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Brain-Computer Interfaces for Non-Medical Applications: How to Move Forward

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Abstract
Brain-Computer Interfaces (BCIs) carry the promise of natural and intuitive human-computer interaction. BCI technology has matured to the extent that it is available for home use. While most BCI technology was developed for medical applications, we identify 7 non-medical applications including device control, user state monitoring and gaming. We rate these on amongst others societal impact and time to market. Breakthroughs are required in the areas of usability, hardware and software, and system integration, but for successful development should also take user characteristics and acceptance into account. We discuss areas of concern like the lack of standardization and provide 10 recommendations to push the field forward.

Keywords
Assistive technology
Brain-Computer Interface
Signal processing
User interfaces
Human-computer interaction

1 Introduction

Brain-Computer Interface (BCI) technology is a potentially powerful communication and control option in the interaction between users and systems and is by definition interaction beyond the keyboard. According to the original definition [1], a BCI is a communication and control system that does not depend in any way on the brain's normal neuromuscular output channels. BCIs carry with them the expectation of the future. Science fiction has since long been playing about the capability of a device that connects your brain to a computer. According to these fantasies, one could experience virtual or remote realities directly through a high-quality connection and control equipment by mere thought. Although current day reality is much more down to earth, remarkable accomplishments have been achieved in the last two decades and BCIs are among us and are here to stay.

The research community initially developed BCI technology as assistive devices, for instance as a communication device for physically challenged or locked-in users. However, the scope of research has widened to include non-medical applications, even to the extent that the first commercial products are available for home use (e.g., Uncle Milton's The Force Trainer and Mattel's Mindflex, see also the sidebar "Commercial BCI technology"). As a result, new disciplines such as gaming and Human-Computer Interaction enter the BCI community, and new research themes and paradigms are introduced. Accommodating this broader scope requires a less strict definition of a BCI (see [2] for an extended discussion on this issue): "a BCI uses brain signals to control a device or to adjust the communication between user and device". Although there seems to be a wide gap between high-end assistive technology and low-end gaming devices, several issues are fundamental to all BCI application areas. It is evident that more recent application areas can benefit from several decades of investments in BCI knowledge for assistive technology, but the newly involved disciplines can in turn help to improve BCI applications for patients.

>>>Insert Figure 1 about here<<<

Medical BCIs are slowly maturing, but non-medical BCIs can still be considered an embryonic technology. However, progress is fast as reflected by the increasing number of conferences, workshops and publications (see Fig. 1 for an illustration). The question arises what is needed to warrant progress for the broad introduction of BCI technology as interaction beyond the keyboard? Besides the transfer of knowledge from assistive technology, there are several crucial issues that are not within the scope of medical BCIs or the impact of which is much less critical in medical BCIs. User state monitoring is a typical example of an application relevant for non-medical users but that is outside the scope and definition of medical BCIs. The intent of this paper is to put together pieces of information in order to summarize the situation and give researchers and stakeholders a clear and concise overview of where we are and what we have to do to extend BCIs to non-medical applications. The results are partly based on several international workshops organized by the authors and attended by representatives from academia and industry (notably the workshops "Other Uses of BCI Technology" and "Non-Medical Communication and Control Applications of BCIs", organized during the International BCI Meeting 2010). We provide a short introduction into the current BCI hardware and software, and look specifically at novel applications and at the technological challenges as we consider them to be the main drivers of near future developments. Other important issues such as the ethical and legal aspects and the need to involve user groups are touched upon in the discussion section. We finally give ten recommendations to advance the field of non-medical BCI applications.

