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Design requirements and potential target users for brain-computer interfaces – recommendations from rehabilitation professionals

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It is an implicit assumption in the field of brain-computer interfacing (BCI) that BCIs can be satisfactorily used to access augmentative and alternative communication (AAC) methods by people with severe physical disabilities. A one-day workshop and focus group interview was held to investigate this assumption. Rehabilitation professionals (N = 28) were asked to critically assess current BCI technology, recommend design requirements and identify target users. The individual answers were analyzed using the theoretical framework of grounded theory. None of the participants expressed a perception of added value of current BCIs over existing alternatives. A major criticism (and requirement) was that the usability of BCI systems should significantly improve. Target users are only those who can hardly or not at all use alternative access technologies. However, such persons often have concurrent physical, sensory, and cognitive problems, which could complicate BCI use. If successful BCI use continues to require a user to sit motionlessly and have intact cognition, then – as previously implicitly assumed – people in the locked-in state (resulting from late-stage amyotrophic lateral sclerosis, multiple sclerosis, spinal muscular atrophy type II or classic or total locked-in syndrome) and people with high spinal cord injury (C1/C2) could be target users.

Keywords: assistive technology; access technology; brain-computer interfaces; focus group interviews; system requirements; locked-in syndrome; amyotrophic lateral sclerosis; spinal cord injury

1. Introduction

For decades one major aim of brain-computer interface (BCI) research has been to provide an access technology to people with severe physical disabilities so that they can successfully communicate messages or operate devices in their daily life.[1] In fact, many BCI papers have almost literally started with this sentence, yet, clear as the aim may sound in theory, we argue that in practice it is still rather unclear. When the technology should transfer from a research stage to a product development stage, some important questions need to be addressed. For example, exactly which people constitute the target group? What do they consider *successful* use of the technology? Which alternative technologies are available for them?

At first thought it seems obvious. BCIs could be useful to people with severe physical disabilities. Tai and colleagues [1] systematically and extensively reviewed emerging access technologies for people with severe physical disabilities and grouped them as follows: mechanical switches, infrared sensing, electromyography, oculography (video-oculography and electro-oculography), computer vision, electroencephalography (EEG), electrocorticography (ECoG), intracortical recordings, and electrodermal activity. The authors suggest that access technologies based on EEG, ECoG, and intracranial recording (the field of brain-computer interfacing) are mainly relevant for persons without extant physical movement. Likewise, within the BCI field the most often suggested user group consists of people in a locked-in state (LIS).

The classic locked-in state is characterized by total immobility except for vertical eye movements or blinking.[2] 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.[2,3] Which access solutions (technological or non-technological) to operate augmentative and alternative communication (AAC) methods do people with LIS currently use? Söderholm and colleagues 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 mouses, head pointers, and mouth sticks.[4] Snoeys and colleagues investigated the health care situation, communication, and quality of life in eight LIS patients in Belgium and found that six out of eight patients

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preferred the (non-technological) alphabet system to communicate and two used an infrared system.[5] Thus, while people with a total LIS definitely need a BCI to establish independent communication,[6] residual LIS patients can generally also use alternative AAC methods.

If the prevalence of classic and total LIS is low, this could explain why there is relatively little pull for BCI technology from the market. It is difficult to find statistics on the locked-in syndrome. Kohnen and colleagues recently found a prevalence of classic LIS of 0.7/10,000 in somatic nursing home beds in all Dutch long-term care organizations.[7] They found only two people in the Netherlands with classic LIS and six people with residual LIS. However, more people with LIS may live at home and remain 'unnoticed'. Nevertheless, it seems that the classic and total locked-in syndrome is rare, at least in the Netherlands.

Maybe to expand the number of target user groups, people with various other disorders and neurological conditions have been asked to participate in BCI studies. Moghimi and colleagues [8] reviewed 39 articles which evaluated the BCI performance of participants with disabilities. The majority (59%) of the participants who were evaluated had amyotrophic lateral sclerosis (ALS). Other conditions reported in the studies were spinal cord injury, cerebral palsy, cerebral paresis, muscular dystrophy, stroke, chronic Guillain–Barré syndrome, multiple sclerosis, spinal muscular atrophy, and post-polio and primary lateral sclerosis. However, the main focus of the studies has been on people with ALS. Interestingly, none of the articles explicitly specified why, although Huggins and colleagues argue that in late-stage ALS commercial access technologies (such as mechanical and eye gaze-operated switches) can become inaccessible.[9] Nevertheless, a clear definition of target users for BCI as an access solution does not exist.

As a result it is also unclear what target users would consider successful BCI use. Moghimi and colleagues [8] found that most current BCI prototypes are evaluated with respect to speed and accuracy. Recently, others have also argued to design for usability, using methods from the fields of human computer interaction and ergonomics.[10–17] 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.[10,19]

Making BCIs usable is of utmost importance to prevent technology abandonment. Many assistive technologies exist which may provide function for users, but are nevertheless rarely or never used by the target group, because they hardly contribute to quality of life, are cumbersome to use or better alternatives are available. Phillips and Zhao [20] found technology abandonment of 29.3% of all devices used by a group of 227 individuals with various disabilities. 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'.[21] Thus, design and development of assistive technology require a user-centered approach which meets all system requirements based on technical, physical, psychological, and environmental factors and constraints to minimize abandonment and increase enjoyment.

