Brain-Computer Interaction and Medical Access to the Brain: Individual, Social and Ethical Implications

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Abstract

This paper discusses current clinical applications and possible future uses of brain-computer interfaces (BCIs) as a means for communication, motor control and entertainment. After giving a brief account of the various approaches to direct brain-computer interaction, the paper will address individual, social and ethical implications of BCI technology to extract signals from the brain. These include reflections on medical and psychosocial benefits and risks, user control, informed consent, autonomy and privacy as well as ethical and social issues implicated in putative future developments with focus on human self-understanding and the idea of man. BCI use which involves direct interrelation and mutual interdependence between human brains and technical devices raises anthropological questions concerning self-perception and the technicalization of the human body.

KEYWORDS: brain-computer interfaces (BCIs), ethics

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1. Introduction

During the past decades, scientific progress has considerably increased our knowledge of the structure and function of the human brain, and has prompted the development and use of various neurotechnologies. These include procedures that now are widely used in clinical practice such as deep brain stimulation or cochlear implants, as well as the innovative field of direct brain-computer interfaces (BCIs) which serve to support persons with severe motor impairments (Berger and Glanzman, 2005; Dornhege et al, 2007). In the wake of these medical applications, awareness is growing of anthropological, ethical and social implications of neurotechnological developments such as deep brain stimulation, brain implants, or brain-computer interfaces (European Group on Ethics, 2005; Bell et al, 2009; Hildt and Engels, 2009; Giordano and Gordijn, 2010). The implications considered, address the close interaction between man and machine, the question of human nature and the idea of man, and how far human functions can be substituted or even enhanced by technical devices.

The need for research into the anthropological, ethical and social implications of biomedical research and new clinical applications is twofold: Firstly, it is necessary to carefully reflect on the ethical presuppositions required before running clinical trials, and on the implications these technologies may have on the persons directly involved, i.e. on the individual patients and users, their relatives and the professionals working in the field. Secondly, the broader implications of the use of these technologies, outside of strictly medial contexts, have to be considered. It is becoming obvious that new developments in the neurosciences are not only of central importance to the natural and medical sciences. They also have various implications for self-understanding and the idea of man. Research into anthropological, ethical and social issues concerning BCI technology has therefore two aims. It serves to support the empirical researchers and medical doctors in the design of study protocols and in their contacts with patients and users. And, it strives to identify – right from the start – aspects of relevance to self-perception and technicalized bodies that need further discussion.

Notwithstanding the fact that BCIs are not yet widespread but mainly used in research contexts, it is important to raise awareness right now of this complex technological field and its implications. BCI technology not only raises enormous hopes for patients with severe motor impairments but also offers fascinating perspectives for possible future uses. It seems realistic to assume that, in the future, BCI technology will spread to a variety of new applications such as computer gaming or rehabilitation. The aim of this article is to contribute to such a timely interdisciplinary debate on BCI technology. This is why it will first briefly sketch the various BCI approaches and then discuss individual, ethical and
social issues related to this technology and possible future developments. Issues to be discussed include the benefits as well as the medical and psychosocial risks involved, aspects relating to user control, autonomy and informed consent, and issues concerning independence, social participation, and privacy. Finally, a particular focus will be on the implications BCI technology may have on the idea of man. In two different ways, anthropological aspects matter here. The first one relates to self-perception and to the question of how BCI users experience BCIs. To what extent may BCI users consider an artificial actuator, e.g. an upper limb prosthesis, an integrated tool in the body’s representation? The second one relates to the indirect implications of BCI use on human self-understanding, i.e. to the broader implications of BCI technology on self-understanding and the idea of man.

2. Brain-computer interfaces

Brain-computer interfaces are characterized by direct interaction between a brain and a technical system. There are two forms of brain-computer interfaces (BCIs) that can be grouped according to the directions in which the interaction between brains and technical devices works: BCIs that extract neural signals from the brain and BCIs that insert signals into the brain (Konrad and Shanks, 2010). The latter include auditory brain-stem implants (ABI) that serve speech recognition in patients with damage to the acoustic nerve (Colletti et al, 2009), visual BCI implants such as the visual cortex surface implant called ‘Dobelle Eye’ (Dobelle, 2000), and visual prostheses that are based on implants located in the lateral geniculate body (LGN) of the thalamus (Pezaris and Eskandar, 2009). In the former type of BCIs, however, brain signals are extracted and used for communication and control of movement. The focus here will be on this particular type of BCI technology. It offers support to patients with motor impairments resulting from amyotrophic lateral sclerosis (ALS), stroke, spinal cord injury, cerebral palsy and similar conditions. Currently, this technology is being developed in clinical research studies (Wolpaw et al, 2002; Lebedev and Nicolelis, 2006; Leuthardt et al, 2006; Birbaumer et al, 2008; Daly and Wolpaw, 2008; van Gerven et al, 2009).