2 Current technologies for BCI: hardware and software

BCIs enable users to interact with a device through brain activity only, this activity being measured and processed by the system. Several hardware technologies are available to measure this brain activity, among which ElectroEncephaloGraphy (EEG), MagnetoEncephaloGraphy (MEG) functional Magnetic Resonance Imaging (fMRI), functional Near InfraRed Spectroscopy (fNIRS), ElectroCorticoGraphy (ECoG) and Subcortical Electrode Arrays (SEA) have all been used for BCI research. ECoG and SEA are invasive recording techniques, based on sensors implanted under the skull, at the cortex level for ECoG and under the cortex for SEA. They provide an excellent temporal and spatial resolution but are not appropriate for non-medical applications, being invasive. fNIRS and fMRI both measure brain activity indirectly, based on the cerebral blood flow, estimated optically for fNIRS and magnetically for fMRI. While fNIRS has the potential to shrink to small and portable devices, fMRI can provide a very good spatial resolution but is far from mobile or even portable. Unfortunately both methods are characterized by a poor temporal resolution with delays around one to several seconds. At the current state, fMRI is very expensive. Finally, MEG and EEG both provide a more direct measure of neuronal activity, from magnetic fields for MEG and electrical potentials for EEG. They are characterized by a very good temporal but a poor spatial resolution. MEG equipment is as bulky and expensive as fMRI, but EEG is relatively cheap and portable. This makes EEG currently the most usable and wide-used brain measurement techniques for BCIs, although it is still not an ideal sensor. Indeed, putting the EEG cap and sensors on requires several minutes, the measured signals are either relatively noisy or require the use of conductive gel between the sensors and the user's scalp. While EEG sensors that do not require gel (the so call "dry" sensors) have been recently released (see the sidebar "Commercially available BCI"), the signal quality they provide is generally not as good as that of gel-based systems.

On the software side, in order to process the measured brain signals in real-time, several solutions are now available (partially as open source). In particular we can mention BCI2000 (http://www.bci2000.org), OpenViBE (http://openvibe.inria.fr), FieldTrip (http://fieldtrip.fcdonders.nl/), Biosig (http://biosig.sourceforge.net) and BCILAB (http://sccn.ucsd.edu/wiki/BCILAB). They provide a variety of signal processing, classification, visualization and presentation modules in order to design, use and assess BCI systems.

3 Non-medical BCI applications

BCIs have a wide range of applications that can be beneficial for users who do not necessarily have a medical indication to use one. This section provides an overview of seven (high-level) application areas and a few examples within each area. We noticed that these seven application areas consequently emerged during the workshops we organised and cover a wider area than commonly identified referring to non-medical applications (e.g. see [2]). We also rate the merits of each application area on the following five criteria: (1) the quality and quantity of relevant research, (2) the societal impact (can the technology contribute to solving important societal challenges, e.g. with respect to aging or quality of life), (3) the economic viability (mainly based on the number of potential sub-applications and potential users), (4) the price sensitivity (i.e. how crucial is the product price), and (5) the time to market. The ratings are not a result of the workshops but based on discussion among the authors and the experts mentioned in the acknowledgements. The ratings are summarized in Table 1.

3.1 Device control

One of the driving forces behind the development of BCIs was the desire to give users who lack full control of their limbs access to devices and communication systems. Under these circumstances, users can already benefit from a device even if it has limited speed, accuracy and efficiency. For healthy users that have full muscular control, a BCI currently cannot act as a competitive source of control signals due to its limitation in bandwidth and accuracy. Also, the generation of control signals and the extraction of these from the brain signals may cause latency in the control loop of several hundreds of milliseconds or more that makes smooth closed-loop control impossible. The introduction of a form of shared control between the device and the user in which the latter gives more high level, open-loop commands may overcome the latency issue. However, it is possible, that healthy users could – for limited application scenarios – also benefit from either additional control channels or hands-free control. Examples include drivers, divers, and astronauts [3] who need to keep their hands on the steering wheel, to swim, or to operate equipment. Brain-based control paradigms are developed for these applications in addition to, for instance, voice control. This field has a strong body of research work on single task situations and for patient users but lacks data on control in multi-task environments and for healthy users. Also, the surplus value over other hands-free input modalities such as voice or eye movement control must be shown (although certainly expected in, for instance, noisy environments). The direct societal impact will be limited, although a spin-off to medical applications may be anticipated. Economic viability is restricted to high-end applications (i.e. operators working at the edge of their physical abilities), price sensitivity is low as long as products are not developed for the consumer market. The time needed to realize viable implementations is expected to be large because the current state-of-the-art regarding parameters like bandwidth and reliability of the control signal has not advanced enough to be of use for device control applications outside assistive technology.

