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Update article

Technology transfer of brain-computer interfaces as assistive technology: Barriers and opportunities

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ABSTRACT

This paper provides an analysis of perspectives from different stakeholders on the state-of-the-art of BCI. Three barriers for technology transfer of BCIs as access technologies are identified. First, BCIs are developed with a narrow focus on creating a reliable technology, while a broader focus on creating a usable technology is needed. Second, the potential target group, which could benefit from BCIs as access technologies is expected to be very small. Development costs are therefore high, while reimbursements are expected to be low, which challenges the commercial viability. Third, potential target users should be much more included in the design process of BCIs to ensure that the end-products meet technical, ethical, legal and social requirements. These three issues need to be urgently addressed so that target users may benefit from this promising technology.

1. Introduction

Since decades, one of the main goals of the field of Brain-Computer Interfacing is to provide an access technology for people with severe physical disabilities so that they can operate, for example Augmentative and Alternative Communication (ACC) software, environmental control devices or wheelchairs. Access technologies are technologies that provide input to other devices. Examples are keyboards and mouse for able-bodied people or single switches that can be operated with residual finger or lip movement, sip-and-puff devices or eye trackers for people with disabilities. Brain-Computer Interfaces aim to provide an alternative access technology for people with severe physical disabilities: commands can be given with voluntary brain activity without the need of residual muscle movement. Traditionally, BCIs are developed for people with the Locked-in syndrome (LIS) or other severe motor disabilities. The classical locked-in state is characterized by total immobility except for vertical eye movements or blinking [1]. Incomplete (or residual) LIS permits remnants of voluntary motion and total (or complete) LIS consists of complete immobility including all eye movements combined with preserved consciousness [1,2].

In the last twenty years, the feasibility of BCI use by people with disabilities and even the Locked-in syndrome has been demonstrated in scientific studies (e.g. [3–12]). Such results are thrilling and promising and often give rise to much media attention. However, despite this apparent success, to our knowledge only 3 companies offer BCIs as access technologies for people with disabilities (g.Tec, Brain Actuated Technologies and Liquidweb) and we estimate (based on personal communication) that these companies have only around 30–50 customers worldwide, many of whom are not disabled but are researchers. In contrast, BCIs for well-being or entertainment have emerged over a couple of years and already have more than a million customers [13]. Thus, the technology transfer of BCIs as access technology from the lab to the users' home seems to be lacking behind.

This paper aims to investigate barriers for technology transfer of BCIs as access technologies. The analysis is based on literature and previous studies which assessed the opinions of different stakeholders [14,15]. First, we discuss relevant literature from the field of assistive technology (AT) on technology transfer and technology abandonment. This summary gives a general idea why technologies may not enter the market or may not be useful to people, even when they are feasible to use by the target users. Second, we summarize how people from the field of rehabilitation, speech and occupational therapy assess the current BCI field and what advise they would give to improve BCIs. Finally, we aim to identify the major barriers that slow down – if not prevent – technology transfer of BCIs as access technology. Most importantly, we will argue that the difficulties related to BCI tech transfer offer an opportunity: they form a case that exemplifies and calls attention for more responsible innovation in the field of assistive technology.

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2. Perspectives from the field of assistive technology

People working in the field of assistive technology know all too well that sometimes there are assistive technologies which may provide the intended function for users, but are nevertheless rarely or never used by the target group. Several reasons can explain this. Some technologies may hardly contribute to quality of life, so the incentive of using the technology may be too low. This occurs even more so if the technology is cumbersome to use. If operation of a technology requires great effort, users will almost automatically search and choose an alternative. Also, the aesthetics of a technology can play an important role in technology acceptance. If a technology does not fit in the self-image of user, they might refrain from using it. Other people might be afraid of technology or may fear that by accepting technology, human support will be replaced with technology altogether. Other reasons for technology abandonment may be a lack of after-sales services or technology-support services from the companies delivering the assistive technology.

Such technology abandonment – the non-use of available technology at the home of a user – is a common phenomenon. Phillips and Zhao found technology abandonment of 29.3% of all devices used by a group of 227 individuals with various disabilities [16]. Similarly, Scherer reports that about one third of all devices are abandoned. Furthermore, she states, "we have no information about the numbers of people who continue to use devices they are unhappy or uncomfortable with because they cannot abandon them without facing more severe consequences" [17]. Not only should these statistics raise alarm because target users are left unsatisfied, but also because health care costs could be significantly reduced by efficient matching of user with technology. Responsibility for matching users with appropriate technologies lies partly with the companies, which consult and deliver AT. However, designers and developers of new assistive technologies should generally be encouraged to use user-centered approaches to increase the usability of technologies, thereby ensuring technology acceptance by users.