A few studies investigated what people with disabilities think of the usability of current brain-computer interfaces and what factors are mediators and barriers to BCI use.[9,10,22] Although we encourage involving users and these studies have yielded profound insight, we would also like to point out several problematic issues. First, users may tend to report on the function they would want to have rather than to assess the usability of the access technology itself.[23,24] A user's desire to control a television or be on social media does not – strictly speaking – justify the development of a BCI. It does justify the development of accessible social media, but says little about the requirements of the access technology that should make this possible. Thus, users may find it difficult to conceptually differentiate and comment on the different components of assistive technology: access technology, user interface, and function. A second problem when involving users is that BCI technology is novel and seems intriguing to people. Almost unanimously, BCI participants are positive about BCI technology. They find it 'impressive', 'thrilling', and 'hopeful'[10] and their motivation for entering a BCI study is 'curiosity' and 'fascination'.[22] More than 80% of 61 respondents with ALS stated they would accept having to wear an electrode cap to use a BCI.[9] However, 98% of the respondents in the study could still operate a keyboard and use a normal PC, so they may not have been aware of alternative, less cumbersome access technologies they could use in a later stage of the disease. Collinger and colleagues [25] presented 57 veterans with spinal cord injury (SCI) a half-page description of BCI technology and found that more than 80% indicated they would use a BCI to assist with activities of daily living (ADL) if it did not inconvenience other aspects of their lives. However, most of the people with SCI in the study could use hand-operated mechanical access technology. We speculate that, had these people been offered a chance to compare their own mechanical access technology with a BCI, then their appraisal might have been different. Thus, we suggest that unless these users with disabilities are also made aware of the limitations of the proposed BCI system and existing alternative solutions, the projected need for BCI technology is probably too optimistic. Professionals from the field of rehabilitation (e.g. rehabilitation physicians, occupational and speech therapists, assistive technology consultants) are generally well aware of existing access technologies and the daily lives of users, and, through experience, often know what works, what does not work, and what gets abandoned. We argue that they could give a critical appraisal of current BCIs and make an inventory of requirements for BCIs.

To conclude, it seems that the field of brain-computer interfaces has a solution (BCI as an access technology) for which there is not (yet) an explicit problem. To complement the studies involving people with disabilities, the aim of the present study was (1) to use the expertise of rehabilitation professionals to appraise BCI technology, (2) to explore potential user groups, and (3) identify common user characteristics which may hinder or facilitate BCI use. Thus, we organized a one-day workshop consisting of three steps. First, we informed the participants about the state-of-the-art of BCI through a mini-lecture. Then, we demonstrated two types of BCI and various assistive technologies to trigger thoughts and feelings about the different technologies. Finally, we held focus group interviews to obtain recommendations.

2. Methods

2.1. Invitation to the workshop

Announcement and invitations to the workshop were sent out by post to over 7000 Dutch professionals in the network of the company QuoVadis. QuoVadis is a Dutch company which matches the needs and capabilities of clients with impairments to technology and provides services through the whole process of assessment, consultancy, application, and distribution. The workshop was free of charge to maintain a low threshold to participate and was organized at the site of the company QuoVadis in the city of Baarn, which is a central location in the Netherlands, to ensure equal access to all participants.

2.2. Workshop participants

A total of 28 people (10 males, 18 females) attended the workshop, which is considered a normal turn-out for a workshop in the practice of QuoVadis. Participants were all professionals from rehabilitation centers, engineering, the health industry, and the medical device industry (22 institutions in total). They formed a heterogeneous group of stakeholders and included five speech therapists, nine occupational therapists, four adaptation consultants, three directors (CEOs) of biomedical or assistive technology companies, two psychiatric social workers, one head of rehabilitation engineering, one biomedical engineer, one information and communication technology specialist, one BCI researcher, and one student.

Eighteen out of 28 participants opted to complete an evaluation survey at the end of the workshop. This survey informed us that 13 of those 18 participants did not know what brain-computer interfaces were prior to the workshop, which confirmed the anticipated necessity to start the workshop with a mini-lecture about BCIs.

2.3. Workshop format

2.3.1. Mini-lecture on brain-computer interfacing

In a plenary mini-lecture, which lasted around 30 min, first the technology of BCI was explained to the participants in a PowerPoint presentation. The mini-lecture was needed to make participants familiar with terminology and to leverage their knowledge about BCI to have a useful discussion about it. BCIs were defined according to a widely accepted definition from Wolpaw and colleagues [26]: ‘A brain-computer interface is a communication system that does not depend on the brain’s normal output pathways of peripheral nerves and muscles.’ Participants were shown the first figure from [27] and different parts of a BCI (e.g. signal acquisition, signal processing, output device) were explained.