3.2 User state monitoring

The future generation user-system interfaces need to be able to understand and anticipate user's state and user's intentions [3]. For instance, automobiles will react to driver drowsiness (see Figure 2) and virtual humans could convince users to follow their diet. These future implementations of so-called user-system-symbiosis or affective computing [4] require systems to gather and interpret information on mental states such as emotions, attention, workload, fatigue, stress, and mistakes. Another application field is the use of BCIs as a research tool in neuroscientific research. Compared to slower, lab-based functional imaging methods it can monitor the acting brain in real time and in the real world and thus help to understand the role of functional networks during behavioural tasks.

>>>Insert Figure 2 about here<<<

Brain-based indices of these user states are extending physiological measures like heart rate variability and skin conduction and are thus complimentary to and not so much in competition with existing technology. There is a limited but fast growing body of knowledge for these applications and a very high societal impact and economic viability. High-end applications for e.g. air traffic controllers and professional drivers (i.e., driver drowsiness detectors) are seriously investigated and may have good spin-offs for the general public. Better user interfaces can have an important contribution to societal challenges such as providing access to electronic systems and services for all (including the aging population and people with cognitive challenges), a healthy life style and (traffic) safety.

3.3 Evaluation

Evaluation applications can be used in an online fashion (by constant monitoring) and an offline fashion. Neuromarketing and neuroergonomics are two evaluation examples. Neuroergonomics has a clear link to Human-Computer Interaction: it evaluates how well a technology matches human capabilities and limitations. An illustrative example is the recent research on cell phone use during driving: brain-imaging results show that even hands-free or voice activated use of a mobile phone is as dangerous as being under the influence of alcohol during driving [5] (see also fig. 2). The body of evidence in this area is mainly based on fundamental neuroscientific studies and would benefit from a transition to more applied studies. The societal impact is rated low; it is merely a tool that adds to current evaluation tools but has no direct contribution to solving societal issues. The economic viability is potentially high: design and evaluation are relevant for many services and products (e.g., electronics, food, buildings). These methods should prove their added value over for instance questionnaires.

3.4 Training and education

Most aspects of training are related to the brain and its plasticity. Measuring this plasticity and changes in the brain can help to improve training methods in general and an individual's training schedule in particular. With respect to the latter, indicators such as learning state and rate of progress (novice / expert) are useful for automated training systems and virtual instructors. Currently, this application area is in a conceptual phase with limited experimental evidence. However, (permanent) education (also known as lifelong learning) and the need for efficient and effective (automated) tutoring systems have a good societal as well as economic impact, especially for societies with a knowledge-based economy, facing an aging population and/or requiring a flexible workforce. Applications may be both in a professional environment and for home use, making the price sensitivity difficult to rate.

3.5 Gaming and entertainment

The entertainment industry is often front runner in introducing new concepts and paradigms; among others in human-computer interaction for consumers (recent examples are 3D movies at home and gesture-based game controllers). Over the past few years, new games have been developed that are exclusively for use with a EEG headset by companies like Neurosky, Emotiv, Uncle Milton, MindGames, and Mattel. Additional, there is a general conviction that experiences of existing game and entertainment systems are enriched, intensified and/or extended by using BCIs [6], for example by tailoring games to the affective state of the user (immersion, flow, frustration, surprise etc.). For instance, several game designers linked mental states to the popular game World of Warcraft® so that the appearance of an avatar is no longer controlled through the keyboard, but reflects the mental state of the gamer. The first (mass) application of non-medical BCIs may actually be in the field of gaming/entertainment where the first stand-alone examples came to the market in 2009 and a broadening to console games may follow soon [7]. We expect that successful applications will be based on state monitoring and not on the user directly controlling the game (although this can add a new fun factor to existing games, see Fig. 3). Although BCIs for gaming were suggested a decade ago, the research basis is still small but growing rapidly in a mainly application-driven manner and and not theory. The societal impact is judged low, but the economic viability is very high (according to a survey held by GameStrata - the leading online community for gamers - in 2008, an average North American gamer spends more than $30,500 on games and gaming hardware over their peak gaming years between 18 and 48). The price sensitivity is very high, with important requirements with regard to ease of use, amongst others.

