Biotechnology and Life Sciences in Baden-Württemberg

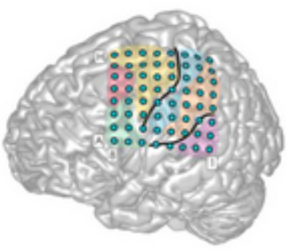
19.08.2013

Brain mapping – 'eavesdropping' on the brain

Although numerous scientists have spent decades exploring the brain and many things are already known, the brain is still considered one of the greatest mysteries of science. While structural elements such as cell and axon distribution can only be mapped post mortem, motor and sensory functions can only be studied in vivo, i.e. using living organisms. Dr. Tonio Ball and his colleagues at the BrainLinks-BrainTools cluster of excellence at the University of Freiburg focus on ways to control movements. They are 'eavesdropping' on the activity of the brain during everyday movements by placing electrodes on the surface of the brain.

For quite some time, the neurosciences have been specifically focussed on obtaining extensive information – correlations and localisations – from the brain. This can be achieved by recording the electrical impulses directly at the neurons using techniques such as electrocorticography (ECoG). As there is often a correlation between brain function and structure, i.e. organisation of the brain tissue, a set of neuroscience techniques can be used for attributing abilities to specific brain regions (brain mapping). "A lot of detailed movement information is encoded in the signals at the surface of the brain," says Dr. Ball from the Bernstein Center and the BrainLinks-BrainTools cluster of excellence at the University of Freiburg.

A broad range of methods



ECoG electrodes placed on the motor (yellow) and sensory (blue) cortex. (© Usai, Brain activity during turn-taking in natural conversations (2012))

However, there are many functions for which the exact anatomical location cannot be accurately determined and emerge only through the interaction of different brain regions. A complex set of methods is therefore needed for the meaningful mapping of brain functions. "We are very interested in finding an answer to the question as to what kind of movements result from the various signals," Ball said. "Most of the information we have gathered so far stems from the movement execution phase." However, the sensory feedback from the muscle back to the brain is always inextricably linked with the signals that relay motor commands for arm and leg movements.

To a certain extent, signals can be attributed exactly to defined brain areas, as one cerebral hemisphere is mainly dedicated to motor and the other to sensory activities. That said, the division between motor and sensory areas is not absolute. If one was to include the planning phase of a movement, i.e. the idea to perform a particular action, the sensory feedback that is added to the pure signal could be largely excluded, at least theoretically. This is a major field Ball and his team at the University of Freiburg are working on. In addition, the researchers are working together with CorTec, a start-up company spun out of the University of Freiburg in 2010, with the goal of developing neuroprostheses.

Electrical activity from the cerebral cortex is either recorded using EEG (electroencephalography), where electrodes are placed on the skull surface, or using ECoG (electrocorticography) on the brain surface. According to Ball, the accuracy of the data obtained with EEG and ECoG are worlds apart. ECoG, where electrodes are placed directly on the exposed surface of the brain, provides far more precise insights than EEG.

A valuable source of information

Different natural ways of grasping things (in this case a mug) lead to distinct ECoG signals in the motor cortex (red vs. blue curves); different types of grasping can be distinguished on the basis of the accompanying brain activity. (© Gunnar Grah, Tobias Pistohl, Tonio Ball)

The studies of Ball and his team of researchers involved mainly patients suffering from epilepsy. Electrodes were implanted into the brains of the patients during a presurgical procedure carried out to determine the origin of the epileptic seizures. This knowledge enables the doctors to assess whether patients suffering from focal epilepsy can undergo surgery to remove the part of the brain in which the seizures originate. At the same time, all normal everyday movements and their correlations in the brain are recorded in order to permanently monitor the activity of the neurons. Ball and his team make use of these natural movements in order to obtain relevant data, i.e. results that can be transferred to everyday situations.

“The data from experimental studies in which the volunteers had to repeatedly perform unnatural movements sometimes looked rather bizarre,” Ball said. “We found functional responses in areas where we did not expect them.” Ball therefore assumes that the tasks of the earlier experiments, i.e. the volunteers having to lift and lower their toes or to stretch and bend a finger, were too different from what is considered an everyday movement. In real life, we carry out movements without even thinking about them: grasping a coffee cup, moving a blanket with our foot or bending our knees in order to sit more comfortably. So these are the types of movement Ball and his colleagues chose for their investigations.