Second, to explain the challenge of BCIs to measure and classify intentional or intentionally induced signals in otherwise noisy brain signals, we then used the following analogy: ‘Imagine that you are standing outside a concert hall with a microphone which captures the faint music coming from within the building. Imagine that one musician is trying to signal you intentionally, but you do not know which musician, which instrument he plays, where he sits and whether he uses pitch, volume or melody to signal you.’

We then proceeded to explain that different neuroimaging techniques (e.g. gelled vs. saline EEG, ECoG, fNIRS, fMRI, microelectrode arrays) are considered for BCIs and that researchers are trying to find an optimal solution for reliable and comfortable use in daily life. We also explained that it is known that different experimental paradigms (e.g. oddball paradigm, movement imagery) elicit discernible features in brain signals (e.g. P300, event-related desynchronization and synchronization of the mu and beta rhythms) and that such

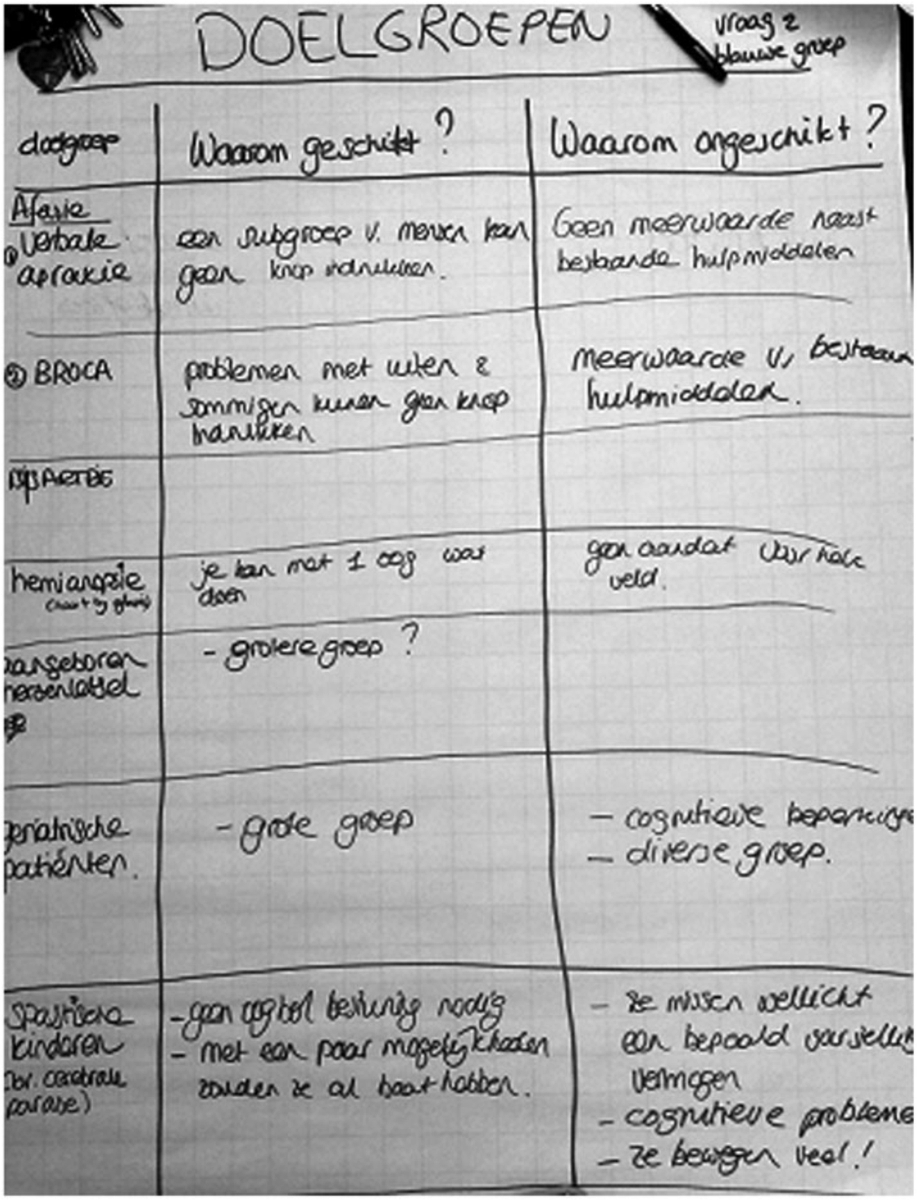

Figure 1. Example of answer sheet. In the left column, the group states potential user groups; in the middle column, they say why this group would be suited for BCI use, and in the right column why this group would not be suited for BCI use.

paradigms are therefore often used in a brain-computer interface (e.g. P300 speller, two-dimensional control of a cursor). No appraisal was given about the performance of different types of BCI or imaging techniques to prevent biasing participants.

