Metacognition

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# Introduction

Many authors define metacognition as “thinking about thinking” (Samuelson, 1982; Fisher, 1988; Blakely & Spence, 1990; Kuhn, 1999; Crystal & Foote,2009; Heyes, 2016). However, this is somewhat of a conceptual definition. Frith (2012) describes metacognition as "the processes by which we monitor and control our own cognitive processes." Flavell (1979) argues that there are four aspects to metacognition viz. “(a) metacognitive knowledge, (b) metacognitive experiences, (c) goals (or tasks), and (d) actions (or strategies).”

A less abstract definition is provided by Schraw & Moshman (1995) who describe metacognition as knowing about one’s own cognitive abilities. Specifically, they refer to three different kinds of metacognitive awareness: declarative, procedural, and conditional knowledge. Declarative knowledge relates to the knowledge of facts (e.g. knowing about things, for example that bananas grow on trees). Procedural knowledge concerns knowing how to do something (e.g. how to peel a banana) and conditional knowledge refers to the knowledge of why and when to do something (e.g. only climb up a banana tree when the banana is in season)

Another view of metacognition is that proposed by Martinez (2006) who argue for a definition of metacognition as "the monitoring and control of thought." Incorporated into Martinez's definition are the areas of meta-memory, meta-comprehension, problem solving and critical thinking. The first two refer to an understanding of one’s own knowledge state but without verbalisation these would be difficult to critically evaluate in mammals other than humans. Problem solving and the ability to critically evaluate alternatives, however, could more easily be demonstrated. Brown (1978) recognises that metacognitive skills can be easily observed with regard to everyday real world problems and situations. For most mammals conducting the various tasks necessary for daily living involves a high degree of metacognitive skill.

With regard to the regulation of cognition Lai (2011) posits that metacognitive regulation is the monitoring of one’s cognition and includes being able to plan activities, being aware of one’s own task performance, and ultimately being aware of how effective one is at monitoring one’s own cognitive ability.

This essay will briefly examine the physiology of metacognition and will then investigate the mammalian domain to determine whether metacognition is observable and if so, to how large an extent.

# Physiology of Metacognition

Research has shown that cognition and consequently metacognition takes place in the anterior cingulate and supplementary motor area, the orbitofrontal cortex, the dorsolateral prefrontal cortex, and portions of the basal ganglia and the thalamus (Fernandez-Duque et al, 2000).

As can be seen from Fig. 1 the orbitofrontal cortex and the dorsolateral cortex form part of the structure commonly referred to as the prefrontal cortex (PFC). Both the caudal and rostral anterior cingulate lie just under the cortex. The dorsal part of the anterior cingulate is connected to the PFC and the thalamus.



Fig. 1 Sagittal human brain with cortical regions delineated (Source: https://commons.wikimedia.org/wiki/File:Prefrontal\_cortex.png)

Whilst fairly simple behaviours, such as being startled by a loud noise, can be carried out by the brain relying on relatively straightforward neuronal activity involving the brain’s input and output systems (Miller & Cohen, 2001) an understanding of the complexity of metacognitive functioning has, to date been somewhat elusive.

According to Fleming & Dolan (2012) metacognition is under “segregated neural control.” Neural control refers to “functional interactions between networks of neurons” (Lalley, 2009) in the brain. Effectively, neurons can transmit, receive and process electrical signals. Bressler (1995) endorses the concept of segregated neural control as he advocates for the concept of a large scale cortical network which, the author believes, provides a framework which integrates neuroanatomical, neuropsychological, neurophysiological and electrophysiological studies on the distributed functioning of the cerebral cortex (Bressler, 1995). Evidence from electrophysiological studies reveals functional connections between the cortical areas as demonstrated by interareal synchronization. This is endorsed by Miller & Cohen, 2001) who argue that the PFC is a collection of interconnected extrinsic and intrinsic neocortical areas that both transmit and receive signals from virtually all of the body’s sensory and motor systems. Bressler (1995) posits that complex functions are processed in parallel in these widespread cortical networks. The function of the PFC may then be the integration, coordination and control of this large-scale cortical network.