There are three main kinds of approaches to the extraction of neural signals from the brain that either capture electroencephalographic (EEG) activity or cortical neuronal activity (Leuthardt et al, 2006; Daly and Wolpaw, 2008). The first kind of approach is non-invasive using scalp recordings (EEG-based BCIs). The second and third kinds however, are invasive strategies that either record
Among the non-invasive EEG-based approaches is the so-called ‘thought-translation-device’, a BCI based on slow cortical potentials. This biofeedback communication system has been used with considerable success by severely paralysed and locked-in patients (Birbaumer et al, 1999). By way of substantial training, patients learn to self-regulate slow cortical potentials of their electroencephalogram. Modifications in brain signals are detected by electrodes located in a helmet, then the signal is modified and transferred to a computer screen for visual feedback. Based on this, patients learn to move a cursor on a screen, so that control of slow cortical potentials can be used to select letters on a screen, process words, access the internet or operate technical devices. Another EEG-based BCI approach uses sensorimotor rhythms (μ-rhythms and β-rhythms) the amplitudes of which change with movement or sensation. By way of motor imagery, individuals can learn to control μ-rhythm or β-rhythm amplitudes in order to move a cursor on a screen or to operate an orthotic device (Kübler et al, 2005; Neuper et al, 2006; Krusienski and Wolpaw, 2009).

In contrast to these EEG-based BCIs that are based on motor or mental imagery, another group of them relies on the so-called P300 stimulus-related brain potential which appears about 300ms after a prominent or attended stimulus (Krusienski and Wolpaw, 2009; Kübler et al, 2009). In most of these systems, a matrix is shown to the user which contains letters and numbers. The rows and columns of the matrix flash successively (brief light stimulus). The user chooses a character he or she wants to communicate by focusing the attention on it. Each time the character is intensified, this elicits an event-related potential (parietal cortex) about 300 ms after stimulus presentation, the so-called P300 response. This signal is detected and can be used for communication. P300 BCI systems allow quite rapid communication (up to 20-30 bits/min). Another advantage of P300 BCI use is that no long learning process is required.

ECoG-based and intracortical BCIs are different in that they are invasive. In ECoG-based BCIs, microelectrode arrays are placed either epidurally or subdurally on the surface of the cortex so that electrocorticographic activity (ECoG) is recorded directly from a small region of the cortical surface (Leuthardt et al, 2004). Up until now however, ECoG-based BCIs have only been used in humans during short-term experiments in which electrode arrays have been implanted temporarily before surgery for epilepsy.

Research into invasive BCI systems, involving intracortical electrodes, is based on spectacular animal experiments. In studies carried out on non-human primates by Miguel Nicolelis and co-workers, brain signals derived from the

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1 In addition, there are also fMRI-based brain-computer interfaces, cf.: Sitaram et al. 2007; Decharms 2008.
motor cortex could be used for artificial limb navigation. Supported by various feedback loops, monkeys learned to navigate prosthetic limbs (Nicolelis, 2001; Nicolelis, 2003; Lebedev and Nicolelis, 2006; Nicolelis and Lebedev, 2009). But there have also been clinical studies involving intracortical BCIs in humans. They aim to improve or restore lost motor function and are based on imagined or attempted movement. Here, multi-electrode arrays are located intracortically within the grey matter in order to record single-neuron activity (Hochberg et al., 2006; Kim et al., 2008). In a clinical pilot study with the Neuromotor prosthesis BrainGate NIS (Cyberkinetics Neurotechnology Systems, Inc.), an intracortical microelectrode array was implanted in the motor cortex of tetraplegic persons. By way of motor imagery, motor cortical neural activity could be translated to achieve two-dimensional cursor control or robotic arm control. Functional effects were achieved for the duration of several weeks. It is important to stress, however, that use of intracortical BCIs in humans is strictly investigative at the moment. Issues that need to be addressed include long-term safety and the stability and duration of signal acquisition.

