs. Specifically, how we train them to go into an MRI and what we are discovering about their brains and what that might tell us about what they feel [1]. The dog literature is clearly constrained but I want to start with this quote [2]:

> *Dogs belong to that select group of con artists at the very top of the profession, the ones who pick your pockets clean and leave us smiling about it. Biologists, if they weren't victims of the same blindness that afflicts us all, wouldn't hesitate to classify dogs as social parasites.*

The quote notwithstanding, this is really quite an excellent quote and I recommend it. Really it comes at the heart of the question in the things that I am most interested in in studying dogs and using modern technology to try to figure out how their minds work [3]. It gets right at the heart of the question of dogs and human relationships. All of the work that we are doing focuses on dogs and human relationships. Specifically, what dogs think of us and how they feel about us.

We are looking at the animals from the outside and we are trying to figure out how they might feel. Sometimes it is obvious and sometimes it is not. You don't have to be a scientist to recognize the fact that animals feel emotions like the pure joy of playing [4], or in this dog probably fear and anxiety [5], or this emotion whatever that might be.

However, you might call that loyalty or love, something having to do with a bond [6]. It is the question that I get asked the most. And I say it is kind of 50/50 out there even amongst dog people whether this is all a scam. What do I mean by this? Is this all a scam [7]? Is it the case that dogs pretty much act all cute and stuff in exchange for food and shelter and that was the evolutionary bargain that we made with them?

One of the reasons humans like to have them around [is that] maybe they were useful some time in the past but mostly today we just like having them around. Dogs are perfectly happy to oblige but the question is do they have any feelings like we do or are they essentially Pavlovian machines?

If this was a human we traditionally have two ways that we can prove someone's mind and their thoughts [8]. We can either ask them what they are thinking and they might tell us. They might tell us something and we can kind of gauge the veracity of based on our own introspection. Or they might not tell us what they actually think or what they actually feel. Sometimes people don't know either [9]. So asking people what they feel and what they think is kind of a tried and true method in psychology but so is looking at what they do. This is kind of more of what I would put in an economic framework for actually observing their behavior. So we can determine what is going on in a person's mind by observing their behavior because we have all sorts of capacities. There are all sorts of theories to determine why they might do something primarily because we can use our own intuitions and our own thought processes to project and figure out what someone else is thinking.

With animals I am going to focus on dogs specifically in this talk and build on the technique. Not to be a canine speciesist, although I have been accused of that. I am going to use dogs to illustrate everything that we are studying but you could easily take any animal and swap them in in terms of processes. The problem, of course, in studying animals is they can't speak to us. Not literally. They don't have the capacity of language and I am not talking about communication. They do not have the capacity to tell us about how they feel so we are stuck observing their behavior and trying to infer their mental states, their feelings, their emotions and so on.

Now as you heard, I am not traditionally in animal research. I came on this on a whim and a passion and being a dog lover. My background is studying human reward systems so when we see problems like this we bring in the heavy machinery [10]. This is an MRI being delivered. It was some kind of jet engine. But that is what we use to study the brain in action. Just a quick note about what we are actually doing and what we are actually studying. This is actually the first picture of a brain imaging experiment [11]. It goes back to the mid 1800s it was drawn by Angelo Mosso who invented the first blood pressure device, which you see attached to this dude's head. Now this guy, his name is Bertino was a stonemason in Mosso's village and Bertino had suffered a skull fracture. He lived but he always had a defect in his skull. It had peeled open the skin but there was always this window into his brain and Mosso had this brilliant idea of attaching his blood pressure device to that hole in his skull and measuring fluctuations in blood pressure as Bertino did all sorts of mental gymnastics like arithmetic and reading and all sorts of things and the story goes that one day they were doing these experiments and the pulsations starting increasing and they asked Bertino what are you thinking to which Bertino replied: *Look I just heard church bells going off in the town square and it reminded me that I had not been to mass.* It is an interesting story in the sense that you can see where they placed the device. It is in the frontal lobe. It is the first demonstration that blood flow increases to parts of the brain that are specifically active at that point in time. Mosso did not know anything about that he didn't know anything about brain anatomy; it was just an observation but that is the basis of what we use MRI for, functional MRI specifically. The other bit we need to know about from MRI is actually discovered by Linus Pauling in the 1920s when he discovered that oxygenated and deoxygenated hemoglobin have different magnetic properties and you can detect this in a modern machine like the MRI. He put these two things together. Specifically when parts of the brain are active blood flow increases to those parts of the brain on a very local scale and you can detect the changes because it is basically a shift between oxygenated and deoxygenated hemoglobin. That is basically how an MRI works.

