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PERSPECTIVE

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Perspective

Assessment of brain–machine interfaces from the perspective of people with paralysis

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Abstract

Objective. One of the main goals of brain–machine interface (BMI) research is to restore function to people with paralysis. Currently, multiple BMI design features are being investigated, based on various input modalities (externally applied and surgically implantable sensors) and output modalities (e.g. control of computer systems, prosthetic arms, and functional electrical stimulation systems). While these technologies may eventually provide some level of benefit, they each carry associated burdens for end-users. We sought to assess the attitudes of people with paralysis toward using various technologies to achieve particular benefits, given the burdens currently associated with the use of each system. *Approach.* We designed and distributed a technology survey to determine the level of benefit necessary for people with tetraplegia due to spinal cord injury to consider using different technologies, given the burdens currently associated with them. The survey queried user preferences for 8 BMI technologies including electroencephalography, electrocorticography, and intracortical microelectrode arrays, as well as a commercially available eye tracking system for comparison. Participants used a 5-point scale to rate their likelihood to adopt these technologies for 13 potential control capabilities. *Main Results.* Survey respondents were most likely to adopt BMI technology to restore some of their natural upper extremity function, including restoration of hand grasp and/or some degree of natural arm movement. High speed typing and control of a fast robot arm were also of interest to this population. Surgically implanted wireless technologies were twice as ‘likely’ to be adopted as their wired equivalents. *Significance.* Assessing end-user preferences is an essential prerequisite to the design and implementation of any assistive technology. The results of this survey suggest that people with tetraplegia would adopt an unobtrusive, autonomous BMI system for both restoration of upper extremity function and control of external devices such as communication interfaces.

S Online supplementary data available from stacks.iop.org/JNE/12/043002/mmedia

Keywords: spinal cord injury, brain–computer interface, brain–machine interface, paralysis, BCI, BMI

(Some figures may appear in colour only in the online journal)

1. Introduction

Paralysis, including spinal cord injury (SCI), is a significant health problem in the United States (US) and around the world. According to the Christopher Reeve foundation, there are approximately 6 million people living with paralysis in the US alone (Reeve Foundation 2013). Of these, there are an estimated 1275 000 people living with SCI. Daily living for much of this population requires assistance from caregivers as well as the need for assistive technology (AT). AT aims to augment function for individuals with disability to increase their ability to perform activities for daily living and interact with the environment (Collinger *et al* 2013a). These assistive technologies can improve the functional independence of persons with SCI, affording them greater opportunity for societal participation and integration (Hedrick *et al* 2006).

With recent revolutionary advances in low-power high-performance electronics, and advances in prosthetic (robotic) arms (e.g., DARPA APL and DEKA arms), brain–machine interfaces (BMIs) are showing increased potential as practical assistive technologies. BMIs translate neural activity measured from the brain into control signals for guiding external devices, or to potentially drive implantable functional electrical stimulation systems (FES) to reanimate paralyzed limbs (e.g., Chadwick *et al* 2011). Although these technologies have shown promise in recent animal and human studies, improving the performance, reliability, and form factor of these systems is critical to their successful clinical translation (Ryu and Shenoy 2009). Numerous research groups are currently investigating many different BMI design features including interface modality, control output (e.g. on-computer-screen cursor control and typing, prosthetic (robotic) or FES arm control) and wireless capability (e.g., Homer *et al* 2013). Although one important and high-visibility goal of BMI research is to provide the ability to restore reach and grasp functionality (e.g., Hochberg *et al* 2012, Collinger *et al* 2013a), many other types of BMI-based assistive technologies are being actively pursued (Hochberg and Anderson 2012). However, despite these impressive technological achievements, the actual utility of these early-generation BMI systems for people with paralysis is still an unanswered question.

As BMI technology is developed, it is critically important to consider end-user needs and preferences. The benefits of any AT needs to be balanced by considerations of cosmetic appearance, donning/doffing of external devices, risks of surgical implantation and the expected functional lifetime of implants, and the possibility of using the technology without the intervention of a caregiver or technician. Collectively, these factors may be considered as burdens associated with the use of the technology (e.g., Gilja *et al* 2011). Considering the importance of understanding user-centered design, there is a need to understand how people with paralysis view the benefits and burdens of BMI technology. To address this need, we conducted a technology survey to determine the level of benefit necessary for this group of end-users to consider using different technologies, given their associated burdens.

2. Methods

2.1. Survey design

Visual and written descriptions were provided for eight different technologies, including seven BMI technologies (four implantable, three externally applied) and an eye tracking system (figures 1 and 2). Each technology was then paired with one of 13 hypothetical applications (table 1) and participants indicated their likelihood to adopt the technology for that particular application. There were nine pages of questions, including one page regarding demographics. Qualtrics survey software (Provo, Utah) was used to design the web-based survey, which was run on our Stanford Neural Prosthetics Laboratory (NPTL) computer servers.