Obviously, the different BCI approaches presented above bear various advantages and disadvantages (Leuthardt et al., 2004, 2006; Daly and Wolpaw, 2008; Konrad and Shanks, 2010). Invasive BCIs which are based on single-neuron activity recorded within the brain have a high spatial resolution. However, they come with significant medical risks, there is limited stability, and there is a problem of how to achieve and maintain stable long-term recordings. Compared with BCI systems that record electrocorticographic activity (ECoG) from the cortical surface, the latter show greater long-term stability and pose lesser clinical risks than single-neuron recordings. Spatial resolution is less than in intracranial systems but better than in non-invasive BCIs in which electroencephalographic activity (EEG) is recorded from the scalp. Non-invasive BCIs bear the disadvantage of low spatial resolution. They involve a number of cumbersome artefacts and often require extensive user training. Nevertheless, their enormous advantage is clearly safety. They have lower medical risks and do not require any kind of surgical procedure. In principle, non-invasive BCIs are not expensive and, therefore, could be widely accessible. Not the least, non-invasive EEG-based BCIs have achieved excellent results that show control capabilities similar to those achieved with intracortical methods (Daly and Wolpaw, 2008). Taken together, these factors considerably favour non-invasive BCIs over invasive ones.

BCI technology may considerably support persons with severe motor disabilities resulting from amyotrophic lateral sclerosis (ALS), cerebral palsy, muscular dystrophies, spinal cord injuries, brainstem strokes or similar conditions. In particular, BCI technology can be useful for people with severe motor impairments, who are not able to use conventional assistive methods (Daly and
Firstly, BCIs aim to increase communication by providing BCI-based access to computers and virtual keyboards. This allows access to internet, e-mail, telephone, environmental control, and entertainment. Secondly, BCIs can be used as a substitute for lost motor functions, i.e. to control neuroprostheses or other devices that assist mobility.

Another possible future use of non-invasive BCIs is in clinical rehabilitation. BCI use may increase motor function recovery, i.e. after a cerebrovascular accident. This may be achieved by inducing activity-dependent brain plasticity. BCI use and motor imagery may help to activate the sensorimotor networks affected by the lesion and contribute to the restoration of normal motor function (Wang et al, 2010). BCI technology has also been used successfully to train people to control brain signals (neurofeedback), e.g. to reduce seizure frequency in epilepsy or to reduce symptoms in attention-deficit hyperactivity disorder (ADHD) (Walker and Kozlowski, 2005; Strehl et al, 2006; Sitaram et al, 2007).

It is important to keep in mind here that BCI technology is a rapidly developing field, but still in its infancy. Currently, BCI use is mainly confined to persons with severe motor impairments, however, the future may see a wider range of BCI applications, possibly also including non-medical uses (cf. section 6).

3. Benefits and risks

Current BCI technology is aimed at providing support to the daily life of people with severe motor impairments by increasing mobility and providing basic communication abilities. BCIs may serve to operate a motorised wheelchair, to control the user’s environment, or to navigate a hand orthosis and, thereby, increase individual independence in everyday life. Access to communication devices, internet navigation, television and other media promotes social participation and allows individuals to effectively share their experiences with other persons. By using BCIs, individuals gain skills and independence which are meaningful and relevant in their daily lives.

Taken together, BCI use may increase considerably independence and self-esteem, positively influence the quality of life and facilitate participation in family and social life. Also, more independence involves privacy gain for persons who otherwise are dependent on continuous assistance and care, i.e. if BCI technology allows users to act independently in a broad variety of contexts. They would be able to choose activities and communicate without the support of relatives or

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2 See also http://www.tobi-project.org/welcome-tobi
caregivers who otherwise – even of course most often involuntarily – are aware of all the person’s activities and communications. This would result in considerable privacy gain. However, it is important to be aware of the fact that, in principle, any kind of computer-based communication can be traced by third persons, caregivers, researchers, etc. So, adequate measures have to be taken to secure privacy in these situations. The same is true concerning data protection in clinical studies.

Whereas reports of individual users and participants in BCI studies clearly reflect positive effects of BCI use (Kübler, 2004; Birbaumer, 2005), the current stage of research has only a limited amount of data available concerning the benefits of BCIs. Thus, it is necessary to carefully evaluate the practical value of BCI use, i.e. the extent to which BCIs improve the quality of life, mood, and independence of individual users (Daly and Wolpaw, 2008). But what about the risks of BCI use?

