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Towards BCI Cognitive Stimulation: From Bottlenecks to Opportunities

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Abstract

Emerging BCI based cognitive stimulation applications, like neurofeedback and gaming, are probably among the most growing market opportunities today. Besides, the rising aging population and its associated cognitive decline create a pressing demand for innovative technologies offering a real chance to preserve general wellbeing. Related research breakthroughs that use BCI as main technology to enhance user's performance are examined, as also the common bottlenecks that still hinder BCI end user adoption.

1 BCI Evolution

Brain-Computer Interaction (BCI) based technology is thriving and has the potential of spreading into society by addressing the needs of various user groups under different application scenarios. Wolpaw and Wolpaw (2012) identified the five principal BCI scenarios or application types that may have evolved so far, namely, *replace*, *restore*, *improve*, *supplement* and *enhance*. Communication is perhaps the most fulfilling immediate use of BCI systems for a patient, her family and caregivers when no intelligible interaction can otherwise take place (Birbaumer et al., 1999). In this case, the BCI output clearly *replaces* the natural patient's communication function lost as a result of injury or disease. Even simple interactions to make needs known, answer questions with a simple yes or no, and select among a small matrix of choices may reintegrate the isolated patient with others. Similarly, a person may wish to *replace* lost limb function using BCIs as wheelchair controllers in real (Philips et al., 2007) or virtual environments (Leeb et al., 2007), or as appliance adjusters, altering body position in an electric bed for comfort as well as to decrease the chance for developing a bed sore. Additionally, BCIs can be used to operate prosthetic or functional electrical stimulation devices in invasive (Hochberg et al., 2006) or non-invasive (Pfurtscheller et al., 2003) *restoration* of lost natural outputs, such as motor or bladder function in paralyzed humans.

Interestingly, BCIs can now be considered as neurorehabilitation tools to *improve* muscular activation and limb movements in impaired post-stroke patients in clinical settings, for example. Generally speaking, BCIs could help stimulate cortical plasticity leading to the recovery of some lost functions (Carabalona et al., 2009). Following this approach, BCI based cognitive rehabilitation may be among the most outstanding applications that could benefit a large number of patients ranging from completely locked-in patients (Kübler and Birbaumer, 2008) to patients with cognitive impairment, to increasingly *improve* their cognitive deficits. Evidence to support the use of computer based cognitive rehabilitation programs has been growing for the last decade with examples extending to memory (Tam and Man, 2004); working memory (Johansson and Tornmalm, 2012); attention (Zickefoose et al., 2013); and, visual perception (Kang et al., 2009). A more futuristic scenario might be using a BCI

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to *supplement* a natural neuromuscular output with an additional, artificial (i.e., robotic) output (Wolpaw and Wolpaw, 2012). Last but not least, another area of increasing recent research interest is in the recognition of the user's mental states (e.g., stress or attention levels, "cognitive load" or "mental fatigue") and cognitive processes (e.g., learning or awareness of errors) that will facilitate interaction and stimulate user's interest. In these cases, by preventing stress or attentional lapses, the BCI *enhances* the natural output. Basically, we can deal with neurofeedback or gaming applications to *enhance* user's performance. In line with the *enhance* scenario, and overlapping the *improve* scenario, the rest of the paper concentrates on exploring potential opportunities and research breakthroughs that may use BCI based cognitive stimulation applications to *enhance* people overall performance in clinical and non-clinical settings to maintain general wellbeing and quality of life. Prior to that, we aim at identifying common bottlenecks that prevent current BCI systems from end user adoption.

2 Solving BCI Bottlenecks & Shortcomings

The usability of current BCI devices is far from perfect. Medical BCI applications are still very limited, and many critical issues need to be addressed before they can be effectively adopted in clinical settings or in users' homes. Carabalona et al. (2009) have discussed several points that need to be considered when designing, selecting and using a BCI system for neurorehabilitation purposes. In particular, they have emphasized the importance of technology acceptance and usability, as well as, issues related to the impact on the patient's emotional and motivational states. Although some users and assistive technology experts may be quite satisfied with some BCI devices (Zickler et al., 2011), others could not imagine using most of the devices in daily life without further improvements. User-centered design is critical, and testing medical BCI applications with healthy users may be inadequate.