Illustrations depicted the structure and design of each technology with relationship to the head and brain (figure 1). The same generic head and face drawing was used for all technology depictions to create a uniform appearance. Each illustration included associated text, which provided the following information: design of the device; its usage (including information on donning and doffing the device, assistance needed, cleaning and maintenance); a description of any surgical procedures required; physical restrictions while using the device; and any known side effects (figure 2). The BMI technologies included Electroencephalography (EEG), Electrocorticography (ECoG), and intracortical microelectrode arrays, in several different form factors. An eye tracker device was also included as an example of a commercially available device associated with minimal burden to the user. Both ‘wired’ and ‘wireless’ examples of implantable and external devices were illustrated, and descriptions were provided highlighting potential differences between them including technician intervention and possible restriction of movement. We chose devices that were currently available on the market, used in a clinical setting, or estimated to be available in the not too distant future. We explicitly avoided providing an expected lifetime for any of the devices, given that this data is not known for some of the more speculative technologies.

For each represented technology, thirteen hypothetical control capabilities were presented and the participant was asked to rate his or her likelihood to adopt the technology given that it could provide one of the control capabilities. Participants rated their likelihood to use each combination of technology and capability on a 5-point Likert scale using the descriptors ‘very unlikely’ ‘unlikely’ ‘undecided’ ‘likely’ and