Miller & Cohen (2001) refer to the ability of the PFC to synthesize diverse information and they advocate that the PFC can modify its distinctive anatomy through experience. The authors relate the functioning of the PFC to the active maintenance of patterns of bias signals throughout the brain. These bias signals effectively guide the flow of neural activity along paths which establish mappings between the external states and internal inputs that are necessary to perform a particular task. From a physiological standpoint, Miller & Cohen (2001) claim that the PFC is well situated to be able to handle diverse information from extrinsic sources in addition to dealing with intrinsic input. The evidence for this claim is that the lateral and mid-dorsal PFC is closely associated with the sensory neocortex while the ventromedial PFC deals with visual, somatosensory and auditory data from the occipital, temporal and parietal cortices. Many areas of the PFC receive inputs from at least two modalities. The dorsolateral PFC has what the authors describe as “preferential” connections with motor system structures while the orbital and medial PFC are more associated with medial temporal limbic structures. In addition, the PFC is highly interconnected with the ventrolateral areas being connected to both the dorsolateral and ventromedial areas.

A recent study by Ridderinkoff et al (2012) of primates and humans found that both the posterior medial frontal cortex (PMFC) and lateral prefrontal cortex (LPFC) contribute to cognitive control. Semendeferi et al (2002) used magnetic resonance imaging (MRI) to measure the volume of cortices in several species including humans. They measured the overall volume of the frontal cortex. Based on studies which demonstrate elevated metacognitive skills in certain mammals (Call & Carpenter, 2001; Smith et al, 1995; Fujita, 2009; Marsh & McDonald, 2012;) it would appear that metacognitive ability is positively correlated with the size of the cerebral prefrontal cortex in these mammals. The results, which show the volume of the frontal cortex as a percentage of the volume of the cortex of cerebral hemispheres. are presented in Table 1 below:

|  |  |
| --- | --- |
| **Species** | **Volume** |
| Human | 37.7±0.9 |
| Chimpanzee | 35.4±1.9 |
| Bonobo | 34.7±0.6 |
| Gorilla | 35.0 and 36.9 |
| Orangutan | 37.6±1.1 |
| Gibbon | 29.4±1.8 |
| Macaque | 30.6±1.5 |
| Capuchin | 29.6 and 31.5 |

 Table 1 Cortical Volume by Species

It should be noted that the prefrontal cortices of dolphin and orca are far bigger and more convoluted than human brains but similar data to that in Table 1.0 is currently unavailable. In addition, it should also be noted that sample sizes in this study were extremely limited, sometimes as low as two (Gorilla) so the statistical validity would have to be questioned.

Recent research by Middlebrooks & Sommer (2012) has reported that metacognitive activity is also linked to the supplementary eye field (SEF) leading the researchers to claim that neural activity in this part of the brain is highly involved in metacognition This is unsurprising as the frontal eye field has variously been described as either adjacent to or part of the PFC (Miller & Cohen, 2001).

# Non-Human Metacognition

Smith et al (1995) realised that researching non-human metacognition would not be an easy task since the traditional methods used to assess human metacognitive skills could not apply to non-human subjects given the need for a degree of conscious introspection and explicit verbalisation of feelings of knowing. For this reason, Jozefowiez et al (2009) have postulated that because the verbal methods used to investigate metacognition in humans cannot be used with animals, researchers have had to devise behavioural criteria in order to observe what may be termed metacognition. Mostly these behavioural assessments involve a discrimination task whose difficulty can be controlled by the experimenter. The theory is that the animal is considered to show metacognition if it purposely chooses to avoid the task (i.e., of emitting a so-called “uncertain” response) on trials where the discrimination is difficult; and (b) is more accurate on trials where the “uncertain” response is available and the discrimination task can be avoided (i.e., when given the choice to choose between the uncertain response and the discrimination task) than on “forced-choice” trials (i.e., where the uncertain response is not available).

Perhaps the first experiment on non-human species was conducted by Smith et al (1995) He worked with a dolphin to teach it to discriminate between high frequency tones (>2100 Hz) and low frequency tones (<2100Hz). The experiment was designed to allow the dolphin to decide if a given tone was either high, low or alternatively the dolphin could opt to decline the decision if it was unable to discriminate. Thus the dolphin could easily decide that an 800Hz tone was low and a 2500Hz tone was high, but if a tone was close to 2100Hz the dolphin wasn’t sure and consequently declined the test. According to Smith et al this is evidence that the dolphin used a degree of “introspection or private metacognition” This type of experiment is regarded in the literature as a perceptual discrimination test.