As a whole, medical and other non-medical emerging applications especially addressed to healthy users may encounter similar shortcomings. Main obstacles vary from the long preparation and setup times, to the ergonomics of the electrode caps, and the low speed and lack of reliability of the BCI system. The learning curve is also a major drawback. That is, the user must learn completely new skills to operate a BCI system. Therefore, there is still an important need to overcome the following identified "key factors" (Allison, 2010) for better BCI adoption:

1. *Cost* (financial, help, expertise, training, invasiveness, time, attention, fatigue)
2. *Throughput* (accuracy, speed, latency, effective throughput)
3. *Utility* (support, flexibility, reliability, illiteracy)
4. *Integration* (functional, distraction quotient, hybrid/combined BCIs, usability)
5. *Appearance* (cosmetics, style, media, advertising)

Following a user-centered approach and increasing the engagement with the appropriate end users while designing, selecting and using a BCI system will offer the opportunity to increase technology acceptance and usability. The possibility of using dry electrodes for EEG acquisition, and the monitoring of psychological effects during BCI tasks may give rise to a broader range of cognitive rehabilitation and stimulation programs (Carabalona et al., 2009). According to such view, we claim that the current problems would be overcome when new technologies provide non-conventional sensors for less obtrusive brain signal recording, and affective interfaces able to adapt the BCI according to emotional status changes in the patient.

3 Potential Opportunities & Research Breakthroughs

Cognitive decline is one of the most pervasive consequences of aging, and it can be associated with loss of autonomy, functional impairment and deterioration in quality of life in modern societies

(Lee et al., 2013). The increasing elderly population is a potential new target for BCI cognitive stimulation applications, such as neurofeedback and gaming, not only for enhancing motor and cognitive rehabilitation therapies in clinical settings, but especially as cognitive training programs in patient's homes. Development of BCI devices with such cognitive stimulation capabilities will definitely benefit almost all user groups, including many groups of patients or disabled users, and even healthy people in training programs (brain-gym like applications). In cognitive rehabilitation, the use of event-related potentials is traditionally limited to an assessment of injuries incurred or disorder severity. However, a tentative BCI based neurofeedback therapy was designed to treat attention-deficit patients with brain injury (Neshige et al., 1995): five patients with chronic mental disturbances received a BCI based neurofeedback therapy for a four week period, and all showed remarkable improvement. Nevertheless, this pioneering work has not yet been followed by a larger clinical study. New research breakthroughs in BCI cognitive stimulation could profit from the inclusion of "cognitive neuroprosthetics" in invasive BCI research programs, in which the cognitive state of the subject, rather than signals strictly related to motor execution or sensation is recorded (Andersen et al., 2010). This knowledge could be used to capture user's intentions and assess emotional states to keep motivation alive, enhance cognitive and motor recovery more efficiently, and increase overall quality of life in the long term. That is, by stimulating patients to acquire new skills – activating specific cortical areas – BCIs might be used for innovative and more effective occupational therapies with new promising clinical applications. Likewise, BCIs could lead to accurate cognitive trainings and learning programs for the entire population.

Lee et al. (2013) examine the feasibility of using a BCI based system with a new game in improving memory and attention in a pilot sample of healthy elderly. The study investigated the safety, usability and acceptability of the BCI system to elderly, and obtained an efficacy estimate to warrant a phase III trial. In the EU project BackHome (http://www.backhome-fp7.eu/), a framework that provides a backdrop to cognitive stimulation tasks performed using a home based BCI system is currently under study. Two serious games – one on memory, and, another one on attention and concentration – were defined and implemented. This is part of a broader telemonitoring home support system (Vargiu et al., 2013) that allows clinicians to prescribe tasks and scales, and monitor its results on quality of life through the use of a remote therapist station. Further, socialization, education, entertainment and even support groups are feasible using BCI via internet email, chats and games (Karim et al., 2006). Thus, in order to ensure equal access to Information and Communication Technologies (ICTs) for all population groups and assure that everyone can benefit from ICT developments, not only people with disabilities, but specially the elderly should not be left behind. New occupational programs aiming at cognitive stimulation tasks to improve ICT skills will turn to be new potential opportunities for BCI based neurofeedback training and innovative serious games.

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