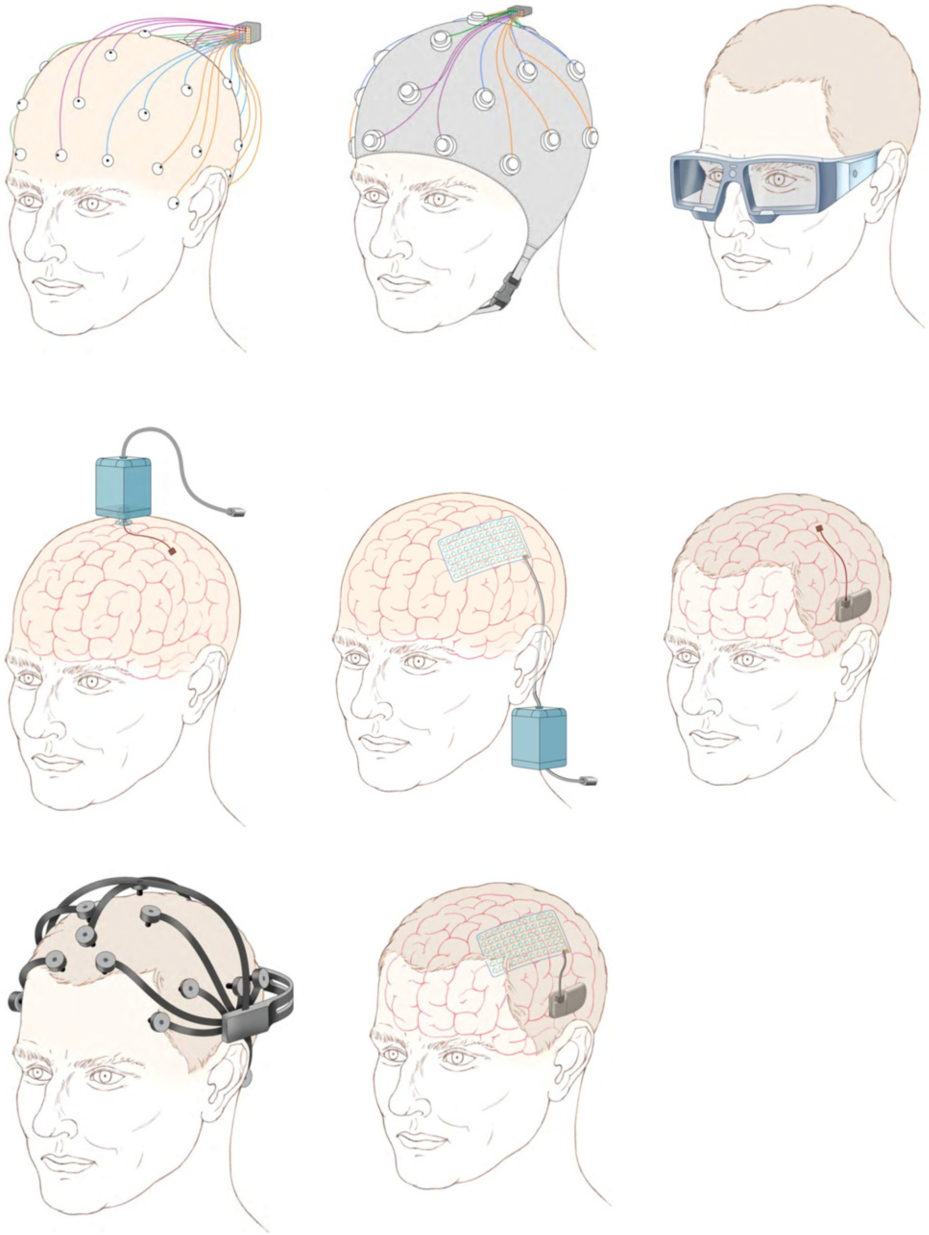


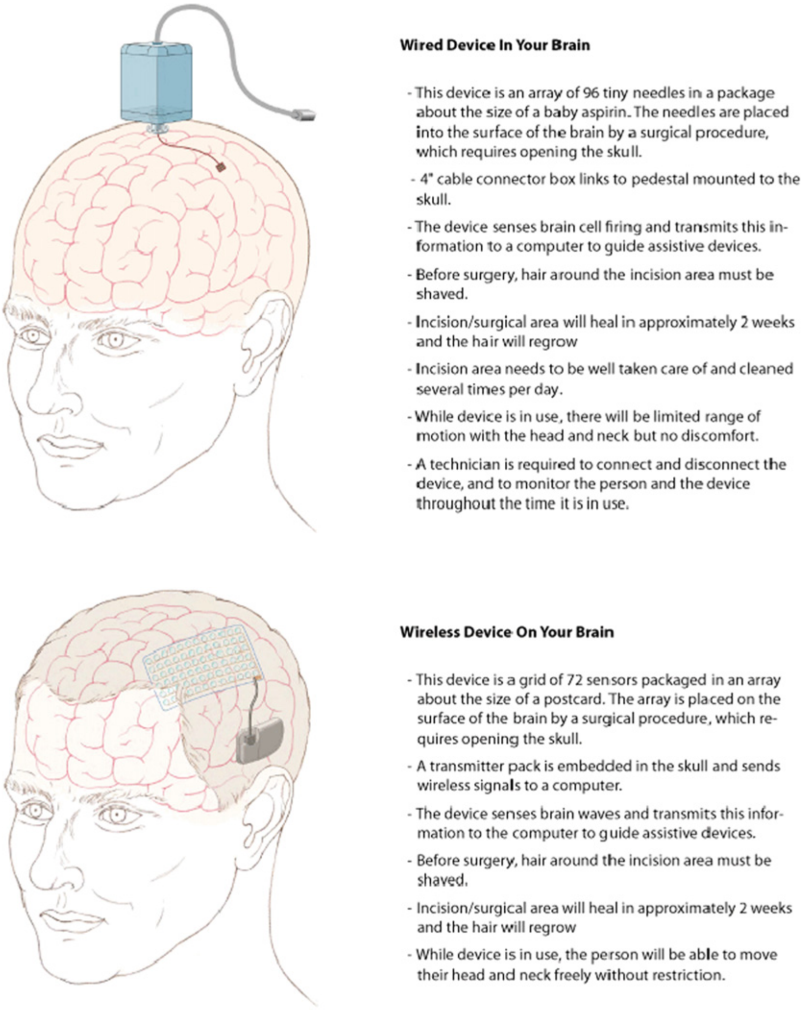
Figure 1. Each illustration was presented to the participant in order to provide a visual description of each BMI technology.

'very likely' (see supplementary materials figure 3, where a copy of the survey will be provided). Thus, the participant provided thirteen rankings for each of the eight technologies, for a total of 104 technology/application ratings. Table 1 lists all of the BMI technologies and control capabilities explored in the survey.

2.2. Participant recruitment

Links to the universal resource locator address of the survey were posted on websites frequented by people living with SCI, including The Christopher and Dana Reeve Foundation's web site discussion group (www.spinalcordinjury-paralysis.org), and SCI and Support forum group (www.apparelyzed.com). Advertisements were also distributed in print by research survey personnel and electronically via SCI discussion group blogs and the NPTL web site. This recruitment methodology is analogous to existing work (Anderson *et al* 2009). Participation in the survey was strictly voluntary and no incentives were given. Only adult individuals (18 years or older) with cervical SCI living in the US were included in this study, excluding people with other causes of paralysis in order to provide a focused perspective on a particular population.