So, onto the dogs. First, we started with really what was a proven concept. Can we take usable data from a dog and does the rewards system actually reflect the salience of direct stimuli [12]. The first point is kind of self-explanatory. The second point deserves a little explanation. We actually know quite a lot about what I would generally call the rewards system. We know a lot about the anatomy in the brain and we know a lot about the circumstances in which it is active in a wide variety of animals. Most of the data comes from humans and of course rats. What we know about the system, I am talking about is centered in an area of the brain called the caudate nucleus. It goes by many other names. It is the part of the brain that is the richest in dopamine receptors. For many years people thought that dopamine was essentially a neurotransmitter of pleasure. That whenever something pleasurable happened to an animal dopamine was released. What we actually know now is that it is much more sophisticated than that. Any time anything happens in the environment that causes an animal to change its expectation about the future particularly in the way that positive value we see activity in these parts of the brain and it is associated with dopamine release.

Our first experiment was to test the functioning of this system in dogs because if we didn't see that all bets were off in terms of using the technique for more difficult and more interesting questions like how does the visual system encode identity and are there individual differences between dogs [13]. The biggest challenge is you can't move. Now if you have had an MRI you know how difficult this is. MRIs are enclosed spaces and they make a lot of noise they are kind of jack hammer loud. Some of these challenges are human type challenges and some of them are particularly difficult for dogs. Before we started this project, we established several ethical principles that went above and beyond what any institutional committee required and it actually goes beyond the Animal Welfare Act [14]. We said we were not going to harm the dogs. These were all community pets. We said we would not use any restraints neither physical nor chemical and we would not use positive reinforcement. The reason for this is we essentially decided to treat the dogs with the same rights of self-determination that we would offer a child participating in one of our experiments. The reason being that if the dogs didn't want to be there they were free to leave the scanner and that is really the best way to know we are getting all of the data and ethically it makes the most sense. If the dogs didn't want to be there they don't want to be there and they will act accordingly.

So, how did we do this [15]? Training is a big part of it. We had to build simulators. This is Andrew Burke who was my grad student at the time [16]. Much of this was done in my garage. We are building two simulators. This is me testing out a mock up of a head coil that picks up the signals [17]. As far as training the dogs, we had to do a lot of trial and error because it wasn't really clear how best to do this because of course MRIs are not designed for dogs [18]. They are designed for humans. So all of this is geared toward teaching the dogs how to stay stationary which by itself is not difficult; dogs can be stationary for long periods of time. The challenge of course is doing it in a tube with these loud banging noises all around [19]. You can also see in order to protect the hearing we had to train the dogs to wear earmuffs [20]. So this is lots of trial and error: how do we best do this how do we give the dogs a specific place to put their heads so they know they are in the right place, various types of chin rests. All of this was initially done in my living room [21]. That was Callie probably after about a month of training using positive reinforcement [22]. By the way she comes from the Humane Society in Atlanta. She actually has other particular skills other than doing this. After we started and gained confidence that we knew how to do this the word got out and we started recruiting other community members [23]. This is what we call the Alpha and Bravo Company. We have many teams now as the project has gotten bigger. This is mostly the A team and Bravo company. You can kind of see initially the range of dogs we have a fair representation of retrievers, which partially reflects their popularity but also because they are so well suited for this task [24-28].