Finally, we explained how most BCIs are developed with the aim to integrate them in AAC or environmental control devices or prostheses. To demonstrate the broader scope of BCI research and to trigger participants' awareness and imagination about different imaging techniques and applications beside the demos shown later, we showed a video of Matt Nagle, who was implanted with a 96-microelectrode array in primary motor cortex which provided him with a 'neural cursor' to handle email and operated devices such as a television.[28]

2.3.2. Demonstration of brain-computer interfaces and assistive technology

After the mini-lecture participants were divided into three groups and rotated through three demonstrations.

We assumed the demonstrations would elicit more emotions, feelings, and thoughts about BCI technology.

The first demo was a BCI-controlled game: a user could pick little monsters from a virtual assembly line by modulating occipital alpha activity. Brain activity was recorded with a commercially available EEG recorder (Emotiv EPOC). This demo showed that the industry is trying to make wearable, user-friendly, and cheap headsets. The second demo was a BCI-controlled communication device where by imagining hand movements to modulate mu- and beta-band activity over the motor cortex users could select options on screen to spell words and control devices. This demonstration used an existing, commercially available, assistive technology and home automation software – (specifically the Grid2 system made by Sensory Software UK[2]) and showed how brain-computer interfaces could be integrated as an access technology with existing software and assistive devices. It also showed participants how EEG is traditionally recorded: a cap with many electrodes is placed on someone's head and all electrodes are filled with electrode gel to ensure a good contact between electrode and scalp. Finally, participants were presented a demo of environmental control through assistive technology. The company QuoVadis demonstrated several devices and software programs that can be controlled with various kinds of access technologies such as eye gaze control and sip-and-puff technology.

2.3.3. *Focus group interview*

The third and final step of this study consisted of focus group interviews with the rehabilitation professionals. Participants were split up into four groups to manage group sizes.

The interviews were equally structured and timed in each focus group in a predefined and rehearsed protocol and had a duration of 60–75 min. The four interviews were led – in parallel but in different rooms – by the first author, the fourth author or one of two staff members of Quovadis. The interviews were not recorded or transcribed verbatim, but four additional assigned staff members noted individual answers of the participants so the interview leader could focus completely on the interview and clarifying answers. The interview leader gathered answers on which the group reached consensus, on large paper sheets (see Figure 1). The interview included the following questions:

(1) We would like to know what your first impressions are of the things you have seen and heard this morning about brain-computer interface technologies.
(2) We would like to ask you which user groups could benefit from BCI technology. What speaks for this user group and what speaks against it?
(3) You just mentioned different user groups. Now could you tell us what we, as product developers, should know about these users so that we can make a good product? What are the characteristics of these persons?
(4) If you could name one, which would be the ideal target group?
(5) What kind of BCI system should we develop?

2.4. *Data analysis*

The individual answers collected by the note-taker and the sheets with the group answers were analyzed for patterns and themes using the theoretical framework of grounded theory.[29] A coding scheme was developed based on the focus group questions (e.g. user groups, user characteristics, ideal BCI characteristics) and on themes that emerged during the focus groups (e.g. BCI hardware criteria, BCI interaction and use criteria). These themes will also be presented in the results section. Finally, for the sake of the understanding of the reader, results from the interviews will be simultaneously discussed and put in the context of the literature. Participants' opinions are presented between quotes and in italics. Literature findings will be presented with citations.

3. Results

3.1. *First impressions of the BCI technology*

Although most participants were enthusiastic about the workshop (*'It is very positive that you include stakeholders'*; *'Fun and educational day. Can we do this again in 3 years?'*) and the idea of BCI technology (*'inspiring'*; *'innovative'*), only 8 out of 28 participants gave an explicit positive appraisal of the current advancement of BCI technology, saying for example *'I was not disappointed by the limitations of the system. I see opportunities for practice'*. Another participant remarked: *'BCIs are surprisingly near. BCI was already attached to existing software this morning'*. However, she went on to say *'so it's positive, but not functional yet'*.

Compatible with the last comment, an additional 11 participants remarked that their first impression was that *'BCI is still in its infancy'* and that *'it is currently too crude'* and that *'more refinement is needed'*. One participant stated: *'BCI technology is disappointing. It will take years before it is applicable'*. None of the participants spontaneously expressed a perception of added value of brain-computer interfaces over existing access technologies.