The following supplemental documents were attached to the survey: an introductory statement explaining the purpose of the survey; directions for participating; a 'Right to Privacy' statement; and an explanation of how the results were to be used. This information served as the informed consent statement, as required by the Stanford Institutional Review Board,



Wired Device In Your Brain

- This device is an array of 96 tiny needles in a package about the size of a baby aspirin. The needles are placed into the surface of the brain by a surgical procedure, which requires opening the skull.
- 4" cable connector box links to pedestal mounted to the skull.
- The device senses brain cell firing and transmits this information to a computer to guide assistive devices.
- Before surgery, hair around the incision area must be shaved.
- Incision/surgical area will heal in approximately 2 weeks and the hair will regrow
- Incision area needs to be well taken care of and cleaned several times per day.
- While device is in use, there will be limited range of motion with the head and neck but no discomfort.
- A technician is required to connect and disconnect the device, and to monitor the person and the device throughout the time it is in use.

Wireless Device On Your Brain

- This device is a grid of 72 sensors packaged in an array about the size of a postcard. The array is placed on the surface of the brain by a surgical procedure, which requires opening the skull.
- A transmitter pack is embedded in the skull and sends wireless signals to a computer.
- The device senses brain waves and transmits this information to the computer to guide assistive devices.
- Before surgery, hair around the incision area must be shaved.
- Incision/surgical area will heal in approximately 2 weeks and the hair will regrow
- While device is in use, the person will be able to move their head and neck freely without restriction.

Figure 2. Each illustration included associated text, which described the design of the device: its usage (including information on donning and doffing the device, assistance needed, cleaning and maintenance); a description of any surgical procedures required; physical restrictions while using the device, and any known side effects.

which approved the study. Written documentation of informed consent was waived.

3. Results

3.1. Participant demographics

Two hundred and ninety-three people living with paralysis completed at least a portion of the survey. Of those 285 individuals, 156 qualified for study participation (i.e., completed all pages of questions, including the demographics section, were living with cervical SCI, and were age 18 years or older). The 129 individuals were excluded in this analysis due to their level of tetraplegia e.g., thoracic, lumbar, other paralysis, or did not complete the entire survey. Age of survey respondents ranged from 15–81 years old (those under 18 were excluded from participation) and time post injury ranged from 1 month to 62 years. Table 2 lists the participants' level of injury, mechanism of injury, and education level. The education level of respondents is considered high compared to the general populace. 31 (20.2%) of respondents have a graduate degree as well as a college degree, 59 (38.6%).

To aid in side-by-side comparison of the large number of individual technologies and control capabilities, we displayed the data in a stacked bar graph format, coloring response categories of 'likely' and 'very likely' so that they could be easily distinguished from neutral or negative responses (figure 3(a)). Each graph divides the respondents into four groups based on their level and time post injury. We divided the respondents into C1–4 and C5–7 levels of injury as we expected these groups to have different needs. For example, most SCI individuals with a level of injury at C1–4 are only able to move their heads and possibly shrug their shoulders, whereas individuals with a level of injury at C5–7 might be able to bend their elbows, extend their wrists, or use their hands, depending on the injury level (Consortium for Spinal Cord Medicine 1999). There were 54 respondents in the C1–4 group and 102 respondents in the C5–7 group. We also divided respondents into those more or less than 10 years after cervical SCI, to assess the hypothesis that respondents who had lived with their injury for a longer period of time

Table 1. Assistive applications and BMI Technologies assessed in the survey.

Assistive applications
To TYPE at 3 words per minute with some errors
To TYPE at 3 words per minute with no errors
To TYPE at 40 words per minute with some errors
To CONTROL a cursor on a computer screen with less than perfect accuracy
To CONTROL a cursor on a computer screen in a complete natural way
To CONTROL a robot with a camera
To CONTROL a robot with a camera and an arm
To CONTROL the steering of a wheelchair
To CONTROL a robotic arm with slow speed and acceptable accuracy
To CONTROL a robotic arm with high speed and accuracy
To RESTORE some arm movement which is useful but not completely natural
To RESTORE natural arm movement without sensation
To RESTORE some ability to grasp with the hand
BMI Technologies
Eye tracking glasses
30+ electrodes glued to the head
Cap with wires
Wireless cap
Wired device on the brain
Wireless device on the brain
Wired device in the brain
Wireless device in the brain

would show less interest in AT in general, and BMI systems in particular.

Results for each BMI technology are illustrated in a separate graph, comparing the likelihood of adoption of each of the 13 control types by the 4 summary groups i.e., typing, cursor, external actuator, native limb (figure 3(b)). Summary graphs are also presented to compare likelihood for adoption for each BMI technology for a given control type (figure 3(c)).

3.2. Survey results

Likelihood to adopt BMI technology varied widely depending on the control type offered (figure 3(b)). For simplicity in the following discussion, the term ‘likely’ will be used to represent the top two categories of ‘likely’ and ‘very likely’ combined, as represented visually with saturated colors in figures 3(a) and 4(a).