>>>Insert Figure 3 about here<<<

3.6 Cognitive improvement

Some argue that improvement of cognitive performance is an everyday reality, for instance through the use of coffee or tea. However, the debate about cognitive enhancement has gained importance, amongst others through the increased use of prescription drugs like Modafinil and Ritalin without a medical indication, by both students and professional workers. BCIs are also considered a means to improve cognitive functioning of healthy users. Neurofeedback training (brain activity alteration through operant conditioning), for instance to improve attention, working memory, and executive functions is relatively common among healthy users. Another potential application area is the optimized presentation of learning content. Although there is currently lack of good experimental data on its effects, the effect size is probably small and limited to specific cognitive tasks. Generally, there may be a thin line between medical and non-medical use of neurofeedback.

3.7 Safety and security

EEG alone or combined EEG and eye movement data [8] of expert observers could support the detection of deviant behaviour and suspicious objects. In an envisioned scenario an observer or multiple observers are watching CCTV recordings or baggage scans to detect deviant (suspicious or criminal) behaviour or objects. EEG and eye movements might be helpful to identify potential targets that may otherwise not be noticed consciously. Also, images may be inspected much faster than normal (RSVP paradigm). It is already known that eye fixations as well as event related potentials in the EEG reflect what is (unconsciously perceived as being) relevant, and that brain signals indicate relevant pictures in a rapidly presented stream of images up to 50 images per second. Other applications in this area include using EEG in lie detection and person identification, but both are under fierce debate. The body of research shows that this application area can be considered a niche and the field is still in a concept development phase. Successful applications can contribute to societal issues, for instance regarding the safety of main transport hubs. The niche character makes the economic viability limited and the horizon to application 5-10 years away.

Table 1. Overview of non-medical BCI applications and their ratings (- denotes low, +/- denoted moderate, + denotes high).

	Body of research	Societal relevance	Economic viability	Price sensitivityof consumers/customers	Time to market
Control of devices	+/-	-	-	-	5-10 yrs
User state monitoring	-	+	+	+/-	3-5 yrs
Evaluation	-	-	+/-	+/-	1-3 yrs
Training and Education	-	+	+	+/-	3-5 yrs
Gaming and entertainment	+/-	-	+	+	now
Cognitive improvement	-	+/-	+	+	3-5 yrs
Safety & Security	-	+/-	-	+/-	5-10 yrs

4 Technological challenges for non-medical BCIs

Developing practical non-medical applications of BCI technology requires solving several technological challenges. Here we focus on the issues that are not necessarily crucial for medical applications, like excessive movements of the user that may occur, e.g., in a gaming context. Despite the difficult use environments, users expect an interface that is as robust, stable and reliable as a mouse or keyboard.

4.1 Usability

A typical user of a non-medical BCI will want to operate the BCI without the help of a caregiver and without extensive training. Generally, the user will have high demands regarding the usability and the comfort of the system. Users will not appreciate having to wash their hair after the use of gel, as required with most current EEG sensors, or a cap that is too tight or that harms the scalp due to friction. Users must be able to mount the EEG cap and set up the equipment fast and intuitively. In order to reach optimal performance, BCI systems require a calibration session which consists of recording examples of EEG signals from the user, in order to tune the parameters for this specific user. The length of a typicalBCI calibration session is about 5-20 minutes at best, which is still too long for most non-medical applications. Indeed, as a comparison, if people had to calibrate their mouse for several minutes every time they used it, they would certainly abandon it rapidly and switch to another interface. Furthermore, the system must be safe (also with respect to hygiene when the cap is used by different users) and maintenance should be minimal. In particular, human factors research must be conducted in order to ensure that the BCI system and application are easy, intuitive and fast to learn and to use, without being too cognitively demanding. Additionally, user experience aspects must be taken into account that go beyond getting the task done and include subjective aspects such as the user's feelings, emotions, and beliefs. Also, to ensure a good acceptance of non-medical BCI applications, they should be ethically sound, in particular with respect to (but not limited to) mind privacy issues and long-term effects of BCI use (please see [9] for an extended discussion on the ethical aspects of BCIs).Although several of these issues are also relevant for medical applications, usability has not received a lot of attention yet and has not been considered as a critical issue. We expect that this will be different for non-medical applications such as gaming.