Usability refers to the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use [18]. Effectiveness is the accuracy and completeness with which specified users can achieve specified goals in particular environments. Efficiency is the resources expended in relation to the accuracy and completeness of goals achieved. So in the context of BCI, not only speed and accuracy would be evaluated, but also the user's effort to reach that performance. Satisfaction is the comfort and acceptability of the work system to its users and other people affected by its use. Performance evaluation should therefore also consider the context in which the system operates. This context would include personal factors, relational factors, as well as environmental factors [19,20].

So how well does the field of Brain-Computer Interfacing design for usable and satisfactory end-products? Moghimi et al. found that most current BCI prototypes are evaluated with respect to speed and accuracy rather than for usability [21]. Recently, others have also argued that BCI engineers should design for usability rather than only reliability, and that methods from the fields of human computer interaction and ergonomics should be integrated in BCI research [18,22].

But even when BCIs are more usable, this may not guarantee that they provide value for many people. Lane provides a conceptual model of technology transfer in the field of assistive technology in which 3 critical events demarcate the progress: idea event, prototype event and product event. At every event, Lane cautions that "the enthusiasm surrounding the initial idea, prototype or product" should not "overshadow the need for healthy skepticism about its uniqueness" [23]. Similarly, the fact that BCIs are feasible and intriguing should not prevent us from scrutinizing the real need and value. BCIs could provide assistance to people with the Locked-in syndrome, but not necessarily should [14]. Alternatives may be better, cheaper and more usable. Söderholm et al. found that all 17 residual LIS patients in their study were able to use AAC through the use of, for example, mechanical and pneumatic switches, infrared head mouse, head pointers, and mouth sticks [4]. Snoeys et al. investigated the health care situation, communication and quality of life in 8 LIS patients in Belgium and found that 6 out of 8 patients would rather use the (non-technological) alphabet system to communicate daily messages than a technological communication aid [5]. Thus, while people with a total or classic LIS need a BCI to establish independent communication [6], residual LIS patients can generally also use alternative AAC methods. BCIs may only be needed by people with a complete or classic Locked-in syndrome.

From a business perspective, this means that the field of BCI can only be targeted at a few users. They constitute a very small niche market, which is not likely to attract attention from industry. The costs of development of BCI technology is high, and is at the moment primarily subsidized – in Europe – by the European Commission (€ 11 million in FP6 and € 34 million in FP7). This is because the expected reimbursement for making substantial commercial commitment is low for industrial players. There is little commercial viability to develop technologies that are by default tailored to a niche group, and not ubiquitous to a wide population of users. Add competition among developers of BCI solutions targeting the small user group, and the likelihood of reimbursement for their investment more than disappears for a niche market. The small size of the target group is a barrier, but does not necessarily need to be a showstopper. There are many examples of technologies designed for people with disabilities which found an application in the marked for able-bodied people [24,25]. A historical example is the sonograph, which was invented by Thomas Edison to allow blind people access to recorded book readings. More modern examples are the eye gaze and voice input control, which were designed to allow people with motor disabilities to operate devices. Now, these systems are built into computers and smart phones of abled-bodied people.

To conclude, from the field of rehabilitation, we learn that novel assistive technology should first be designed for usability rather than only reliability. The field of BCI has improved to meet this goal, but more effort is needed. Second, from a business perspective the market size for BCIs as access technologies is very small and industry might not feel drawn to pull the technology onto the market. BCI developers need to think early about creative commercialisation strategies.

3. Perspectives from rehabilitation professionals

BCIs are typically developed by people who are not necessarily familiar with the daily life of people with disabilities. A recent survey among attendants of the largest BCI conference worldwide showed that most respondents identified themselves as computer scientists, neuroscientists, electrical engineers, cognitive scientists or artificial intelligence researchers [15]. All respondents ($n = 145$) indicated in this survey that they believed that BCIs as access technologies will be available on the market and all were very positive about its prospects.

Nijboer et al. investigated if people from the field of rehabilitation – those who work on a daily basis with people with disabilities – were equally optimistic [14]. A one-day workshop and focus group interview was held. Rehabilitation professionals (speech and occupational therapists, assistive