Overall, participants were most likely to adopt technology that would allow restoration of natural upper extremity movement and/or hand grasp. 91% of respondents with injury level C1–4 who were less than 10 years post injury said they would be ‘likely’ to adopt a BMI technology if it could restore some grasp of their hand or restore natural arm movement without sensation (figure 3(b)). 78% of C5–7 participants would be likely to adopt BMI technology for restoration of hand grasp, while 67% would be likely to adopt BMI technology for restoration of natural arm movement without sensation. This high interest in restoring upper extremity function is not unexpected, given prior surveys on this topic (Anderson 2004, Snoek *et al* 2004).

Control of external devices such as prosthetic (robotic) arms, computer cursors and wheelchairs was of moderately high interest to participants with upper cervical injuries (more than 60% of C1–4 respondents less than 10 years post injury) (figure 3(b)). Participants with injuries at C5–7 were much less likely to adopt these control capabilities unless they were described as being fast, accurate or natural. Across all groups, the two external control capabilities of most interest were high speed typing of 40 words per minute and control of a fast prosthetic (robotic) arm. In fact, those with injuries at C5–7 were more interested in either of these modalities than in restoring less-than-natural native arm movement, via FES (figure 3(b)).

Form factor of the BMI system had a large influence on the likelihood of adoption (figure 3(C)). 80–95% of respondents would be ‘likely’ to adopt eye-tracking glasses or a wireless EEG headset resembling the ‘Epoc’ manufactured and sold by Emotiv (San Francisco, California). Across all control types, externally applied EEG systems, either glued to the scalp or integrated into an elastic cap, were no more likely to be adopted than surgically implanted wireless intracortical electrode arrays or wireless ECoG grids. According to survey data, these surgically implanted wireless technologies were twice as ‘likely’ to be adopted as their wired equivalents; the median likelihood of adoption was statistically significantly higher for each control type ($p < 1.3 \times 10^{-5}$ by sign rank test for all pairwise comparisons; false discovery rate < 0.005). Wireless systems are not currently available today; however, it is likely that they will be available in the no-too-distant future (Homer *et al* 2013). Wired systems and arrays are available and used in clinical settings and research trials (e.g., Simeral *et al* 2011, Hochberg *et al* 2012, Collinger *et al* 2013b, Nuyujukian *et al* 2014, Pandarinath *et al* 2014). Somewhat surprisingly, respondents were more interested in adopting an implanted wireless intracortical array compared to an external wired EEG cap (see figures 4(b) and (i)). 39% of C1–4 respondents that had been injured for 10 years or more were likely to adopt the wired EEG cap, whereas 52% of the same population were likely to adopt the wireless intracortical technology.

Given that interest in restoration of hand grasp was the highest priority, we used this metric to compare the likelihood to adopt several different technologies. 48% of C1–4 respondents and 45% of C5–7 respondents with less than 10 years post injury were likely to adopt the wireless ECoG technology to restore some grasp of the hand, whereas 60% of C1–4 and 46% of C5–7 of the same group were likely to adopt wireless intracortical technology if it could restore some grasp of their hand (see figure 4(b)). This level of interest was sustained for restoration of almost any upper extremity function (figure 4).

Interestingly, C5–7 participants that had been injured for 10 years or longer expressed quite a bit of interest in using