4.2 Hardware

The hardware improvements required to develop usable non-medical BCI applications are probably among the most challenging but also among the most important ones. In particular, EEG sensors would need several improvements in order to bring BCI systems outside laboratories and hospitals. First, sensors have to be dry (i.e., they should be able to record good quality EEG without the need to use gel to improve the contact) in order to be comfortable, convenient and easy to mount. Second, these sensors must offer a good signal quality even in very noisy environments and/or with moving users. Indeed, although it has been shown that BCIs can be used outside laboratories or with a moving user [10], their performance is generally not as good as under laboratory conditions. The development of better active electrodes with active shielding could prove very useful. Another issue that needs to be tackled is the optimal number and placement of electrodes and how to achieve a consistent placement of the electrodes while ensuring an easy mounting without external help. Furthermore, an ideal BCI device (sensors, amplifier and possibly computer) is wearable, light, unobtrusive, comfortable, wireless, and visually appealing. Finally, for many non-medical applications, reducing the cost of the BCI hardware to the hundreds of dollars range is a prerequisite (see also Table 1).

On a more long term perspective, it would be necessary to design and explore alternative or additional sensor technologies. NIRS could be such an additional sensor [11]. Although its low temporal resolution and inherent delay may not make it suitable for communication and control applications, it could be very useful for mental state monitoring, where short reaction times are not crucial. However, NIRS is currently still too bulky and expensive for practical applications.

4.3 Signal processing

In addition to advances at the hardware level, advances at the signal processing level are also necessary. Usable non-medical BCI applications require progress in the following four areas: (1) robustness to noise and changing signal characteristics (non-stationarity) of brain signals, (2) asynchronous and continuous operation instead of synchronous and discrete, (3) minimal calibration time, and finally we need (4) algorithms to classify signals from novel sensors and new BCI paradigms to extract mental states.

BCI performance must be independent of the user's environment, which means that the BCI signal processing algorithms must be robust to external noise, as sensors will most probably be unable to suppress all kinds of noises. Also challenging (but not unique to non-medical BCIs) is the non-stationarity of brain signals due to internal sources of variability. To this end, new unsupervised (adaptive) signal processing algorithms provide first solutions [12].

While the vast majority of current BCIs are synchronous and discrete, non-medical BCIs need to be asynchronous (self-paced) and/or continuous. Self-paced BCIs are indeed the most natural BCI to use for communication and control applications, as they enable the user to send mental commands anytime at will. For mental state monitoring applications, the BCI should be continuous. More research efforts are needed because the performance of current self-paced BCIs is still too low for practical applications.

Reducing or suppressing the BCI calibration time is essential to enable immediate use of the BCI. With current BCI systems, EEG signals from the user have to be collected for a relatively long and inconvenient calibration procedure. A few recent machine learning developments have suggested solutions to re-use EEG signals collected from previous BCI sessions (session-to-session transfer) or from different users (user-to-user transfer). These approaches aim at shortening or even suppressing the calibration session. However, they generally have lower classification performances than those obtained using a full-length calibration step, which shows the potential of and the need for further research in this area.

Finally, while a large body of research has been dedicated to the design of efficient algorithms to process signals such as motor imagery and Event Related Potentials, algorithms to process other kinds of brain or sensor signals appear to be rather scarce or even non-existent. In particular, algorithms to perform mental state monitoring are clearly lacking and fNIRS signal processing and classification algorithms have just begun to be investigated. Therefore, the challenges here are to explore and design various feature extraction and classification algorithms to decode mental states. Indeed, it is still an open question whether such kind of mental states can be reliability decoded from brain measurements such as EEG.

