Investigating How the Brain Shapes Perception

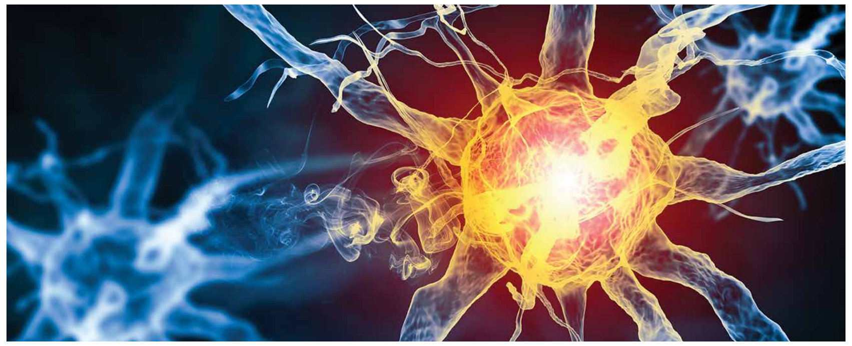
Dr Detlef Wegener

INVESTIGATING HOW THE BRAIN SHAPES PERCEPTION

Neuroscientist **Dr Detlef Wegener** and his colleagues at the University of Bremen's Brain Research Institute in Germany study how cognitive processes influence the way we perceive the world in which we live and act.

How Does the Brain React to Keep Us Alive Minute by Minute?

Everyone has seen him at one time or the other, perhaps portrayed by Johnny Weissmuller in the classic movies or maybe Alexander Skarsgård in a more recent rendition – Tarzan of the Apes. That wonder of a man swinging from tree to tree and leaping from branch to branch. Of course, humans don't do that very well, swinging and leaping through the trees. But monkeys can, and they do it with apparent ease. If you've seen a monkey jumping through the trees, quickly deciding on its next target branch, computing the distance and precise location of its target, programing and executing the movement and landing with precision before leaping off at its next target, it's quite amazing! To do so, the monkey has to precisely select the relevant information and, at the same time, disregard effectively what is not important from the multitude of information reaching its senses in order to avoid errors that might lead to a fall and death on the jungle floor. And all of this must



occur on a very short timescale. The monkey can't stop and pull out a pocket calculator to figure out the next jump – it has to occur almost without thinking. This is the stuff that interests Dr Detlef Wegener and the scientists at the Brain Research Institute at Bremen University.

Maybe humans can't swing through the trees like monkeys, but they do things on a routine basis that are quite similar to the monkey's daunting jungle antics. Humans are continuously faced each day – indeed, each minute – with a huge amount of sensory information. Just think about riding a bicycle through a modern city, swerving in and out of traffic and around pedestrians. Each second there is a huge and fluid amount of data arriving at our senses, like motion patterns, colours, objects, faces, and sounds that are received by the biker's brain. Only some of this information is relevant for successfully managing a path through the traffic, while others are irrelevant and potentially distracting. Our brain provides us with an amazingly rich perception, but assimilating all the incoming information in parallel exceeds the brain's processing capacity by

'My research interest is to understand how the brain shapes the way we perceive the world'

far. Focussing on the dress of the woman on the sidewalk might have a positive influence on mood, but it may impair the biker from quickly detecting the fast car coming from the side. Hence, moving through the traffic while avoiding other vehicles, people and stationary objects, flying a supersonic jet plane, or playing sports, all relies on the human brain's ability to select and process the relevant pieces of data in a short period of time to shape our perception in a manner that fits to our current behavioural goals. How does the brain do this?

Small Processes That Generate Complex Results

Dr Wegener carried out his first experiments during his undergraduate education, at Glasgow University in Scotland, where he looked at a particular class of neurons in the nervous system of a leech. Later, during his undergraduate thesis work at Bremen University, he studied a specific class of retinal ganglion cells in a particular species of lungless salamanders. Dr Wegener tells Scientia: 'Both of these projects had in common that they aimed to understand the specific functional characteristics of a cell class by studying the underlying principles, like the presence of a specific class of genes or the specific arborisation pattern, respectively. More generally, they addressed the question how complexity emerges from simple principles – something that is at the core of brain function and fascinated me as a student, and probably fascinates neuroscientists from all fields.' When Dr Wegener looked for a doctoral position, he wanted to study these mechanisms in larger brains and with respect to cognitive processes and mechanisms that are closer to human perception and consciousness. What else but monkeys? But how do you get to work with monkeys?