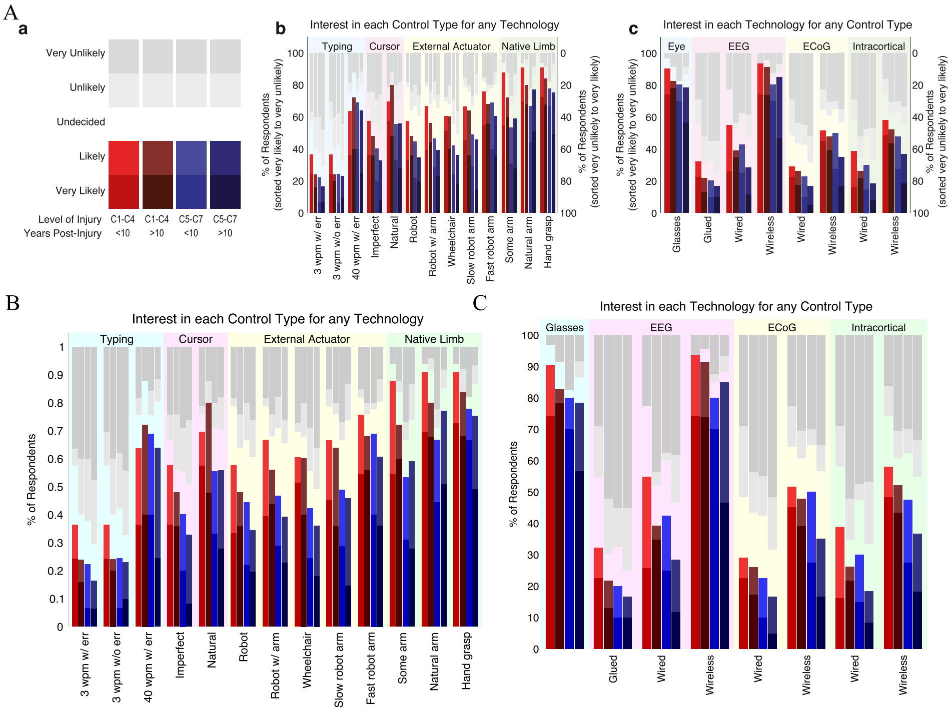


Figure 3. (a) Legend used throughout for creating the composite graphs of technology, control type, and likelihood of adoption. Red colored bars denote upper cervical injury, while blue colored bars denote lower surgical injury. Each of these groups is subdivided further into participants <10 years post-injury (lighter colors) and >10 years post-injury (darker colors). Categories of 'likely' and 'very likely' were depicted in increasingly saturated colors, with 'very unlikely' and 'unlikely' depicted in shades of gray, and 'undecided' depicted as white. (b) Composite graph showing likelihood of adopting any particular control type, independent of the BCI technology used as a sensor. (c) Composite graph showing likelihood of adopting any BCI technology, independent of control type. (b) Interest in each control type for any technology. (c) Interest in each technology for any control type.

Table 2. Participant demographics.

Total	
Level of injury	
C1–2	8 (5.1%)
C3	18 (11.5%)
C4	28 (17.9%)
C5	60 (38.5%)
C6	30 (19.2%)
C7	12 (7.7%)
Regarding mechanism of injury	
By vehicle crash	63 (47%)
By diving accident	31 (23.1%)
By sporting accident	23 (17.2%)
By fall	16 (12%)
By violence	1 (0.7%)
Education level	
Grad school	90 (58.8%)
College Graduate	59 (38.6%)
Some college	32 (21%)
Tech school	15 (9.8%)
High school degrees	16 (10.5%)
Severity of injury (by self-report)	
Incomplete cervical spinal cord injuries	90 (60%)
Complete cervical spinal cord injuries	60 (40%)

BMI technology for computer cursor control. 56% of C5–7, and 80% of C1–4 respondents, all injured for 10 years or more were likely to adopt a technology if it could control a cursor on a computer screen in a completely natural way (see figure 3(b)). The same population was interested in a BMI technology for high speed typing; 64% of C5–7, and 72% of C1–4 respondents, would be 'likely' to adopt a technology if it would allow them to type at 40 words per minute with some errors (see figure 3(b)).

3.3. Respondents' comments

At the bottom of each page of questions, and at the end of the survey, a comment box was offered to the respondent. These comments provided a better understanding of how the respondents viewed each technology. Respondents left a total of 228 comments throughout the entire survey. Of those 228 comments, 17 comments related to aesthetic and cosmetic appearance, 26 related to the needs for independence, and 20 related to maintenance, cleaning, and concerns about surgery. Table 3 is a selection of representative comments left by survey respondents.

4. Discussion

As BMI technologies move closer to practical clinical implementation, it is very important to take into consideration