4.4 System integration

Non-medical BCIs require quick, easy and seamless integration with existing systems. For instance, it would be convenient to simply plug the BCI device to the PC USB port to be able to use it, as we would do with a new mouse. In other words, an ideal BCI device should be "plug 'n' play", which would require hardware (to design a physical interface with existing systems) and software developments (to write drivers and make the device comply with international standards). Moreover, for several non-medical applications, the BCI device will not be used on its own, but rather as a hybrid BCI in combination with other input devices or bio-sensors. For instance, the BCI can be used as an additional control channel in a video game that already uses a game pad, or it can complement other bio-signals such as electrocardiogram or blood pressure in an application monitoring driver's alertness. Integrating BCIs with these other modalities should also be made as simple and seamless as possible. To this end, standardization efforts at the hardware and software level prove necessary. The first standardisation efforts are made by the TOBI project (http://www.tobi-project.org) by proposing interface protocols and providing reference implementations. Community-based decision processes are supported by http://www.bcistandards.org, e.g. towards common definitions and terminology. The open-source framework PyFF (http://bbci.de/pyff) defines a uniform high-level interface for BCI applications and provides a number of PyFF-compliant applications for download.

5 Discussion and recommendations

Potentially, BCIs can become an important building block in the next generation user interfaces. As we argued in the introduction: BCIs are among us and are here to stay. A recent survey on the marketability of BCI technology was described in [7]. Results showed than in 2010 two thirds of the respondents in this survey expected BCIs for healthy users to be available on the market before 2015. More than a quarter of the respondents answered that they were already on the market by mentioning gaming applications such as the one described in section 3.5. This is consistent with our estimates, but applications outside gaming require solving several technological issues, as described in the previous section. These are not necessarily unique to applications for healthy users and progress will be beneficial to both patient and healthy BCI user groups. However, solving the technological challenges alone is not enough to realize large-scale BCI use. Important factors that should be taken into considerations are user characteristics, needs, expectations and acceptance. Why would healthy users want to use a BCI? Only for fun or out of curiosity? Healthy users may not have the inherent drive of patient users to employ a BCI. Non-medical applications require a clear picture of the target user group, the added value a BCI can bring and the minimal requirements to be met (e.g., regarding speed, accuracy and training). If these prerequisites are not met, users will easily abandon the BCI because there are better alternatives. Therefore, user groups should be involved as early as possible, and user feedback should be systematically obtained. Mass applications in, for example, gaming would certainly result in more insights in the above mentioned factors, on the device's adaptability and thus potential improvement with prolonged use, and on the features users desire.

A point of concern is that developments in non-medical BCIs are lacking coordination in the areas of communication, research efforts, standardization, and ethics. Although BCIs are a regular topic in the media, communication about its promises, ethical issues, etc. is usually limited. To reduce the risk that this becomes an obstacle in the near future, it is crucial that developers of non-medical applications sketch a clear picture of what BCIs have to offer and what not (e.g., the surplus value over current technology, the task environments that could benefit, proof of effectiveness by controlled studies) and the expected progress and potential risks. It is also advisable to refrain from using terms like 'enhancement' and 'mind reading', and even 'mind control' although this is not to say that risks and ethical issues should be ignored. On the contrary, we should actively seek for (safety) certification of equipment and promote the ethical debate on the non-medical use of brain signals. We also plead for the coordination of research efforts in the BCI field. We should especially try to line-up the research efforts for medical and non-medical applications. A shared roadmap and research agenda would be of benefit to both areas (even the latest international roadmap [2] still has separated and sometimes contradictory sections on medical and non-medical BCIs). This could be realized by involving influential, multidisciplinary national and international organizations such as IEEE and ISO. This also relates to our third issue of concern, the lack of standardization. Standards (in the area of software, hardware, and ergonomics) can ensure that systems are designed with sufficient concerns for interoperability and usability. BCI systems for non-medical applications should not be designed as 'stand-alone', but preferably as a modular system ensuring interconnectivity and enabling easy integration with existing technology. Therefore, efforts in this direction should be encouraged and supported. For the field to mature, it is also important to agree upon a golden standard to compare performance of BCI systems across paradigms, sensors, and algorithms.

Putting it all together, we come to the following ten recommendations that we think will help to advance the field of non-medical BCIs:

1. Focus on the research and development of BCIs that assess the user state, rather than on BCIs for the direct control of devices.

2. Identify the near-term 'killer applications' that could be of benefit to many users and use these applications to drive BCI research and development.