Reasons for this appraisal were manifold. Whereas only one participant explicitly noted that the reliability of BCI as an access technology seemed low and that control of assistive technology would therefore be error-prone, more participants (n = 3) were worried that *'it [BCI use] needs high concentration and cognition'* and that '*this is not always present in users'*. Even more participants (n = 5) recommended that BCI developers should *'consider reality'* of users and *'recognize practical problems'*. One participant encouraged developers to put a BCI system in the market *'to get experience with it in reality'*. Four participants worried how sensors and wearable recording systems might *'interfere with ventilation'* and *'cannot be on the back of the head because users are likely to be in bed or in a wheelchair'*. Five people did not see the added value of the presented BCI technologies over existing alternatives *'I do not know what the added value over what we have now is'* said one participant. Others remarked that *'EOG measurement could be implemented right now!'* and wondered if *'BCI will be the next new thing after pupil control [eye tracking]'*. Although we did not provide information about potential prices of future BCI technologies, two participants had the impression that the BCI solution would be *'too expensive'* compared to existing solutions. Interestingly, two participants remarked that BCIs as access technologies are already in use in the Netherlands: *'Brainfingers is already used!'* and *'Brainfingers is already applicable.'*[3] Four Dutch individuals with severe disabilities use Brainfingers for access to their assistive technologies in daily life. See for example the story of Onur Keçeci.[30] Although some BCI scientists argue that this system is *'not a real BCI system'*, because *'it does not or not only measures brain activity'* (personal communication and [31]), the fact remains that the rehabilitation professionals in our study perceive this as a BCI and that future BCI technologies will have to compete with systems such as Brainfingers.

To conclude, participants did not see an added value of BCI at present, mainly because alternative access technologies exist and state-of-the-art BCI design does not sufficiently consider environmental and user issues. In the following section we will summarize the requirements which professionals recommend to fulfill when developing BCIs and assistive technologies for users with disabilities.

3.2. BCI system requirements

We asked participants 'What kind of BCI system would you like to see developed?' The 28 professional gave 47 different answers in total. Three themes emerged from the answers. First, professionals defined requirements of the hardware of BCI technology. Second, they defined requirements for the interaction with and use of BCI technology. Third, ethical, legal, and social requirements were mentioned.

3.2.1. BCI hardware requirements

BCI hardware consists of sensors and usually also of a physical interface. Participants remarked that ideally the physical interface of an access technology should be invisible or completely integrated with the interface of the assistive technology under operation. When full integration is not possible, then the following requirements should be met for the additional BCI hardware components:

(1) *'[BCI screen] should not be placed in front of the user'* otherwise it blocks the user's view which consequently may exclude the user in a social setting or hinder during wheelchair navigation, thus *'position it at the side'*.
(2) *'Make it [BCI screen] small and it should be like a PDA: present but not visible'*. Users may already have bulky equipment under (e.g. wheelchair) and around (e.g. robot arm) them. BCIs should not add to the bulkiness.
(3) *'Make it [BCI system] portable'* so you can carry it with you and use it in different environments (e.g. home, school, bus). Contrary to general belief, people with severe disabilities, even locked-in patients, do leave their houses and will need to rely on their access technology in all environments.
(4) *'Make it [BCI system] robust and sustainable'*. The lack of maintenance and reimbursement for broken (parts of) assistive technology is a general issue of nuisance to users with disabilities and often leads to technology abandonment.[21]

With regard to the sensors, participants defined the following requirements for an ideal system:

(5) *'sensors should be invisible'* for esthetic reasons.
(6) *'BCI [sensors] should be wearable day and night for control and alarm purposes'*. An ideal access technology is readily available and does not need to be placed in position first by caregivers. In the case of an emergency, users need to use access technologies to alert their caregivers.

Therefore, one participant suggested that '*electrodes should be implanted or have a single electrode so they are invisible'*. However, if these ideal sensor requirements cannot be met then at least:

(7) *'sensor setup should be automatic'* and not constitute (yet another) complex task for caregivers.
(8) *'sensors setup should maximally take 2 min'*.

(9) *'sensors should not be placed on the back of the head'* because users rest their head against the wheelchair or on a pillow.
(10) *'sensors should be wireless'* so they do not interfere with caregiving activities or hinder mobility.
(11) *'sensors should not interfere with ventilation [for respiratory support]'*.

To conclude, according to the requirements of the professionals BCI technology should be robust, portable, minimalistic, easy and quick to set up, readily available and should not interfere with other technologies around or on the user.

3.2.2. Interaction and use requirements

Besides hardware requirements, participants also provided requirements for the interaction between the user, the caregivers and the BCI technology to ensure usability. Requirements were categorized along the three dimensions of usability.

First, BCIs should be effective in that they get the job done. Effectiveness closely relates to user experience. For example, one participant remarked that *'it should be a system that makes you feel safe. The feeling of safety is a result of the reliability of the system'*. In other words, BCI users need to be able to trust that their BCI will work over time and in different environments. Effective use of BCI technology also includes easy integration and exchange with existing assistive technologies. One participant said: *'make it [BCI access technology] broadly employable'* and another *'integrate it into existing normal systems'*. Although participants mainly stressed that compliance with standards has the advantage of access to many applications, from human-computer interaction we also know that compliance to standards promotes learnability and memorability, and provides a certain level of intuitiveness because users have seen it before. Thus:

(12) BCIs should be reliable.
(13) BCIs should adopt standards from assistive technology software.

Second, BCIs should be efficient in that the benefits of BCI use are worth the resources spend to use a BCI. Participants provided several comments with respect to efficiency. More specifically, comments such as '*a thought [..] should automatically result in the user getting coffee without motor imagery'* implied the requirement that:

(14) BCI control should be intuitive.