Risks vary considerably between the various applications: non-invasive approaches bear definitely less medical risks than invasive ones. Invasive BCIs, in particular intracortical, involve considerable medical risks which are associated with the implantation of electrodes and other neurotechnical devices. There is risk of irreversible effects of intracortical trauma, hemorrhage, and infection. Also, long-term functionality and biocompatibility of implanted material is a crucial and currently a rather problematic issue (cf. Leuthardt et al, 2006; Konrad and Shanks, 2010). Irreversible side effects, in particular, are problematic not only from a medical point of view but also from an ethical point of view. The implantation site is the human brain, i.e. the organ of central relevance to a person’s overall existence and individual personality. Complications and side effects may include health problems and unforeseen modifications in physical or mental traits.

Should future BCIs involve direct information input into the brain via feedback loops, additional considerations will have to be taken into account. Although not realised in clinical contexts so far, there have been animal experiments with BCI systems involving a feedback loop in which information is sent back to the brain for tactile of proprioceptive feedback (Lebedev and Nicolelis, 2006; Nicolelis and Lebedev, 2009). The question of the extent to which such a feedback loop may involve modifications in brain functioning or individual traits needs careful evaluation.

The medical risks are considerably smaller using non-invasive BCIs – if they exist at all – for the EEG signals are derived externally from the scalp. Nevertheless, there are currently unresolved questions regarding BCI use and brain plasticity that need further elucidation. Plastic modifications in brain structure and function are brought about to a certain extent in any kind of learning or external influence. There undoubtedly is a highly repetitive use of certain pathways which may involve particular ‘rearrangement’ problems. This leads to
the possibility that non-invasive BCIs involve negative effects on brain structure and functioning via long-term stereotyped use of specified brain signals. Although there are yet no reports of problematic influences of non-invasive BCIs on brain structure and functioning due to brain plasticity, this possibility has to be taken into consideration. In current and future trials, it is very important to monitor and analyse possible rearrangement effects that might result from BCI use.

In addition to medical risks there are psychosocial risks posed with BCI use and the participation in BCI studies. Persons get involved with complex devices and are required to cooperate intensely with sophisticated and demanding technical systems. Currently, most approaches require extensive training. Users invest considerable time and effort learning to navigate the systems but, especially for persons with severe motor impairments, considerable physical coordination and cooperation strains are associated with the training sessions.

In case the BCI system does not function as expected, and does not lead to the hoped-for improvement in the quality of life and independence, frustration can be expected. The individual may have invested in an enormous effort without achieving significant benefit. This may incite negative feelings and disappointment. Adequate precautions have to be taken in order to limit these risks of negative psychosocial effects (cf. Grübler and Hildt, work-in-progress).

At the current stage of development, BCI technology is an experimental approach and, due to technological complexity, it is confined mainly to research environments. For the time being, BCI technology requires considerable individual and technological effort, and benefits are limited to specific clinical situations. A particular problem consists in the fact that BCI systems currently require intense and continuing technical support which can be provided only by a few research groups worldwide (Daly and Wolpaw, 2008). Without any doubt, an important prerequisite for broader use of BCI technologies will be to further improve ease and convenience of BCI use. It will be necessary in the future to devise more flexible and sophisticated solutions – technical devices that are easier to navigate and do not presuppose considerable ongoing technical support but can be manipulated at home and other environments familiar to users.

To sum up, before considering BCI use, it is important to carefully balance the medical and psychosocial benefits and risks for the person involved. But in many respects, neither risks nor benefits are well known at this experimental stage. It is quite obvious, however, that non-invasive BCIs pose limited medical risks compared to invasive BCIs. Only in those cases in which there is no comparable non-invasive and less risky alternative available, and considerable benefits may with good reason be expected, should invasive BCIs be taken into consideration.
4. User control

In BCI applications, the individual user forms part of a complex functional system which involves the direct cooperation and mutual dependence between a person and a technical system. Generally speaking, BCI use involves shared control insofar as the person forms part of a system and, together, the individual and the technical complex achieve some output signal (Hildt, 2005; Tamburrini, 2009). BCI technology is intended to increase the user’s ability to independently manage everyday life and, in order to achieve that, exerting control over the BCI system is of crucial importance.

In particular for persons with conditions such as amyotrophic lateral sclerosis or partial or complete locked-in-syndrome, the power to exert control over the system is directly associated with independence and autonomy. The person’s quality of life - the ability to communicate, perform motor functions or other manoeuvres - strongly depends on the technical system and its correct functioning. BCI technology may improve independence and autonomy considerably. By contrast, dysfunctions and failures have direct negative impact on the user. In particular for locked-in patients, severe problems can arise in the case of a sudden interruption of BCI communication (cf. section 5).