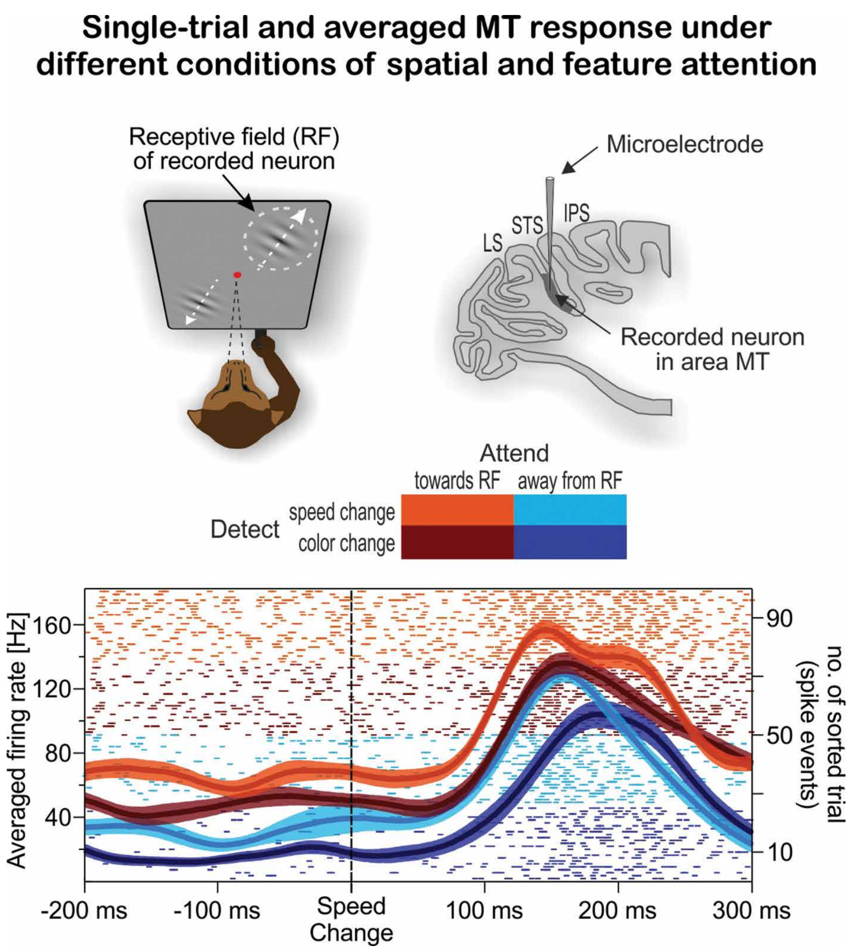
Serendipitously for Dr Wegener, at about the same time he was finishing up his undergraduate work a new institute was founded at Bremen University. It was part of a new collaborative research centre on neurocognition, specifically dealing with the question how cognitive processes like e.g. attention influence the activity of neurons, and how groups of neurons communicate with each other. Dr Wegener applied for a PhD position even though none were advertised at that time and the new institute had not even opened. He secured a position, and then, as he describes it, 'literally starting with only two pens, we built the lab from scratch within the following two or three years, including all the experimental setups, the laboratories, the animal house, a surgery room, and the hundreds of little things that need to work in order to perform this sort of research.' He likens it to a jump into the cold water, learning new things every single day.

After finishing his PhD, Dr Wegener received his first German Research Foundation grant, which allowed him to define his own set of experiments, develop new approaches and techniques, and optimise others. He continued with monkey neurophysiological studies, and also added human psychophysical and electroencephalographic experiments. 'Training monkeys on sophisticated behavioural tasks requires a lot of time,' Dr Wegener says. 'Studies in humans allow us to first test and sharpen our hypotheses and then design the specific behavioural tasks for the monkeys. Monkeys can learn demanding cognitive tasks, similar to those we use for humans, and this is why we can then perform precisely targeted neuronal recordings and address the distinct neuronal mechanisms that may underlie ours, and the monkey's perceptual and attentional abilities.' With this approach, Dr Wegener and his colleagues at the centre are working on many ongoing projects, which have led to some ground-breaking discoveries to date.

How the Brain Processes Visual Input

Like the monkey in the trees, when we humans ride, drive, fly or otherwise make our way through our world, we are processing the incoming information based on our own intentions and goals. The same sensory information may be processed with high priority in one condition, but gets largely suppressed in another situation, depending on whether it is actually important or not. How does the brain achieve this performance? What are the brain's signals that determine the degree to which we process the information from our environment? How does this influence our conscious perception, and how does it affect our behavioural performance? In terms of neuronal computation, Dr Wegener thinks this constitutes a huge accomplishment that can teach us a lot about the neuronal mechanisms that are inherent to the vertebrate brain. He also believes that understanding these processes may help us to better understand what is going wrong in the diseased brain.