Although intuitive control may be a trivial requirement for any user interface, participants pointed out a particular need for intuitive use in assistive technology. BCIs should *'circumvent language'* and not place a *'high demand'* or *'fatigue'* users. Many 'typical' users may have concurrent cognitive impairment and may not easily understand instructions or complex paradigms or be able to maintain attention. In addition, many participants remarked that users will often have concurrent sensory impairments and BCIs should *'not necessarily use visual feedback on a screen'*. Thus, requirements to increase efficiency by reducing resources needed from the user include:

(15) BCIs should work despite several cognitive and physical user constraints.
(16) BCIs should be multimodal (availability of visual, auditory, and tactile interaction).

Lastly, BCI use and its outcome should give satisfaction. Participants urged BCI developers to *'please make the system user friendly'* and added that it is important that *'caregivers and family members can use it too'* which is compatible with findings from [10]. Furthermore, a participant noted that *'the system should detect awake and sleep states so it switches on automatically when needed'*. User-aware systems can create a more pleasant user experience.

(17) BCIs should be user-friendly and manageable for users and their caregivers, family, and friends.
(18) BCIs should be user-aware.

In addition, we would like to point out that the hardware requirements will also influence effectiveness, efficiency and satisfaction. If electrode setup takes longer than 2 min, users may opt to not use BCI technology and use an alphabet system with a caregiver as an interlocutor, [32] because it takes less effort. If electrodes are placed on the back of the head, and the user experiences discomfort, then he might abandon the BCI.

3.2.3. Ethical, legal, and social requirements

Developing a technology which is effective, efficient, and enjoyable is still not a guarantee that the technology will be used by individuals in society. Values and norms in society as well as laws and policies also influence the use and usability of BCI and other assistive technology. Although we did not speculate on future costs of BCI technology, several participants concluded that *'It [BCIs] is expensive'*. Participants noted that BCI developers should *'make it affordable or ensure that the user gets reimbursed through health insurance'*. Thus,

(19) BCIs should be cost-effective.

Similarly, participants also warned that *'replacement will probably not get reimbursed by health insurances'* and that thus *'systems should be sustainable'* (see hardware requirements). Expensive BCI technology or maintenance costs also give rise to the ethical issues of increased risk of inequity in distribution of BCI technology. Such knowledge also brings forth an important requirement:

(20) BCIs should be developed in commercial and legal frameworks to ensure transfer to the market and fairness of distribution.

Participants also expressed concerns over BCI acceptance by society. *'Please make sure that it is socially accepted. It should not be stigmatizing to use a BCI'.* Indeed, many users already struggle with how other individuals in society view their disability or the assistive technologies and gadgets they are equipped with. Scherer [21] comments that disability is not so much the problem of an impaired body, but more the problem of an impaired society which cannot cater for access for all its citizens. In any case, BCI developers should be sensitive to user and societal values and either lobby for acceptance or use existing trends. For example, we speculate that the entrance of Google Glass on the market may be beneficial for the acceptance of wearable EEG headsets. The goal may not be to prevent further damage to the users' reputation, but rather to enhance their reputation.

(21) BCIs should be designed to fit the society, culture, and fashion in which they are used.

3.3. Potential user groups and their characteristics

Participants were asked to brainstorm about potential user groups for BCIs and provide arguments for and against targeting these user groups. Participants deliberated on a total of 13 potential user groups; however, some groups were thought of with other types of BCI applications in mind than BCIs as an access technology. It was remarked that BCIs could help, for example, extremely aggressive people in psychiatric institutions or people with an IQ below 70 (learning disability) to emotionally express themselves. It was also suggested that people who practice meditation could use a BCI to help monitor their brain states or that BCI could be used to make a better diagnosis in people with brain injury or coma. Although these points may be valid, in this study we were interested in the application of BCI as an access technology for AAC. Therefore, we exclude groups from the analysis that were mentioned by participants with different types of applications in mind. The resulting eight user groups were: late-stage amyotrophic lateral sclerosis (ALS), late-stage multiple sclerosis, spinal muscular atrophy type II (SMA type II), Duchenne disease, Rett syndrome, cerebral palsy (CP), high spinal cord injury (SCI), and the locked-in syndrome (LIS).

To provide an exhaustive review of each user population goes beyond the scope of this paper, but we encourage developers to obtain all information about target users. However, in the following section, we will extract common characteristics between user groups to sketch a typical target user for BCI.

3.3.1. Common characteristics of typical target users for BCI

On a functional level, a typical target user for BCI would have severe dysarthria or anarthria combined with an inability to (easily) use a mechanical, pneumatic, ocular or EMG-based switch. The inability to operate a switch could result from severe paralysis (as in late-stage ALS, late-stage MS, SMA type II, complete SCI at C1/C2 or LIS), or, alternatively, because intentional movements are not possible due to spasms, ataxia (e.g. in cerebral palsy), tremors (e.g. in Rett syndrome) or seizures.