Several factors influence user control. The first relates to the difficulties that have to be overcome in order to navigate the system. In general, the easier a system is to handle, the better the user control that can be achieved. Invasive systems may prove much easier for manipulation of external devices than non-invasive ones. Invasive systems have higher spatial resolution and signal processing would be easier. However, invasive BCIs presuppose a surgical procedure, a fact that clearly is a hindrance from medical and practical points of view.

Another challenge consists in the number of training sessions required to achieve adequate skills for successful BCI performance. The aim is a minimum of training sessions for maximum user control. In particular, for some of the non-invasive BCI systems, for example the so-called ‘thought-translation device’, this is very hard to achieve. In addition, BCI performance varies considerably between individuals. A minority of individuals show so-called ‘BCI illiteracy’ (cf. Popescu et al, 2008), and, in many cases the attempt to achieve adequate user control is an exhausting experience.

Limitations to an individual’s ability to exert control over a system may also be due to irreversible effects. Non-invasive BCI systems can be flexibly adjusted to the individual person, and external devices modified and exchanged without great difficulties. With invasive BCIs however, the need for brain surgery can limit user control considerably. Electrode arrays can be misplaced and relocated, and reduced biocompatibility results in functionality loss. In addition to
that, invasive BCIs risk irreversible effects such as brain lesions, surgical trauma or modifications in brain structure and function, all of which can limit user control. Seen from this perspective, the degree of user control can be expected to be substantially higher with non-invasive BCIs.

Interpretive errors that lead to a different output signal than intended by the user may also cause serious problems. In particular, with BCI use in locked-in patients, the question can arise regarding the extent to which the communication achieved actually represents the will of the locked-in person. A similar problem, inherent to shared control of robotic systems, relates to liability issues in case of harm brought about by brain-actuated mobile robots due to misclassifications or other interpretive errors (cf. Tamburrini, 2009).

Furthermore, user control depends on the period of time during which continuous functioning can be achieved. It seems that the ideal BCI would be a system that is able to work permanently. In order for a person to control her overall situation as much as possible during the course of the day, a system is required that offers correct and continuous functioning without any involuntary disruptions. That is why future developments in BCI technology should aim at systems that in principle can be used 24 hours a day, 7 days a week, in the home or other familiar environments. However, due to the enormous technological complexity, most systems currently work only for a very limited time span and in controlled research environments. To take an example, EEG-based BCIs are currently functional only for relatively short periods of time in a controlled environment with professional support. Wet electrodes are used in these systems and they require a complicated filling procedure and handling. Function continues only for a few hours as electrodes run dry. In order to achieve better user control and more independent and flexible use, the challenge is to aim at dry electrodes that will overcome this problem (Popescu et al, 2007, 2008). Improving user control in this way will also be an important precondition for a more widespread use of EEG-based BCIs.

5. Informed consent

Before involving a person in any kind of BCI training or BCI study, it is absolutely necessary to obtain the person’s informed consent, i.e. his or her free and well-informed decision concerning BCI use. The need to acquire informed consent before undergoing medical treatment is a general standard in medical practice, based on the concept of individual autonomy (Faden and Beauchamp, 1986; Wear, 1993). It is crucial to thoroughly inform individuals of the benefits and risks involved in BCI use, and be sure they consent freely, i.e., it is necessary to secure that participation in clinical studies is not based on unrealistic hopes or governed by undue influence of third parties.
It has to be clearly stressed that, for the time being, BCIs are an experimental approach with limited functionality. Researchers and medical doctors have to be careful to give a realistic picture of the current state of BCI technology and not raise expectations to levels that cannot be fulfilled. Otherwise, there is the risk of enormous frustration, leading to negative feelings and the impression of having been bothered with inadequate complex technology and superfluous training sessions. Another problem relates to the fact that in clinical research studies, technical devices may have to be withdrawn at the end of study participation. In those cases, in which BCI technology has a positive effect on the user’s quality of life, the withdrawal of technical support risks psychosocial problems (cf. Grübler and Hildt, work-in-progress).

Serious conditions such as amyotrophic lateral sclerosis and partial or complete locked-in syndrome need special consideration (cf. Kübler, 2004; Haselager et al, 2009). In view of the difficulties these patients have communicating, questions are raised as to how a valid free and informed consent is obtained, and how to be sure that the person actually consents to the proposed procedure in a well-informed way. Here, the enormous importance of communication for these patients has to be taken into consideration but, also, constraints that are manifested in the lack of available alternatives to support them.

