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Cognitive evolution: Darwin on the mind

Darwin's theory of evolution is uncontroversial in modern biology. However, when it comes to applying evolutionary theory to the mind, the debates are far from settled. In a recent cover article in Nature, Professor Johan Bolhuis of the Behavioural Biology group in the Helmholtz Institute and his colleague Clive Wynne of the Psychology department, University of Florida, explain why evolution theory cannot be used to explain human and animal cognition.

In The Descent of Man (1871) Darwin proposed that species that have a relatively recent common ancestor (such as humans and apes) will have similar cognitive functions, whereas animals that are more distantly related (such as birds and man) will have very different cognitive functioning. This is what the authors call Darwin's concept of continuity of mind. Evidence from laboratory studies shows that this is an oversimplification. For example, because apes are our closest relatives, many have searched for speech and language ability in these animals, but mostly in vain. One of the prerequisites for speech is being able to imitate sounds that are created by someone else, but primates show no inclination to do this. Yet, in his own lab at Utrecht University, Bolhuis has observed both behavioural and neural similarities between human speech acquisition and song learning in zebra finches, with whom we share a common ancestor that dates back some 300 million years. In a Current Biology paper (2007) with his former PhD student Sharon Gobes, who is now a postdoc at Harvard University, he showed that the process through which young songbirds learn their song resembles the way human infants acquire speech. Both processes involve a practice stage, called subsong in birds and babbling in humans, where song or speech is learned from a tutor. There are also functional similarities between the human and avian brain. A similar neural dissociation between speech perception and production in humans can be found in zebra finches. On the basis of this and other examples, Bolhuis and Wynne conclude that “The appearance of similar abilities in distantly related species, but not necessarily in closely related ones, illustrates that cognitive traits cannot be neatly arranged on an evolutionary scale of relatedness.”

Bolhuis stresses that he does not want to invalidate the theory of evolution. It simply means that cognition has evolved not only by common descent, but also by the selection pressures that a species has encountered. This is called convergence where evolutionary remote species can arrive at similar solutions to problems because they experienced similar selection pressures. In cognitive neuroscience, the study of animal cognition is often used as a model for human cognitive functioning. Generally, non-human primates are considered to be the best model as these animals are our closest relatives, but this leaves convergence out of the equation.

The authors go on to argue that evolutionary

There are behavioural similarities between language acquisition and song learning.

theory cannot be applied to the mechanisms of brain and cognition. An example is evolutionary psychology, which tries to explain human cognition as evolutionary adaptations. For instance, our greater fear of spiders compared to our fear of guns is often explained by the fact that our Stone Age ancestors evolved in an environment where poisonous spiders posed a real threat, whereas guns did not yet exist. But we can only guess at the cognitive capacities of our ancient ancestors, and it is likely that our mind has been shaped by other factors, such as development and cultural evolution. Evolutionary theory should be used to study the history of brain and cognition, not its underlying mechanisms, Bolhuis argues.

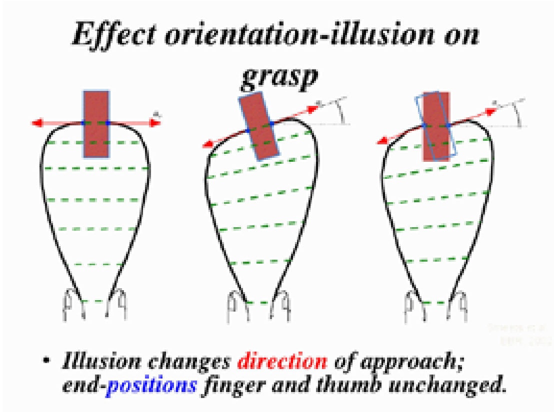
Asked whether we now have to search for species that have encountered similar selection pressures, Bolhuis reminds us that it is very difficult to determine which animals will have met similar ecological pressures. However, there is one advantage to studying animals that are less related to humans. We easily identify with primates and therefore might confuse interpretations of animal behaviour with our own. For example when a primate, in front of a mirror, touches a painted spot on its skin this has been interpreted as evidence of a higher level of self consciousness. But if a bird displays the same behaviour, we are less biased by human identification and more likely to take the behaviour for what it is, allowing for scientific study of the underlying mechanisms.