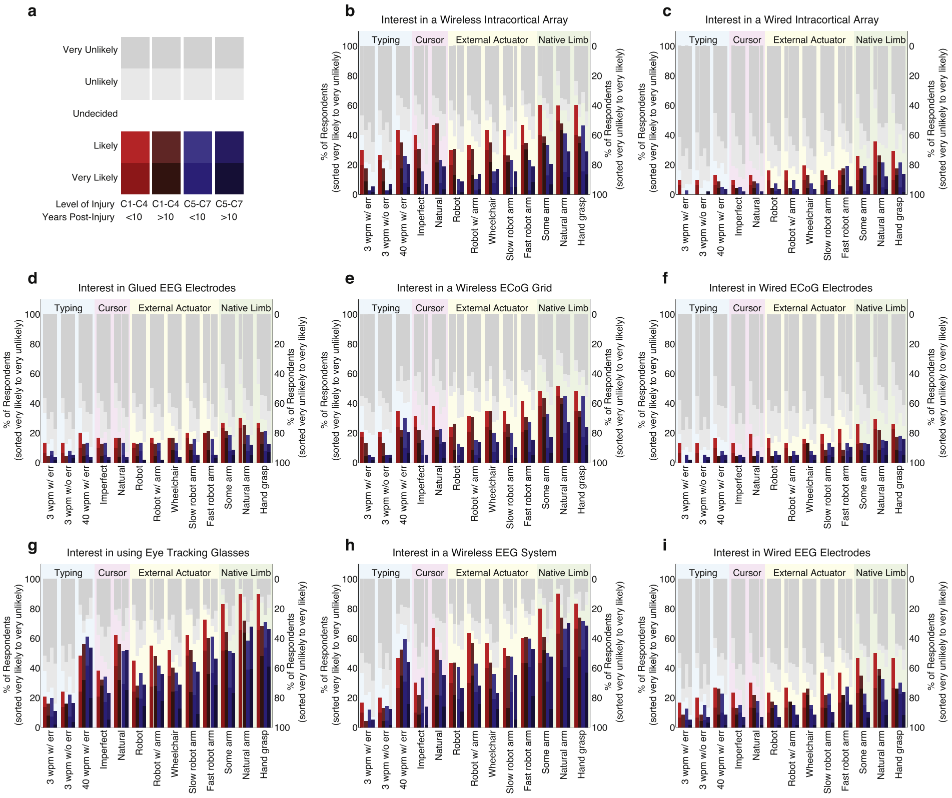


Figure 4. (a) Legend (see figure 3(a)). (b)–(i) Composite graphs showing likelihood of adopting each of the eight different BCI technologies for a given control capability.

the preferences and priorities of the intended population of end-users. This survey was designed to cover a broad range of technologies and capabilities in a hypothetical manner, understanding that some of the technologies listed are not presently (and may never be) able to provide restoration of some of the more advanced functions listed (e.g., an EEG wireless cap to restore grasp of the participant's hand). We chose BMI technologies that are currently on the market, used in clinical trials, will be available in the near term, or are actively being developed and researched. A number of findings emerged from analysis of the survey results that should be of interest to researchers working in this field.

Restoration of upper extremity function is a high priority for people living with cervical SCI. We found that 80% of all survey respondents would consider adopting at least one of the presented technologies if it could restore some hand grasp. Up to 60% of respondents would undergo a neurosurgical procedure if the system could provide improvements in upper extremity function. These results are consistent with other surveys that have suggested that restoration of hand grasp is an important goal. Snoek and colleagues (Snoek *et al* 2004) surveyed 565 members of the Dutch and UK participants living with paraplegia and tetraplegia to identify how their quality of life would be impacted by improvements in different functions. 75% of Dutch participants and 80% of UK participants stated that they expected the greatest improvement in quality of life to occur with improved hand function. Anderson (Anderson 2004) surveyed 681 participants with SCI to rank the recovery of seven functions in regard to improving quality of life. Again, the highest priority for survey participants with cervical SCI was to regain arm/hand function, with 48.7% indicating that regaining arm and hand function would most improve their quality of life, regardless of time post injury. Collinger and collegues surveyed 57 SCI veterans, 21 (37%) with tetraplegia and 36 (63%) with paraplegia, to assess their knowledge about currently available assistive technologies and to determine whether they believe BCIs have the potential to increase their function and improve their quality of life (Collinger *et al* 2013a). The majority of participants (80%) indicated that they would use a BCI if it did not inconvenience other aspects of their lives. Most participants felt that BCI would be most useful for controlling FES devices to restore movement or function to their own muscles. Collinger and colleagues asked the participants how likely they would be to have surgery to implant a BCI. Noninvasiveness was rated as a high priority; however, a majority would consider having surgery; 24% with tetraplegia and 33% with paraplegia said definitely, and 33% with tetraplegia and 27% with paraplegia, reported that they would be very likely to undergo surgery for a BCI implant (Collinger *et al* 2013a).

AT, which can include devices such as BMI systems, is less likely to be used if it is aesthetically unpleasing, unreliable, or difficult or embarrassing to use (Wielandt *et al* 2006). A national survey on technology abandonment found that 29.3% of all devices obtained were abandoned (Phillips and Zhao 1993). There are many reasons for AT abandonment. When technology-using family caregivers were surveyed, the

Table 3. Comments from survey respondents.

Aesthetic/cosmetic appearance
'I like that it [wireless device] would be under skin, undetectable… no wires coming out to accidentally rip out, or get infected.' C4–6, Female, Injured in 1991.
'Make the [wireless EEG] cap something desirable to wear. This would be a challenge in an office setting.' C1–3, Female, Injured in 1969.
'I think some of this is interesting but a lot of devices are extremely awkward and don't think that I would functionally use them.' C5, Male, Injured in 1988.