From a physical point of view, typical target users could have several hindering factors in common. First, many users who are functionally disabled also have head/trunk instability which would complicate EEG-based BCI use. They are often positioned in a slanted position in a wheelchair or in bed, which would make it difficult to apply electrodes at the back of the head. Alternatively, their heads are strapped to the wheelchair with a headband (which would press on the electrodes) or their heads occasionally drop (which would cause artifacts in the EEG or shift electrodes).[33] Second, many users would suffer from fatigue (e.g. users with ALS [34,35]), which could decrease efficient and satisfactory BCI use, leading to technology abandonment. Third, as many as 50–90% of people with Rett syndrome [36] and 25–50% of people with cerebral palsy have concurrent epileptic seizures [37,38] which may interfere with BCI use. Fourth, typical users may have spasms. As many as 70–80% of people with cerebral palsy [37,38] and 65–78% of people with chronic SCI [39,40] have symptoms of spasticity.

Related to physically hindering factors for BCI use, many users will have sensory impairments which complicate use of AAC technologies, including BCI. For example, Lulé and colleagues [41] found progressive functional deficits in secondary/higher-order visual, auditory, and somatosensory processing areas in people with ALS. Vision impairment may also concur with MS.[42] People with LIS can also suffer from visual blurring, diplopia, impaired accommodation and – with inappropriate care – corneal ulceration.[43] Such sensory impairments in target users argue for the need to develop auditory, tactile, and multimodal methods of BCI.[9]

Cognitive impairment may also be present in target users with, for example, ALS,[44] MS,[45] Duchenne disease,[46,47] Rett syndrome [36] or CP.[37,38] Such cognitive impairment may hinder users from understanding how to use a BCI or lead to fatigue.

4. Discussion

This study set out to investigate (1) how rehabilitation professionals appraise current BCI technologies, (2) which system requirements they define, and (3) which potential user groups they could identify once requirements are met. We assumed that rehabilitation professionals would be better able to provide a critical appraisal than users and that the mini-lecture on the state-of-the-art BCI technology and demonstrations could help bring participants up to speed for a discussion.

4.1. A critical appraisal of state-of-the-art BCI technology

Participants' appraisal certainly was critical, but also very constructive. First, none of the professionals expressed a perception of added value of current brain-computer interfaces over existing access technologies. A major criticism (and requirement) was that the usability of current BCI systems should significantly improve. Professionals say that of course BCIs as access technologies should be effective and reliable over time, but they seem to place more emphasis on requirements toward efficiency and satisfaction. They argued that, considering the often concurrent cognitive, attention, and sensory impairments in target users, great care should be taken to lower the resources needed to control a BCI. BCI paradigms should use more intuitive strategies. This could mean, for example, that BCIs based on mental imagery of movement,[48] musical rhythms [49,50] or calculation [51] are, even if feasible, not usable strategies for target users.

The rehabilitation professionals in our study therefore strongly recommend that BCI developers involve users in the BCI design and consider user characteristics and concurrent neuropsychological symptoms. Truly considering user characteristics may imply clear consequential decisions for the BCI design. If, for example, self-induced paradigms through mental imagery prove to be unusable for users, then for example evoked BCI paradigms (e.g. P300 BCI) could be used. This in turn could exclude target users with epilepsy as it is hypothesized that (visual) P300 BCIs could trigger seizures.

The overall aim should be to develop effective, efficient, and satisfactory novel access technologies which provide added value over existing alternatives.

4.2. Design requirements

In order to achieve this goal, participants defined 21 requirements a BCI access technology should fulfill. Eleven requirements focused on BCI hardware. To sum up, if BCI use requires additional screens then these screens should be positioned on the side, and be small, portable, and robust. BCI sensors should ideally be invisible and wearable day and night. If that is not possible, then BCI setup should be automatic and take no more than 2 min. Also, sensors should be compatible with the sitting or lying position of the user (e.g. not be placed on the back of the head), be wireless, and not interfere with ventilation. We suggest that the sensor requirements could all be met with implanted electrodes such as ECoG. A BCI setup with EEG electrodes may prove to be too inefficient or burden caregivers or family members, negatively influencing the user's relationships.[10]

Seven requirements focused on how the user interacts with the BCI. BCIs should be reliable and adopt standards from other assistive technologies. Also, BCI use should be intuitive, multimodal, and work despite users' cognitive or physical problems. Finally, BCIs should be user-friendly and user-aware. From an ethical, legal, social, and business point of view three requirements were defined: BCIs should be cost-effective, developed in commercial and legal frameworks, and designed to fit in society and therefore avoid further stigmatization and exclusion of people with disabilities.

Some of these requirements can contradict each other and future work should investigate priorities for target users. However, the main message from the rehabilitation professionals seems to be that the field of BCI should take into account the various practical and human problems users face in daily life rather than concentrating solely on technological problems.