Particularly serious problems concerning autonomy and consent arise in cases where the BCI for locked-in patients stops functioning. Similar problems may appear in cases of abundant or obvious interpretive errors. But, when the relied-upon communication system breaks down, it is suddenly next to impossible to find out the person’s will and decide on how to proceed with them. It is important to mention here that it is not yet known whether BCI use is possible in completely locked-in patients (Kübler and Birbaumer, 2008). Advance directives may be helpful here. They are far from resolving all of the problems, however, for it is seems almost impossible to anticipate the full implications of situations with locked-in patients. (cf. Birbaumer, 2005).

On the issue of balancing benefits and risks, it is important that the risk-benefit-ratio is different for each patient, and in each situation. Risks that seem less acceptable under less serious conditions might be worth considering in the case of more serious disabilities. In addition, there undoubtedly is a subjective component: risks one person considers unacceptable may be considered acceptable by another. Konrad and Shanks (2010) stress this aspect, pointing out that in their experience, patients with significant disability are willing to take higher risks and to consider neurological device implants in the hope of improving their quality of life. Whereas balancing of risks and benefits undoubtedly depends on individual factors, reflections like these should not be taken as a carte blanche for carrying out risky clinical studies on vulnerable
patients. Instead of stressing that patients with severe motor restrictions might be willing to take considerable risks in order to improve communication, mobility and their quality of life - and thereby there is some kind of justification for running risky procedures - it is important to develop low-risk approaches with more favourable risk-benefit ratios. The premature development and clinical use of approaches involving considerable risks for brain damage would imply an undue instrumentation of patients and their hopes.

6. BCI use: present situation and possible future developments

At the current stage of development, direct brain-computer interfaces are mainly supporting patients with severe motor impairments, and their applications require considerable individual and technological effort. That is why, for the time being, BCIs are confined to clinical contexts. It may be expected, however, that in the not-so-distant future, BCI technology will improve considerably and provide valuable options for communication and motor control that will be much easier to handle than current solutions.

BCI technology is undoubtedly a very promising, fascinating and innovative field of research. Notwithstanding hopes and expectations, it is important to stick to reality in public reports on BCI technology and BCI research—to avoid an overoptimistic picture and raising expectations too high (Haselager et al, 2009). For example, media reports or documentaries that are too future-oriented or based on spectacular developments may unduly influence patients and their relatives by facilitating unrealistic expectations.

Whereas both invasive and non-invasive BCIs may be of relevance in specific medical contexts, it is only the non-invasive BCIs that currently possess a potential for broader use and a more widespread distribution. In contrast to invasive BCIs, non-invasive BCIs bear very low medical risks. They could be accessible to a larger number of persons, they do not require surgery or medically intensive support, and are therefore also much cheaper than invasive BCIs. In view of these factors, one may expect future non-invasive BCIs hat stretch beyond strictly clinical settings. One field of possible future application is support for individuals with minor motor restrictions. Another field is clinical rehabilitation, and a third is ICT in general, i.e. the use of BCIs for computer gaming or other recreational contexts.

To achieve wider uptake and use of non-invasive BCI technology, practical and technical problems need sorting out. In particular, improving user-friendliness is necessary. This includes the use of dry electrodes and the reduction in calibration and training sessions required to achieve adequate functioning. It also includes the development and broad availability of small high-performance computers and other specialized devices.
First steps in this direction can be seen from current commercial BCI developments in the field of computer gaming. Among them is the Neural Impulse Actuator, NIA™, a headband with carbon nanofiber-based sensors developed by OCZ Technology. The NIA™ PC Game Controller records bioelectrical signals (electromyogram (EMG) signals derived from forehead and eye muscles, and EEG signals), transformed to control computer keyboard and mouse. This allows for reflex-based game play, a reduction of reaction time and an enhanced gaming experience. The EPOC headset, developed by Emotiv Systems, takes a similar approach. In both cases, the idea is to detect and record the user’s thoughts, feeling and expressions for game control.

In addition, there are toys such as the so called Star Wars Force Trainer, developed by NeuroSky. According to the manufacturer, a wireless headset reads and interprets brainwaves to allow users the manipulation of a sphere within a training tower, i.e. it aims to confer abilities analogous to those seen in the Star Wars films. It may be questioned, however, whether these commercial developments are actually based on electroencephalography and direct brain-computer interaction.