Seeking independence
'Device requiring a technician would not be helpful in every day life. I would be willing to try anything that would give me any movement to my arms.' C4–5, Female, Injured in 2003.
'If device cannot be operated independently, what's the point? Might as well have the assistant perform [tasks].' C7, Male, Injured in 2006.
'Any device that limits movement of head will be difficult.' C6, Male, Injured in 2006.
'Needing a technician around nullifies the benefits to me—not needing one would make this attractive.' C3, Male, Injured in 1996.

Maintenance concerns
'Why take chance of infection with invasive technology—if constant human monitoring must be at hand—they can perform the task.' C7, Male, Injured in 1972
'Limited range of motion, periodic daily cleaning and constant supervision unacceptable.' C5, Male, Injured in 2010
'Don't like the idea of having something permanently coming out of my head, and required cleaning per day.' C4–5, Female, Injured in 2003.

three leading perceived barriers to technology use were the following: (1) technology will be too expensive (37%), (2) technology doesn't solve or address a caregiving issue (22%), and (3) belief that the relation (patient) would resist accepting the technology (20%). This qualitative survey queried 1000 technology-using family caregivers (Caregiver Survey, 2011). However, caregivers may have different perceived barriers than end-users.

One survey did attempt to identify and understand the use of AT to restore mobility from the perspective of persons with SCI (Denise Brown-Triolo *et al* 2002). This survey assessed various priorities including standing, walking, climbing stairs and transferring, as well as minimally acceptable levels of mobility for adopting AT. Other questions in this survey addressed cost of the technology and willingness to experience related risks. Visibility of assistive devices was consistently seen as an area of concern. For individuals with an already physically stigmatizing condition, such as SCI, these cosmetic barriers may provide a high burden to adoption, even if the device provides significant restoration of function. Importantly, invasive procedures such as surgery were often as acceptable as less-invasive therapy and exercise (Denise Brown-Triolo *et al* 2002).

The National SCI Statistics Center (2013) divides data into categories of SCI persons with a level of injury at C1–4 and C5–8. Level of injury clearly plays a role in the likelihood of adopting a BMI technology, although certain technologies and control capabilities were of uniform interest to all people with cervical SCI. For example, there was no difference in the likelihood to adopt a system for fast typing (>40 WPM) between those with upper and lower cervical spine injuries. Looking at figure 4(c) ('Interest in each technology for any control type'), there is about a 10% difference between the responses from participants with injuries at C1–4 compared to those with injuries at C5–7.

An unexpected finding was the interest in high-performance typing by people with SCI of all levels, particularly those with retained arm movement. For all BMI technologies, C5–7 respondents would be more likely to adopt the technology for high speed typing than for steering a wheelchair or using any kind of robotic assistive device. This suggests that communication is a very important priority and that emphasis should be placed on development of high performance typing interfaces.

Penetrating electrodes with a smaller form factor were slightly preferred to surface electrodes that covered more area. Thus, electrodes 'in the brain' were preferred to electrodes 'on the brain', perhaps because of their smaller form factor. Wireless systems were more appealing to respondents than wired systems. In fact, respondents preferred wireless brain implants to wired EEG caps, suggesting that the convenience and cosmetic advantages of a wireless system outweighed the concern for surgery. This finding suggests that development of wireless systems should be a very high priority in BMI research.

Allowing the opportunity for survey respondents to provide comments allowed a more detailed view of individual attitudes, which provided valuable context to the numeric results of the survey. In concordance with prior surveys, aesthetic appearance is a very high priority, even potentially outweighing concerns about undergoing a neurosurgical procedure. Overall, respondents were more likely to adopt a wireless version of any technology than its wired counterpart. The ability to operate a BMI system independently, without reliance on caregiver or technician assistance, was frequently mentioned as a potential barrier to adoption.

5. Conclusions

Understanding the needs of the SCI community is of paramount importance in the design of BMI devices. Discovering the limitations to using BMI technologies including procedure, cosmetic appearance, assistance needed, and daily usage of each device is imperative in the early stages of development.

In our survey, respondents were concerned about aesthetic factors, issues with daily maintenance, and the potential requirement for technician intervention. For BCI systems to achieve widespread adoption, they will need to be autonomous, unobtrusive and require little to no maintenance. They must also provide high performance in order to be widely adopted by people with all levels of paralysis. These factors seem to favor a surgically implanted system that is 'always on,' requiring no donning/doffing or caregiver intervention. In terms of output, there was a preference for restoring natural movement, which might be accomplished through FES. However, there were a substantial number of people interested in a variety of applications, including prosthetic (robotic) arms, wheelchairs, and computer cursors. Overall, these results show strong enthusiasm in the community of people living with paralysis, specifically SCI, for the development of BMI assistive technologies.

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