★ Despite extensive research much remains to be discovered about our brain mechanisms, work which the Peract project is playing a key role in advancing. The impact of this work will be significant, says **Professor Hanspeter Mallot**, not least in terms of treating brain damage or disease following a head injury

Just how does the brain control behaviour?

How does the brain control behaviour? Both the common sense and traditional scientific approaches to this question focus on the spontaneity of behaviour, meaning that they assume plans are worked out in a kind of high-level planning centre within the brain and are then executed by the motor system. Those who take this view hold that sensory input has no immediate role in formulating behaviour, but rather enters into the planning instance only if requested by the planning centre. A clear exception is the reflex, where sensory input stimulates immediate action.

Neurobiologists take a different view on how behaviour is formulated. They suggest that reflex actions are not exceptions but rather demonstrate the simplest case of a general scheme in which sensory input and action output are just two sides of the same coin – the cycle of perception and action. In this view, central processing in the agent's brain serves as a feedback controller which receives sensor readings and – when these sensor readings are unfavourable – takes actions that drive the sensor readings back into a favourable range. This view of behaviour is not limited to simple reflexes, but nevertheless goes a long way to explaining behaviour.

One consequence of the perception-action view of behaviour is that perception is always considered to be a means of controlling behaviour. Information gathered from the environment is relevant if it has consequences for behaviour, while 'salient' views irrelevant to action should generally be ignored. This can be transferred to evolutionary argument: the advantage gained by an animal when it acquires some novel sensory ability lies in the improvements in reproductive success made possible by enhanced senses. The same principle holds true for the evolution of memory systems in the brain and other cognitive traits.

While the relevance of the perception-action cycle is widely acknowledged, experiments in this area are often hard to undertake, as both sensory input and effector (usually motor) output has to be measured jointly. In recent years, however, the development of interactive computer graphics, virtual reality systems, mobile eye tracking systems, and non-invasive techniques of measuring brain activity have allowed novel experimental approaches to the topic. The Peract project (Perception and Action in Space) explores the action-perception approach to behaviour in a number of experiments using these methods.

Driving behaviour

Driving is the primary mode of transport in most western societies and is commonly associated with personal independence and autonomy. Good visual sense – including visual acuity, colour vision and stereoacuity – is an essential criterion in assessing an individual's fitness to drive. However, conventional kinetic and static perimetric methods for the assessment of an individual's visual field, conducted under strict gaze fixation, are rather artificial. In everyday life everybody scans visible objects by shifting the direction of their gaze, which allows the shifting of binocular visual field defects. Intact exploration ability can thus compensate for the visual fields defect through the activation of the efferent oculomotor system.

The central focus of the Peract study was on comparing the visual performance of patients with coincident visual field defects in both eyes (homonymous visual field defects, HVFDs) and healthy controls in a standardised virtual reality (VR) environment. We also investigated whether visual field related parameters were capable of predicting visual performance under VR conditions, as subjects with binocular visual field defects (scotomas) use compensatory viewing strategies in order to reduce the impact of their impairment.

In the Peract project 32 patients with homonymous visual field defects after vascular brain injury were compared with 32 healthy controls with a similar age and gender profile. Their performance was measured in visual field perimetry (binocular static and kinetic perimetry), and in a driving task under standardised, virtual reality conditions, where free gaze and head movements were allowed. During the experiment study subjects had to drive safely through a junction and their performance was measured.

The driving task was within the abilities of 24 of the fully sighted group, although there was greater individual variability among the patients. The extent of the visual field loss was loosely related to visual performance. This finding suggests that visual performance in the simulated driving task cannot be adequately predicted using visual field parameters alone. Active exploration ('scanning') by saccadic eye movements and active head turns indicated better performance and therefore compensated for scotoma-related problems. Thus the visual performance of patients with binocular field losses should be assessed in terms of their visual field extent, exploration efficacy and compensation ability. Greater variability in the patient-group indicates individual differences in the ability to develop compensatory strategies, which may be influenced by the size and location of the cerebral lesion. We aim to discover whether there are characteristic gaze patterns capable of predicting whether obstacle avoidance in the virtual-reality (VR) scenario will be successful, and to ascertain the best examination procedure to predict and quantify visual performance.