4.3. Potential user groups

Participants identified eight user groups who could benefit from BCI for AAC. We looked at common characteristics between those user groups to sketch a typical target user. We conclude that target BCI users are only those who can hardly or not at all use alternative access technologies. However, such persons often have – besides their physical disability – concurrent physical, sensory, and cognitive problems, which could complicate BCI use. If successful BCI use continues to require a user to sit motionlessly (as with EEG-based BCI) and have intact cognition, then – as previously implicitly assumed – people in the locked-in state (resulting from late-stage ALS, MS or SMA type II or the classic and total locked-in syndrome) and people with high SCI (C1/C2) could be target users. People with Duchenne disease, CP, or Rett syndrome may have too many concurrent physical (such as epileptic seizures or spasms) and cognitive problems to be able to effectively and efficiently use and enjoy a BCI unless BCI researchers and developers find ways to handle artifacts resulting from physical problems and make BCI use significantly more intuitive. People with residual LIS are probably not ideal target users either, since they can effectively and efficiently operate alternative access technologies and will thus probably find those more usable [4] or they may even prefer the (non-technological) alphabet system over an access technology.[5]

Thus, the explicit recommendations of the rehabilitation professionals in our study are in line with the implicit assumption of the BCI field and the review from Tai and colleagues [1] in that BCIs are mainly interesting for people without extant physical movement, with intact cognition, and without too many concurrent problems such as spasms, cognitive impairment or seizures. Unfortunately, this conclusion is particularly bad for those people with Duchenne disease, CP or Rett syndrome who are unable to operate an access technology. They continue to fall into a void and innovative access technologies are needed. Functionally, these people may be as locked-in as people with the locked-in syndrome.

4.4. *Limitations of this study*

The appraisal of the rehabilitation professionals presented here may not be representative of the general view on brain-computer interfacing in the wider field of rehabilitation engineering. First, only 28 professionals gave their opinion and, second, they consisted of, for example, occupational and speech therapists, CEOs of medical device companies, adaptation consultants, and psychiatric social workers. This sample did not include important stakeholders such as rehabilitation physicians, who may have provided more medical user characteristics, nor did it include CEOs from companies producing access technologies, who may have had a more profound insight into market mechanisms, mediators, and barriers. Moreover, all professionals were Dutch and worked in the Netherlands. Their appraisal and recommendations can be based partly on Dutch policies and availability of alternative access technologies in the Netherlands. Similarly, we cannot exclude the possibility that the content and organization of the mini-lecture or the choice of demonstrations biased the participants. For example, because the demonstrations included only examples of non-invasive sensors, participants may have been primed to view this as the future application. However, although our sample may have been biased due to reasons mentioned above, we feel the participants contributed many useful recommendations which the wider BCI community can profit from.

Furthermore, because answers in the focus group interviews were not recorded or transcribed verbatim, we cannot exclude potential bias of the note-takers. Although they were instructed 'to try to literally note down every response of every participant', this proved difficult in the real interviews. Moreover, although interviewers attempted to provide equal time to answer for all participants and for all themes, some participants may have contributed more than others. However, because the interviewer also noted the answer on which the group reached consensus, we could test for this confounding and did not find it.

Finally, although rehabilitation professionals encounter many users with various disabilities, they might not have many encounters with people in the locked-in state. Therefore, it may be difficult for professionals to estimate the added value of BCIs over existing technologies available to such users. Future research should therefore always combine perspectives from different stakeholder groups, including people with LIS themselves.

4.5. *Future outlook*

Access to society and inclusion of individuals with disabilities can be facilitated through technology provided that the technology increases the quality of life of the individual and does not create more burden. In particular, those individuals with severe physical disabilities combined with cognitive or sensory disabilities need well-designed access technologies and assistive technologies, because they depend on them so much. Brain-computer interfaces could, but not necessarily should, be a novel access solution. Lane [52] provides a conceptual model of technology transfer in the field of assistive technology in which three 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 scepticism about its uniqueness'. Similarly, the fact that BCIs are feasible and intriguing should not prevent us from scrutinizing the real need for and value of them.

We therefore strongly recommend that BCI developers assess the need and characteristics of target users and adapt BCI design accordingly even if this has radical consequences for the design. We would also welcome a direct comparison between the usability of mechanical switches or oculography-based switches (e.g. eye tracking) and various types of BCI switches, for example in terms of mental workload, which determines the efficiency of access technologies.[12] This would inform rehabilitation professionals to better match users with the right assistive technology – including BCIs.

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Notes

1. Assistive technologies can be described in terms of different technological components: a users' (1) functional intent needs to be sensed by (2) an access technology (e.g. head mouse, sip-and-puff device) which in turn gives commands to (3) a user interface which in turn controls (4) a function (e.g. wheelchair control). We refer interested readers to [1].
2. See www.sensorysoftware.com.
3. Brainfingers is a commercially available access technology developed by the company Brain Actuated Technologies, Inc. and distributed in the Netherlands by the company HEServis (www.heservis.nl). Brainfingers includes the wearable headset device called NIA from the company OCZ technology (www.ocz.com) and is also used for gaming.

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