Computer games, designed to allow reflex-based gaming using on EEG signals, raise some privacy-related issues that need further discussion. A person’s thoughts, feelings or expressions can be seen directly on the computer screen when BCIs that serve to trace moods are being used. This is particularly true when signals are derived from tacit, embodied, and thus mainly unnoticed, reactions and know-how of the user. Obviously, however, it is particularly this aspect that seems to exert the spontaneous fascination, as can be seen from excited comments that praise EEG-based gaming for higher gaming experience. Concerning the Neural Impulse Actuator (NIA), the company’s website makes available enthusiastic comments, among them the following extract from the Turkish Oyungezer Magazine:

To command games without our hands, just with our thoughts... NIA isn’t supposed to fill in the space for a keyboard and mouse, it’s aim is to take your gaming experiences to the next level. The waves which are transferred to digital platform are transformed into commands for you to be able to command the games much more better than ever. NIA isn’t just simply reading our thoughts. It educates us to convert the unconscious responses to conscious ones and mimic these

3 See http://www.ocztechnology.com/products/ocz_peripherals/nia
4 See http://www.emotiv.com/apps/epoc/299/
5 See http://company.neurosky.com/products/force-trainer/
7 See http://www.ocztechnology.com/products/ocz_peripherals/nia
responses whenever we want. When we accomplish this the only thing left to do is to associate these responses in our head with the controls we use in the games and NIA does the rest for you [sic].

In view of the fact that computer gaming also involves situations and contexts that often imply emotional or even extreme emotional involvement, this may lead to various problematic and revealing situations which are not only unexpected to individual users themselves but also to their companions.

Furthermore, a field for future BCI applications is in the military. Currently, a considerable amount of BCI research is supported with military funding from the US Defense Advanced Research Projects Agency (DARPA) which clearly indicates potential applications outside the clinical field (Hoag, 2003; Gordijn and Buyx, 2010). Possible future uses by the military include BCI-controlled airplane navigation and remote control of robotic and other technical instruments for military purposes. In various other professional fields, approaches to direct control of virtual reality by the brain, or of robot arms, may have applications in the future.

Applications like these that do not serve to restore human health or normal human functioning have to be seen as human enhancement—the term ‘enhancement’ used to characterize “interventions designed to improve human form or functioning beyond what is necessary to sustain or restore good health” (Juengst, 1998: 29).

7. Neurotechnology and the body concept

BCI use and the direct interplay between the human brain and computer technology, needs further theoretical and also anthropological consideration. In contrast to the ordinary use of technical devices and tools whereby, for example, a hammer, a TV set or a mobile phone, are used and displaced by anyone who likes to do it, BCI use poses a different situation.

A feature characteristic of BCIs and other neurotechnological applications is direct interaction between man and technical devices: the technical devices are in direct contact with the human brain. BCI technology requires an intense interaction between man and a computer system which involves complex adaptation processes and mutual learning. In view of this mutual interdependence, in a certain functional sense, the boundaries between man and technical system are blurred in unprecedented ways. This aspect is most obvious when an artificial limb is being controlled by a BCI.

In view of the intensity of functional interaction between man and

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machine, there is an anthropological question relating to self-perception and body ownership. Can a technical device become integrated into the self-conception of the person who navigates the device, which then leads to some kind of bodily reconfiguration? This implies the question of whether or to what extent a person considers the artificial actuator, for example a prosthetic limb, to be part of herself.

In order to get some idea on issues related to self-perception and bodily identity in BCI use, it is helpful to resort to some anthropological reflections. In particular, Lucy A. Suchman’s work on human-machine reconfigurations matters here (Suchman, 2007). According to Suchman’s position, intimate human-machine interactions imply new hybrid agencies that are enacted. In this context she writes:

The task for critical practice is to resist restaging of stories about autonomous human actors and discrete technical objects in favor of an orientation to capacities for action comprised of specific configurations of persons and things. (Suchman, 2007: 284).

Similar thoughts, one may argue, apply to BCIs. In case of BCIs that navigate prosthetic limbs, the idea of reconfiguration may be most obvious. Here, it seems that the prosthesis can be considered to be an additional limb the person learns to control. Sometimes less apparently, however, reconfiguration plays some role in almost any kind of neurotechnologies as there is always close interaction between a technical device and a human body resulting in some kind of hybrid function. Needless to say, before a person starts to learn how to navigate a BCI, the prosthesis - or more generally speaking the artificial actuator - is obviously an external technical device and not part of the person’s body. It is not experienced by the person as a part of her body.

Any kind of body experience or ascription of body ownership requires some internal perception. In a person’s experience of her own body, the body schema, i.e. the internal representation of one’s body constructed by proprioceptive, visual and somatosensory signals, is of crucial importance. Often, the term ‘Leib’ is used in order to characterize this experience of one’s body from the internal perspective, cited from the basic reflections by Maurice Merleau-Ponty on these issues (Merleau-Ponty, 1981).