## Primates

In 2001 Call & Carpenter stated “there is an extensive literature on metacognition that shows that humans respond to uncertainty by either escaping from those situations or seeking information.” They developed tests to verify this hypothesis on 2½ year old children, chimpanzees and orangutans which involved “a finding game in which food or stickers were hidden in one of two or three tubes.” In some cases, the object was hidden in plain sight and in others the subjects did not observe where or what was hidden. The basic premise was that if the subjects had full understanding they would not hesitate in selecting the correct tube but if they did not know where the object had been placed they would employ information seeking behaviour. The results showed that both children and apes sought to reduce uncertainty by gaining information about the location of a reward, and they did so preferentially when they were prevented from visual access to the baiting procedure. Moreover, there was some evidence that some subjects were capable of extra-efficient search strategies, which consisted of selecting a tube without bothering to inspect it after having found the alternative tube(s) empty. Thus the subjects were able to infer ‘if not this then that’. According to the researchers this may indicate evidence of meta-knowledge in apes.

 In a later paper by Smith et al (2003) simple, yet clever experiments were used to provide data which supported the hypothesis that rhesus monkeys were able to make the cognitive decision to skip a test when the test was too challenging for them and the outcome of their performance was not certain. Smith et al (2003) described the tests these animals underwent as “metamemory tasks”. The results showed that similar to humans, monkeys consistently chose to decline tasks rather than make an error of judgement. Thus, it may be argued that the monkeys were able to demonstrate that they could be adaptive in situations of uncertainty which supports the theory that they possess declarative knowledge.

However, a similar study by Fujita (2009) found that tufted capuchin monkeys provided weaker evidence for metacognitive abilities.

Marsh & McDonald (2012) developed experiments to test for metacognition in orangutans. By varying the requirement to seek further information in a foraging task they were able to conclude that orangutans displayed the same type of sophisticated discernment, adaptiveness and flexibility when making the decision to seek further information or not as might be expected in a human child.

Beran et al (2014) conducted information-seeking experiments on chimpanzees who had been specially trained in language representation to ascertain if they had the capacity to accurately respond when presented with incomplete information. The results of the study were positive and the researchers concluded that as opposed to having learned rules for responding, the chimpanzees demonstrated metacognitive skills.

Malassis et al (2015) assessed the metacognitive abilities of baboons by setting up an experiment where the subject reported the position of a target stimulus that had previously been displayed on the screen. The subjects were presented with the option to respond directly or alternatively to ask for the initial stimulus to be repeated. The results found that the baboons consistently asked for the image to be repeated when they felt they lacked the information to proceed.

## Non-Primates

From recent studies it would appear that not only primates can demonstrate metacognition. McMahon et al (2010) conducted experiments on dogs which involved the subject choosing to prefer an informant who pointed to where a treat was hidden as opposed to a non-informant who remained uninvolved. However, the dogs failed “to make an information-seeking response that involved re-positioning themselves in space” thus resulting in them not being able to view the treat.

In 2007 Crystal & Foote conducted a study on mammals other than primates. They used rats as their subjects. The rats were taught to discriminate between short and long noise stimuli. On deciding the correct response, the subject was presented with three options. One lever was associated with a short noise stimulus and the other was associated with the longer stimulus. There was also a third option which was to decline the test. Rewards were given apposite to the choice. A correct response earned a large food reward whereas an incorrect response earned no reward. If the subject opted to decline the test it received a small yet guaranteed reward. The study also included a ‘forced test’ which did not give any choice to decline. The researchers found that as it became more difficult to discern between the noise stimuli the frequency of declining to respond increased. This was attributed to the fact that the rats knew that they didn’t know and consequently opted to decline the test. This is in agreement with the hypothesis that if the rats possess the knowledge that they are not able to complete the test correctly they would be more inclined to decline the test in favour of the uncertainty option.

# Conclusion

The debate regarding non-human metacognition is far from over. Researchers including Hampton (2009) argue that many of the studies which claim to demonstrate metacognition in non-human subjects, could, in fact, be explained by associative learning or other mechanisms that do not require invoking introspection or metacognitive knowledge of one’s own cognitive state.

Given the use of subjects who are mostly used to laboratory testing it is also possible that the subjects involved in the metacognition tests have developed a degree of experience in task related testing.

Ultimately Beran & Smith (2014) sum up the current state of play stating “metacognition may not be an all-or-none thing,” and “animals may share some facets—but not all facets—of metacognitive experience with humans.”

# References

Crystal, J.D. and Foote, A.L., 2009. Metacognition in animals. *Comparative cognition & behavior reviews*, *4*, p.1.

Samuelson, J.A., 1982. Metacognition: Thinking About Thinking. *The Review of Education/Pedagogy/Cultural Studies*, *8*(2), pp.133-141.

Fisher, R., 1998. Thinking about thinking: Developing metacognition in children. *Early Child Development and Care*, *141*(1), pp.1-15.