3. Realize easy integration of BCI systems with existing hardware and (gaming) software.

4. Get more hands-on experience and feedback by larger scale implementations outside controlled laboratory environments.

5. Involve users and industry in an early phase.

6. Realize clear and honest communication and promotion of BCIs and encourage the ethical debate on non-medical use of brain signals.

7. Set a shared research agenda and roadmap, integrating medical and non-medical BCIs. A related effort, aiming at creating a roadmap for BCI research is completed in 2012 as part of the Future BNCI European project [2].

8. Realize transfer of knowledge, capabilities and technologies between medical and non-medical BCI applications.

9. Involve national and international (standard) organizations.

10. Work towards standardization and possibly certification of BCI systems, including defining ethical guidelines. For instance, as part of the TOBI project (http://www.tobi-project.org), a common implementation platform is being created in order to enable the conjoint use of multiple BCI platforms. Such research efforts should be encouraged and followed.

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Biography

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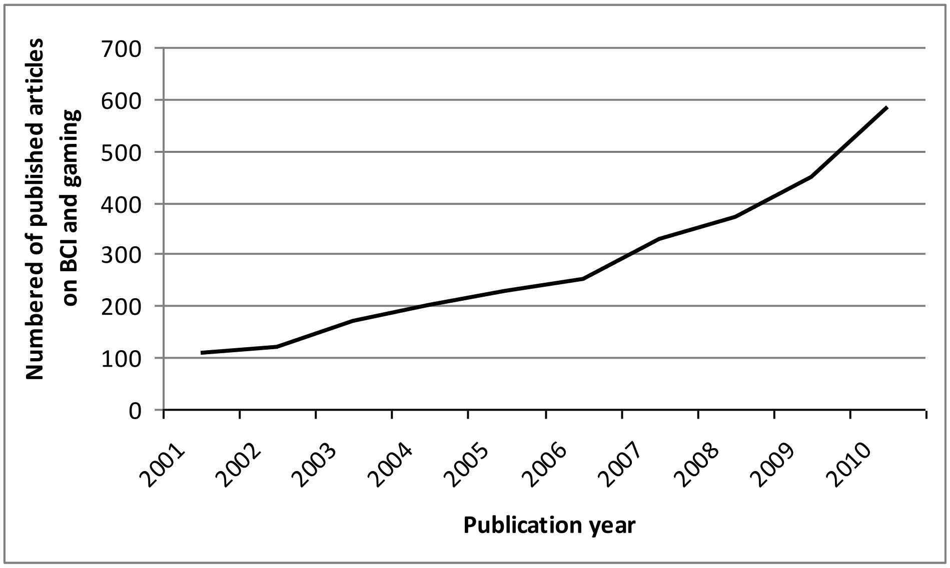

Fig. 1.The number of published papers per year on BCI and gaming. The graph shows a five-fold increase during the first decade of this millennium. (source: Google Scholar).

Fig. 2. Gaming is considered an important application area of non-medical BCIs. Brain control results in the development of new games but can also add to the fun factor of existing games.

Fig. 3. Brain signals can be used to monitor for instance driver workload or to evaluate in-vehicle systems that may interfere with the primary driving task.

Sidebar

Commercially available BCIs

Due to the recent advances and increased interest in BCI technologies, several companies are now commercializing BCI products. Such products range from high quality and expensive systems for scientists and medical applications, to cheap low-end devices for the general public. Among them, we can mention the IntendiX® (g.tec medical engineering GmbH, Austria, www.intendix.com), which is a complete BCI solution for spelling dedicated to patients at home. At the other end of the spectrum, we can mention the BCI devices provided by Neurosky (www.neurosky.com) or Emotiv (www.emotiv.com). Those companies provide cheap dry sensors technologies together with dedicated software, mostly for gaming applications. It should be mentioned, however, that due to the sensors location in those systems, they most likely also measure and use muscle activity (ElectroMyoGram – EMG) and thus might not be considered a pure BCI (see, e.g., http://spectrum.ieee.org/consumer-electronics/gaming/loser-mental-block/0). Independently from this definition, from an application point of view, using EMG together with EEG signals could prove useful and rewarding.

Left: IntendiX running on a laptop and user wearing the active electrodes. Right: dry EEG technologies by Emotiv.

More details about BCI companies can be found in [7]