Some of these pictures are old but I like them because they kind of capture their puzzlement of what exactly are we doing here [29-31]. That is Rebecca Hunter our vet tech who is there for virtually all of our scans to look out for the dogs [32]. The earmuffs actually are more for protecting their hearing but also to muffle the sound but unfortunately they don't stay on very well so we often end up just wrapping their heads

[33-34]. This is kind of what it looks like from the business end [35]. So the dog goes into the scanner and interacts with humans in various ways and this is what it looks like. The first thing that we did was hand signals [36-38]. There are a variety of reasons for that; probably the biggest one was we needed to communicate with the dogs over the noise of the scanner so we did hand signals. So this hand signal means you are going to get a treat. And this hand signal means no treat. That is all. A simple Pavlovian experiment where this should promote activity in the caudate nucleus and this should not. Actually, the reason that we have this hand signal is just a control condition for hand signals. Everything you do with an MRI you need a base line comparison [39]. So ideally you control as much as you can possibly think of except for the thing that you are interested in.

On to the MRI dogs… we have eighteen dogs that have done this [40]. It gives you an idea of the range of dogs. Let me say something about brain anatomy first before we get to the results [41-42]. This is not to scale, maybe it's not obvious. Dog brains are quite small but I up scaled it so you can see the similarities. You can see obvious things like the brain stem here in the dog and here in the human, cerebellum, thalamus, those are kind of all of the similarities. Those actually look virtually the same except for some minor size differences. Where the brains actually differ is up in the cortex. Humans of course have much larger cortices and there is a lot more folding going on. Dogs of course have a cortex but it is not as big, not as many folds.

Now one of the great challenges of doing this especially in community dogs is we have to take all comers who want to volunteer and dogs who can do the training and aren't noise sensitive and are calm and not easily startled. What that means is we have this wide range of size and shape dogs [43]. At the lower end we have two sixteen pound dogs both terrier mixes. My dog Callie weighs twenty-five pounds. Tigger is a Boston Terrier, he also weighs twenty five pounds. He has a very differently shaped head and actually the brain looks quite different. All of the morphological differences you see in dog skulls also translates into their brains. It creates quite a challenge. On the other and we have a dog I call Big Jack; he is a one hundred and five pound Golden Retriever. He is on the overweight side.

So what do these things look like? Without going into the statistics of how we do this, this is a very common way in brain imaging that we present results. What it presents is an average response to two different hand signals. Basically, the difference between this (upper left brain scan) and this (upper right brain scan). Keep in mind we are not studying dogs eating food. That is not interesting. What we are studying is the response to hand signals that indicate food. This is a statistical image where the redder or hotter areas indicate greater and more significant activation [44]. We put the cross hairs on the area of maximal activation near the caudate so we could locate it that way. Looking at it a little bit differently, this is a more edited version of that averaging all of the dogs together [45]. I won't have time to go into how we do that. It involves taking the dogs' brains, digitally marking them, and matching them all into one standard space. So the cross hairs are on the part of the brain that we are most interested in and you can see here that it is quite active with the rewards signal. There is nothing going on here with the no reward signal. We take the difference and all of the noise falls away and we are left with the parts of the brain that are most significantly active. This is where we started. This was when we first did it. It was very exciting. We still do this for all of our dogs it is kind of a final test of their training. They can get through an actual MRI but we have since gone on to more difficult questions.

The next thing that we did was we studied olfaction and in particular we were interested in the response to biological odors [46]. This is what it looks like in training. This is Katie being presented with a cotton swab. In training there is nothing on the cotton swab but in the actual scans we have five different scents that are presented: familiar human, strange human, familiar dog, strange dog and self. You may be wondering what kind of scents are we talking about. For the humans these were underarm wipings. These were actually for the familiar human; it was from someone else in the household, not a handler because the handler is there during the scans and we assume that their scent is all over the place anyways. So most of the handlers were women, the other human tended to be their husbands. Sometime it was a child. Strange human and strange dog was someone they never met. Familiar dog, the dog scents were basically butt wipings basically going off of what dogs sniff when they greet each other. So, familiar dog was another dog in the household.