Is it possible to extend one’s bodily perception to a tool or technical device that is regularly used? To what extent can a regularly used tool become integrated into the body schema? Already in the 1940s Merleau-Ponty discussed this question when he described the way in which a blind person’s stick is integrated in that person’s bodily perception. Similar examples relate to the regular use of a typewriter and the implications that go along with this. In this context, he alludes
to “a bodily auxiliary, an extension of the bodily synthesis” (Merleau-Ponty, 1981: 152).

More recent studies point to the possibility of an integration of regularly used tools into the body concept. For example, in a study run by Iriki et al (1996), monkeys learned to use a rake in order to retrieve distant food. The researchers recorded the activity of bimodal cortical neurons in these monkeys and found an extension of the visual receptive fields of some of the bimodal cortical neurons along the length of the rake. These results show that the regular use of a tool may lead to plastic modification of the body representation in the brain and to the integration of the tool into the body concept.

Additional results of similar studies support the idea of tool incorporation in the body schema, i.e. of reconfiguration (cf. Maruishi et al, 2004; Maravita and Iriki, 2004). For example: The results of an fMRI study carried out by Maruishi and collaborators (Maruishi et al, 2004) can be interpreted in a similar way: In a study in which the task was to navigate a virtual myoelectric hand prosthesis on a computer screen, an increase in brain activity was detected in the region of the right ventral premotor cortex. This was interpreted by the authors to be the result of an integration of the virtual tool into the body concept. Also, concerning prosthetic devices in BCI use, an incorporation of the artificial actuator into the user’s body representation seems possible. To a certain degree, it may even be considered to be necessary in order to secure proper BCI functioning. Most probably, integration is facilitated by providing the brain with multiple sensory feedback from the artificial actuator.

Nicolelis and Lebedev (2009) reflect on this issue as follows:

…but at its limit, cortical plasticity may allow artificial tools to be incorporated as part of the multiple functional representations of the body that exist in the mammalian brain. If this proves to be true, we would predict that continuous use of a BMI should induce subjects to perceive artificial prosthetic devices, such as prosthetic arms and legs, controlled by a BMI as part of their own bodies. Such a prediction opens the intriguing possibility that the representation of self does not necessarily end at the limit of the body surface, but can be extended to incorporate artificial tools under the control of the subject’s brain (Nicolelis and Lebedev, 2009: 535-6).

Thus, long-term usage of BCIs may pose cortical and subcortical remapping leading to the integration of the artificial actuator into the body schema. This may result in the subjective experience of reconfiguration, i.e., the person’s experience of hybrid agency. It is conceivable then that, due to brain plasticity, the long-term usage of a brain-computer interface (BCI) results in the
user considering the actuator to be no longer a mere tool, but to be – at least partly – the body, a part of his or her own body.

8. Implications on the idea of man – some concluding remarks

What are the indirect implications of BCI technology, i.e. direct interaction between man and computer, on our idea of man and on human self-understanding? In several respects, BCIs seem to contribute to a functionalist view on persons and their brain functions. For in BCIs, mental processes are considered to be functional processes within the man-computer hybrid. Within the system, neuropotentials and brain functioning serve as a controlling component that is entirely compatible with and similar to computer functions and computer software.

In view of this direct interaction, BCIs may be considered to encourage a reductionist, technological view on human beings. On the one hand, it cannot be denied that there is a certain kind of technicalization going on in the sense that BCI use involves intimate interaction with technical devices. The greater number of technical components in a man-computer hybrid system, the more the individual user may seem dependent on computer technology and at the mercy of a complex system. On the other hand, anthropological considerations that stress the emergence of new hybrid agencies from man-machine interactions (cf. Suchman, 2007), may point to a different way of thinking that does not rely on a reductionist view on man. In addition, strong science-fiction-like fears are not warranted. It is important to stress that BCIs are supportive systems devised for specified purposes, i.e. to assist persons in medical or non-medical contexts. Adequate BCI functioning requires the active cooperation of the user involved. In sharp contrast to science-fiction scenarios, BCIs do not involve some kind of an independent, autonomous computer system that aims to take over the control.

Issues like these undoubtedly point to the various implications BCI technology has not only for the persons who use them but also for the broader social context. In order to allow an adequate use of this technology, theoretical, ethical and social issues have to be carefully discussed, based on realistic descriptions of possible chances and risks of BCI use. In this respect, it is important to keep in mind not only the current clinical BCI applications – which may seem rather limited – but also possible future uses in various professional fields or for recreational activities.
References