Illusions of speed perception

Through its work on the effect of stimulus size on speed perception the Peract project has found that our perception of speed is not exclusively determined by the velocity of a moving visual stimulus. We used a sequential binary choice task in which five subjects had to report, through a key-press, which of two stimuli moved faster. The stimuli were presented on a high-speed computer monitor. We found that the size of the stimulus had a pronounced effect on judgement. When there was no difference in velocity the responses of the subjects were made at random, therefore close to 0.5. If the first stimulus had a diameter of 5 degrees and the second 10 degrees then the responses shifted towards a higher frequency. Thus some respondents concluded that the first stimulus moved faster, even if there was no difference in velocity. However, if the second stimulus was smaller, then the responses were biased towards reports of a faster second stimulus. We were later able to document that the strength of this illusion is independent of dot density and life time in the stimuli, but increases with increasing ratios of the stimulus size and speed. The results of our study provide additional insight into the mechanisms responsible for erroneous speed perception, such as the underestimation of your own speed after prolonged motorway journeys or in foggy conditions.

Classification of acoustic scenes by echolocating bats

Echolocating bats emit ultrasonic pulses and analyse the returning echoes to ascertain their surroundings. Although the abilities of echolocating bats have been studied for decades, the field of echo classification itself has been neglected. A few studies have tried to examine the object specific information available in the echoes but most did this in the context of simple objects that created simple echoes. A bat flying in natural surroundings encounters a huge range of echoes, many of which are stochastic. Nevertheless, behavioural observations still show that bats are able to use the information in the echoes to perform their everyday tasks.

The project therefore aims to widen our understanding of natural complex echoes through developing algorithms that allows us to use the information they contain and relate it to the bat's behaviour.

Driving simulator used in experiments on visual obstacle avoidance. The virtual scene is projected onto a curved screen providing a wide field of view

So far this has involved three independent studies. In the first project we used a large data set of highly complex natural plant echoes acquired in the lab. The ability of a learning-based classifier to distinguish between different plants according to their echoes was then tested. The results were surprising. A rather basic linear classifier was able to learn simple features of the plants' echoes that then enabled the classification of new unknown echoes. This study gave us an insight into how bats can fulfil a task formerly thought to be very difficult.

Through the second project we set out to learn more about the statistics of natural echoes and their relationship with natural objects. This was done by analysing the statistics of the echoes in the aforementioned database, by building actual models of simple plants and also by applying a computer model that creates complex echoes. The results of this study showed that natural echoes share a statistical nature similar to that found for natural images. We were also able to show that the fine details of these statistics correlated to the structure of the object creating them.

The third main aim of the study was to compare the performance of bats at recognising an acoustic scene with a computer-generated algorithm. As part of the classification task we taught the bats to recognise the calls of other individuals and then compared their performance with that of the algorithm. The bats performed extremely well in the experiments, showing that they can learn to recognise their counterparts. We then compared the bats performance with that of the algorithm in terms of not only the overall performance, but also the types of errors the two made. This comparison revealed very interesting similarities between the two, and gave us some insight into just how individual recognition is possible. ★

At a glance

Full project title

Perception and Action in Space
Call identifier FP6-2002-Mobility-2

Partners

Spatial Behavior and Functional Perimetry:
U. Schiefer (University Eye Hospital)
Color-Guided Behavior:
A. Werner (University Eye Hospital)
Sensori-Motor Integration:
U. Ilg (Neurological Clinic)
Cortico-Cerebellar Interplay:
H.P. Thier (Neurological Clinic)
Spatial Reference System:
H.-O. Karnath (Neurological Clinic)
Navigation and Spatial Cognition:
H. A. Mallot (Dept. of Zoology)
Neuroethology and Spatial Behavior:
H.-U. Schnitzler (Dept. of Zoology)
Self-Supervised Motor-Learning:
B. Schölkopf (MPI for Biological Cybernetics)

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Hanspeter Mallot was appointed Professor of Cognitive Neuroscience at Eberhard-Karls-University, Tuebingen in 2000. His research focuses on spatial cognition in rats, humans and robots, using behavioural experiments in virtual reality, eye-movement recordings, and simulated agents in both hardware and software. He is also involved in the EU Strep "μDrone" project, building insect-like obstacle avoidance mechanisms for unmanned autonomous vehicles.

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