'In our lab, we study these cognitive processes by performing experiments that involve some form of change detection, usually a change in the colour or the motion of a visual stimulus,' he tells us. The



processing of motion signals takes place in a dedicated visual area of the brain – the so-called area MT – where neurons are highly sensitive to the direction and speed of motion. By requiring their monkeys to either attend to the motion or the colour of a stimulus on a computer screen, Dr Wegener and his team investigate the response of the neurons in this specialised area under changing behavioural conditions. 'We found that these neurons are highly affected by the relevance of the motion information,' he says. 'When we investigated their activity, it turned out that many parameters of their response were dependent on the behavioural relevance of motion.'

When under similar experimental conditions, human observers must detect changes in a stimulus as quick as possible, they will be much faster to report a change in the speed or direction of a stimulus when they concentrate on motion as compared to when they are expecting a colour change. 'In line with this, we found that neurons in area MT respond with short-termed but very pronounced changes in their firing rate to these sudden motion changes,' explains Dr Wegener. 'Focussing on the motion of the stimulus caused that these firing rate changes occurred earlier and were stronger.' When analysing the reaction times of the monkeys to report these motion changes, Dr Wegener and his group found that they were closely related to the speed of the firing rate change of these specialised neurons. 'This shows that attention influences the very early stages of visual processing and that those modulations are directly influencing our behavioural performance.' Thus, when the biker is focussing on the motion information he may disregard the woman on the sidewalk, but because his attention is prioritising neurons in the motion-sensitive regions of the brain, he will be faster to react to the sudden appearance of a car from the side.

Dr Wegener and his group obtained more interesting insights into this phenomenon. One of their studies showed that attention modulates the selectivity by which neurons in this visual area of the brain can distinguish between different motion directions, while another showed that these neuronal modulations are reflected directly on the behavioural level. Their results indicate that when the brain is exposed to a lot of visual input, attention allows it to maintain a high selectivity for important information and weed out external 'noise'. The team hypothesise from these findings that the inability to ignore distracting input might be a major cause in some forms of attention-deficit-hyperactivity-disorder and milder forms of attention difficulties in humans. After all, this isn't just about monkeys – it's ultimately about the human brain and how it works in health and illness.

The Work Is Only Just Beginning

Importantly, Dr Wegener and his colleagues can rely on techniques and methods not available one or two decades ago, mainly due to the massive computational power and storage capacities available today. These allow not only the ability to record the activity of a single neuron, but of hundreds of neurons at the same time. They can study populations of neurons in one or several areas and gain access to their dynamic interactions. 'New recording and analysing techniques have to be developed, but colleagues in systems neuroscience and accompanying fields – computational neuroscience, machine learning, neuroengineering, and others – have done great jobs during the last years to achieve this,' Dr Wegener says. In his home university, for example, many people from different institutes have participated in designing, manufacturing, and implementing new high-density multi-electrode arrays that are now used to study distributed brain activity and record signals from the brain's surface. Dr Wegener says such approaches will become very important for future clinical approaches and that they will allow us to study and hopefully also treat neuropsychiatric diseases. Because of the rising number of such illnesses, this will be one of the central challenges neuroscience faces during the next decade or two. 'Any such progress, however, critically depends on the precise understanding of the healthy brain in terms of the neuronal interactions going on during conscious perception and action,' Dr Wegener says. If we can understand how the monkey's brain solves a demanding cognitive task, perhaps we can find ways to cure patients with brains that can't do this anymore.

Meet the researcher

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Dr Detlef Wegener carried out his undergraduate studies in Biology at the Life Sciences Department of Glasgow University in Scotland in the UK and at the University of Bremen, Germany, where he received his degree in 1997. While at Bremen, Dr Wegener worked at the Brain Research Institute and wrote his undergraduate thesis on the identification of morphological specificities of plethodontid salamander retinal ganglion cells according to their projection sites. After that, he joined the newly founded Department of Theoretical Neurobiology of the Brain Research Institute at Bremen and was involved in the development and setup of the department. It was here that Dr Wegener performed his doctoral work, writing his dissertation on the influence of selective visual attention on stimulus selectivity and synchronised, oscillatory activity patterns of single cells in the macaque middle temporal visual area, receiving his PhD in 2003. After receiving his doctorate, Dr Wegener stayed on at the Brain Research Institute where he is currently a Senior Scientist and continues research on the influence of attention on visual processing. He also teaches Bachelors and Masters classes in Neuroscience, and served as lecturer at the University of Applied Sciences in Bremen, teaching Animal Physiology in the Faculty of Biology there.

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