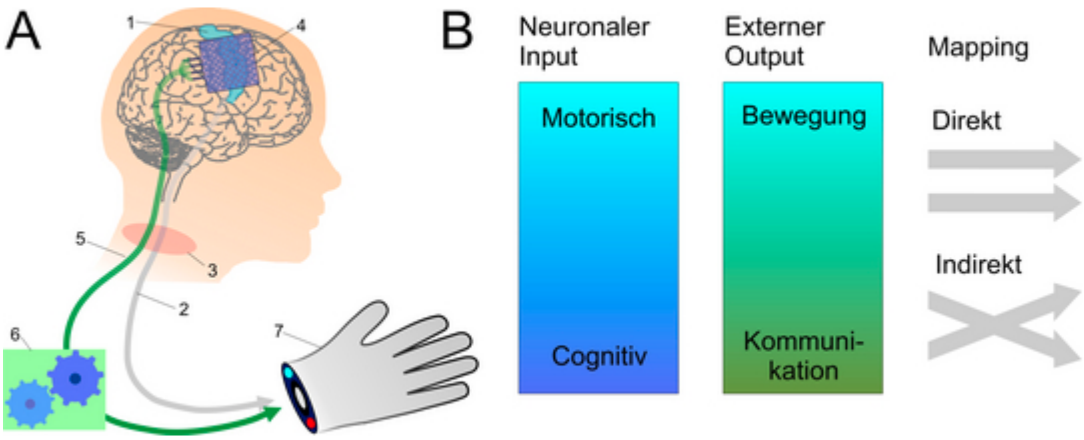
Greater accuracy – and relevance

“Investigating brain activity under everyday conditions is still a grey area on the research map,” said Ball. “But brain activity is less chaotic than previously thought and methods for its investigation are now clearer. In fact, it is now true to say that certain effects are easier to recognise under natural conditions than under experimental conditions.” In addition, many patients, small children for example, are not very suitable for such experiments. Ball’s approach can also solve this problem: “The spontaneous natural movement corresponds well with the expected anatomical brain areas; the data make more sense because these conditions reflect the situations in which the brain normally functions,” Ball concluded.

It can be assumed that the new findings can improve the accuracy of presurgical diagnostics. It is of crucial importance to localise the speech centre prior to surgical interventions, for example, in order to prevent aphasias and other disorders from occurring. Presurgical diagnostics is also vital in order to prevent the development of hand paralyses or walking disabilities after surgery.

Brain-machine interfaces

Tonio Ball is particularly focussed on developing better electrodes and better measuring methods, “on developing better ears in order to eavesdrop on the brain”, as Ball puts it. “On the other hand, we must learn to better understand the signals we are measuring, not only at the cellular level, but also at the level of local networks and the global organisation in the brain.” In summary: Ball is of the opinion that an accurate and evidence-based map of the human brain already exists, but that further research needs to be undertaken in order to complement and improve this map.



Brain-machine interface (BMI): (A) 1. Projections from the motor cortex. 2. Neurons connecting the motor cortex with the spinal marrow. 3. Lesion between brain and muscle. 4. Implanted electrode for recording motor-cortical activity. 5. Signal transmission system. 6. Determination of movement information from neural data. 7. Artificial effector system. (B). The "neural input" of a BMI can consist of a motor and a cognitive signal, which may be used to control movement or communication. (© Modified by Tonio Ball from the open-access paper by Thinnes-Elker et al., Intention concepts and brain-machine interfacing research, Frontiers in Cognition (2012))

Brain-machine or brain-computer interfaces are being developed to facilitate the life of severely paralysed people. Working with Prof. Wolfram Burgard, a leading autonomous robot expert, Tonio Ball is developing intelligent neuroprostheses. This research is part of the BrainLinks-BrainTools cluster of excellence. These brain-machine interfaces receive direct commands from the brain and can thus be used by paralysed people to control movement and communication. Although such implants are still in the development and certification phase, Ball is highly optimistic that their work will soon allow people with paralysis to lead a more independent life.

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The neurosciences(18)

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