So, what did we find? In some ways, we know a lot about smell and in many ways it is probably the least understood of the senses. We looked first in two places [47]. The first place we looked we took a sphere of what we call a region of interest around the olfactory bulb just to make sure we were registering responses to these scents because if we don’t get that then there is probably something wrong with the technique, maybe the dogs are moving too much. And you can kind of get a sense that on the left are the human scents and on the right are the dog scents. So the dog scents are a little stronger with a little more activity than the human but statistically no different so that is good confirmation that it worked. Then when we go in and we look at the caudate which is the same part of the brain that we are studying in reward processes this is where it gets really interesting because it was only the scent of the familiar human that activated the caudate. This is, I think, the most exciting thing that we found so far because traditionally the caudate is associated with a positive expectation of things. The way to think about that structure is it is activated when an animal or a human encounters something probably that it likes and that structure helps orient the animal to that thing and usually approach it or consume it. So this is quite profound because the human donor is not physically present. The handler is there but the human donor is someone else in the house. None of the scent donors are physically present. So what this indicates is that the dog's brain, their caudate nucleus, is distinguishing the scent of their human from all of the others and it is most likely associated with positive expectation.

These are just kind of fancier pictures of what is going on in the brain. This is just looking at the whole brain now [48]. We can also start to break it down on dimensions of familiarity or strange human and dog, that sort of the thing. So that was the smell paper which was actually just published last week so that is kind of hot off the press. The other thing that we are doing currently which is also kind of along the same lines is we have been training dogs to look at computer images [49]. This dog, his name is Huxley, that type contraption we call that the treat for dog it is just a piece of PVC pipe and we basically skewer treats on a long stick and push them up through the pipe right up to the dog's mouth.

The reason we are doing that is we are trying to go back to our original experiment and separate out what is purely a Pavlovian response from maybe an added response from a kind of social bond. The computer images are showing literally cartoon versions of the hand signals to the dog so to have the kind of same associations but without a human giving them. That is why we have the treat kebob because we have to have some distance from the human and the dog to disassociate this. We call it the treat kebob; sometimes I just call it the dog crack pipe because they kind of get glued to the pipe and just wait for the treats to come out. It is a fun experiment. The dogs were already being trained to watch the computer screen which is not trivial. Not all dogs like to watch TV. We also have thrown in some random images kind of along the lines of the scent experiment. We can show images of people in the house, dogs in the house as well as strangers. This is a work in progress. We don't have quite enough dogs to do a lot of statistics [50]. This is actually the back of the brain which is where the visual cortex is. We are trying to lay out areas that may be associated with facial processing certainly with the visual system.

What does it mean [51]? So, I come back to this question: Is it all a scam [52]? I started the talk with the love issue and I put this slide up to point out or kind of undermine this idea that these dogs are "just Pavlovian responses" because I think we can make that case equally about human relationships [53]. You can just as well say that the nature in this case of romantic love is because one person makes the other person feel good in some way. Is that so different from this kind of relationship where also both parties feel good and seem to get something out of this above and beyond things like food? What we are seeing in the MRI data is starting to paint a picture that it is more than food. The smell data in particular I think support this idea because the humans weren't there. Their scent lingered and the dogs seemed to recognize or at least their brain differentiated and it is associated with a positive response. So if I have to make an analogy I would say it is kind of like smelling the perfume or cologne of someone you love and it kind of triggers that memory and that emotion. This is where we are going with this and I think we are getting closer and closer to demonstrating that dogs indeed do have emotions very similar to ours and probably more similar than we ever anticipated [54-55].