Bolhuis, J.J. & Wynne, C.D.L. (2009) Can evolution explain how minds work? Nature, 458, 832-833. (with accompanying podcast).

How do we pick up a cup of coffee?

"We spot the cup of coffee and then make a movement to pick it up," many would say. But not prof. dr. Jeroen Smeets of the Human Movements Sciences group of the Helmholtz Institute. He challenges the common idea that perception and action are serial processes, which means that we would perceive the object and then use that information to grasp it. Instead, he argues that perception and action are parallel processes. Smeets has been awarded an NWO VICI grant to address this perception / action theme.

We act in a three-dimensional world and in the perception process, visual information from different depth 'cues', such as binocular disparity, motion and texture, has to be combined to perceive the three-dimensional space around us. Most authors suppose that all available information is combined in an optimal way before this representation of the world is used to control the motor process. But Smeets proposes a new approach to investigate the sensorimotor process without this unique and coherent representation of the three dimensional motor goal. He argues that there is no integration of all the information into one representation but that each perceptual variable is used to control different motor variables. For instance, the perceptual variable 'perceived speed' would be used to control the motor variable 'speed of the movement'.



In his VICI project entitled: 'Making movements: optimal or inconsistent?' Smeets will further develop his theory on how information is combined to control movement. Doing this, he will focus on the hypothesis that combination occurs in terms of independent perceptual variables controlling motor variables. These motor controllers start the muscle activity.

Smeets gives the example of catching a ball: the optimal movement when you have a few milliseconds is different from the optimal resolution for when you have a few minutes available, because there is no time for all the information to be processed and combined. Some types of visual information are processed faster than other types. For instance, it takes the visual system more time to process binocular disparity compared to motion. Still there are classical theories that don't take into account this crucial variable: time. If all the information had to be combined to create a single percept, we would have to wait until the slowest information was processed and we would be very slow in action!

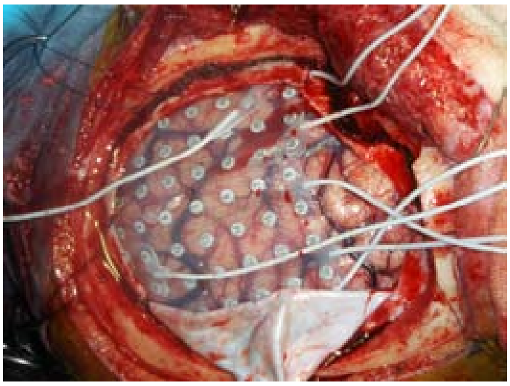
As Smeets argues that visual information is used differently in different tasks, he will investigate several motor behaviours: point-to-point, grasping and interception. Even within a task, information can be combined differently for different aspects of that task. When intercepting a moving object we need to determine its motion, which can be determined relative to oneself or relative to the world. The calculated motion relative to the world influences the timing of the interception, but not the interception-position (so for this we only use relative information in a self-based coordinate frame). Since not all perceptual variables give the same information, behaviour can be inconsistent. For instance, direction and position can suggest different paths for pointing to a dot, but the trajectory of the movement would be an arrangement of these two.

After a series of experiments to address the above-mentioned hypotheses have been performed, Smeets aims to describe visuo-motor behaviour by a mathematical model. Such a model allows for the formulation of specific hypotheses on human functioning and can be used in robotics and the development of prostheses. This model should account for human limitations, both spatial and temporal ones and include situations where there is feedback and others where there is not. For example, when throwing darts it is not possible to correct the movement after throwing. But when picking up a cup of coffee, we can correct our movement.

Grid Patients – HH and UMCU collaboration

The ultimate test of brain functionality is to study behaviour during direct interaction with brain functioning. Usually, this is only a neuropsychological ideal, and the consequences of a change in brain functioning are studied after a disease has hit the brain, as in the case of stroke. Today, dr. Chris Dijkerman and dr. Martine van Zandvoort of the Neuropsychology Group of the Helmholtz Institute are involved in the development of a task battery using a method which allows for direct stimulation of the cortex by means of large electrode grids, placed on the surface of the brain (the cortex). We spoke to them about the development of the project and possibilities of the technique.