Blakey, E. and Spence, S., 1990. Developing Metacognition. ERIC Digest.

Kuhn, D., 1999. A developmental model of critical thinking. *Educational researcher*, *28*(2), pp.16-46.

Heyes, C., 2016. Who Knows? Metacognitive Social Learning Strategies. *Trends in cognitive sciences*.

Frith, C.D., 2012. The role of metacognition in human social interactions. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *367*(1599), pp.2213-2223.

Martinez, M.E., 2006. What is metacognition?. *Phi delta kappan*, *87*(9), p.696.

Brown, A.L., 1978. Knowing when, where, and how to remember: A problem of metacognition.

Flavell, J.H., 1979. Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American psychologist*, *34*(10), p.906.

Schraw, G. and Moshman, D., 1995. Metacognitive theories. *Educational psychology review*, *7*(4), pp.351-371.

Lai, E.R., 2011. Metacognition: A literature review. *Retrieved from: images. pearsonassessments. com/images/tmrs/Metacognition\_Literature\_Review\_Final. pdf on July*, *17*, p.2015.

Middlebrooks, P.G. and Sommer, M.A., 2012. Neuronal correlates of metacognition in primate frontal cortex. *Neuron*, *75*(3), pp.517-530.

Fernandez-Duque, D., Baird, J.A. and Posner, M.I., 2000. Executive attention and metacognitive regulation. *Consciousness and cognition*, *9*(2), pp.288-307.

Fleming, S.M. and Dolan, R.J., 2012. The neural basis of metacognitive ability. *Phil. Trans. R. Soc. B*, *367*(1594), pp.1338-1349.

Lalley, P.M., 2009. Respiration–Neural Control. In *Encyclopedia of Neuroscience* (pp. 3433-3441). Springer Berlin Heidelberg.

Ridderinkhof, K.R., Ullsperger, M., Crone, E.A. and Nieuwenhuis, S., 2004. The role of the medial frontal cortex in cognitive control. *science*, *306*(5695), pp.443-447.

Smith, J.D., Shields, W.E. and Washburn, D.A., 2003. The comparative psychology of uncertainty monitoring and metacognition. *Behavioral and brain sciences*, *26*(03), pp.317-339.

Fujita, K., 2009. Metamemory in tufted capuchin monkeys (Cebus apella). *Animal cognition*, *12*(4), pp.575-585.

Beran, M.J., Smith,D.J. Perdue,B.M

Psychol Sci. Author manuscript; available in PMC 2014 May 1.

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PMCID: PMC3902479

McMahon, S., Macpherson, K. and Roberts, W.A., 2010. Dogs choose a human informant: metacognition in canines. Behavioural processes, 85(3), pp.293-298.

Semendeferi, K., Lu, A., Schenker, N. and Damásio, H., 2002. Humans and great apes share a large frontal cortex. *Nature neuroscience*, *5*(3), pp.272-276.

Jozefowiez, J., Staddon, J.E.R. and Cerutti, D.T., 2009. Metacognition in animals: How do we know that they know. *Comparative Cognition & Behavior Reviews*, *4*, pp.29-39.

Smith, J.D., Schull, J., Strote, J., McGee, K., Egnor, R. and Erb, L., 1995. The uncertain response in the bottlenosed dolphin (Tursiops truncatus). *Journal of Experimental Psychology: General*, *124*(4), p.391.

Hampton, R.R., 2009. Multiple demonstrations of metacognition in non-humans: Converging evidence or multiple mechanisms?. *Comparative cognition & behavior reviews*, *4*, p.17.

Call, J. and Carpenter, M., 2001. Do apes and children know what they have seen? *Animal Cognition*, *3*(4), pp.207-220.

Marsh, H.L. and MacDonald, S.E., 2012. Orangutans (Pongo abelii) “play the odds”: Information-seeking strategies in relation to cost, risk, and benefit. *Journal of Comparative Psychology*, *126*(3), p.263.

Malassis, R., Gheusi, G. and Fagot, J., 2015. Assessment of metacognitive monitoring and control in baboons (Papio papio). *Animal cognition*, *18*(6), pp.1347-1362.

Beran, M.J. and Smith, J.D., 2014. The uncertainty response in animal-metacognition researchers.

Foote, A.L. and Crystal, J.D., 2007. Metacognition in the rat. *Current Biology*, *17*(6), pp.551-555.

Miller, E.K. and Cohen, J.D., 2001. An integrative theory of prefrontal cortex function. *Annual review of neuroscience*, *24*(1), pp.167-202.