Patients who suffer from epilepsy have been studied intensively, both in modern and classical neuropsychology. In the 1930's and 1940's, dr. Penfield developed the 'Montreal Method' to efficiently remove brain tissue in which the seizures started. This method is still widely applied on patients with intractable epilepsy, those who do not respond to any type of medication and sometimes suffer up to 70 seizures a day. During brain surgery, electrical probes were used to stimulate the brain in awake



Grid implanted in the brain.

patients in order to assess functionality of the underlying structure. This way, the neurosurgeon can get the necessary information about where to resect and where to stay out.

At the IEMU (Intensive Epilepsy Monitoring Unit) of the UMCU led by Dr. Frans Leijten, patients are treated with a more modern and informative manner of grid stimulation. Instead of implanting individual electrodes at the time of the surgery, a grid of sometimes up to 100-125 electrodes is placed subdurally on the brain a few days prior to the resection surgery. This method is highly valuable to patients with epilepsy, as the focus of the epilepsy can be more precisely determined, and the removal of healthy tissue will be minimised. Moreover, the crucial functions can be localised and spared during removal of the epileptical focus. Candidates for neurosurgical removal of the epileptical focus are admitted to the IEMU a week before surgery to get the grid implantation. During this week, continuous Electrocorticography (EcoG) - an electrical signal from the cortex - is recorded in combination with video registration of the patient in order to monitor seizures.

Dijkerman and Van Zandvoort represent neuropsychology in the multidisciplinary group. Their role in the project is two-fold: clinical and fundamental neuropsychological research. Functions such as language, locomotion and sensibility can be easily related to specific brain areas ('mapped'), but other cognitive functions, such as arithmetic, perception and attention, require a more delicate approach, as more widely distributed networks are involved. Dijkerman and Van Zandvoort are developing methods to map these functions. They need to combine theoretical knowledge about the underlying processes with knowledge about how to tap these functions with tasks during stimulation. For example, they need to know whether stimulation induces excitation or inhibition of a cognitive process. Prior to the grid implant, patients are also tested with functional MRI, which provides a coarse handle in the localisation of functions. However, the fMRI results do not provide information about which areas are most crucial for normal functioning, and needing to be spared during resection. At this point, the grid implant can give direct information about the underlying functionality of the cortex, and allows for more precise functional mapping. Dijkerman and van Zandvoort also aim to conduct fundamental research in the field of visual, spatial and tactile perception. An advantage of studying epilepsy patients is that in most cases they do not suffer from cognitive impairments that may interfere with online assessments of cognition. Some interesting findings have already been obtained. For example, during left angular gyrus (AG) stimulation, a patient showed impairments on an arithmetic task. This finding provides supporting evidence for previous work with fMRI showing that the AG is activated by arithmetic facts. Furthermore, stimulation of the right occipital cortex has been found to produce reliable visual hallucinations in line with hypothesised functionality of the tertiary visual cortex.

However, it is also a very delicate and challenging field of research. The intensive monitoring of the patients allows treatment of only 12 patients per year. In addition, the impact of the grid implant on the patients, while relatively small, also might hamper in-depth neuropsychological research, due to fluctuating or decreased arousal of the patients, or due to unforeseen complications. Nevertheless, research on grid patients is one of the most direct ways to measure and interact with the relationship between functions and the brain. The project is still developing, but the long-term goal is to develop a battery of tasks suitable to map cognitive functions.

Suggestions, ideas & contributions:
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News & agenda

Helmholtz lectures

- June 22, 2009. Christof Koch (California Institute of Technology, USA) From attention in visual cortex to sparse coding in the medial temporal lobe.

Symposia

- October 9 – 11, 2009. Autumnschool ‘ From stimulus to understanding in perception and language.’ Doorwerth, the Netherlands.

PhD defences

- May 27, 2009. Titia Gebuis (Experimental Psychology, Universiteit Utrecht) From quantity to number: studies on magnitude processing.
- May 27, 2009. Christa van Mierlo (Human Movement Sciences, VU Amsterdam) Cue combination for slant.

New people

- Rob van Beers, postdoc, (Human Movement Sciences, VU Amsterdam) Project: ‘Combining cues for slant.’
- Ben Harvey, postdoc (Experimental Psychology, Universiteit Utrecht) Project: ‘Development of the population receptive field model for retinotopic mapping of the visual cortex.’

Other news

- Hans Kolijn (Physics of Man, Universiteit Utrecht) retired from his function as technical assistant by April 1, 2009.

Colofon:

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