Functionality of a Brain Computer Interface Powered Wheelchair

Literature Review

Jessica R. Hammers and Ryan T. Mavretish

Occupational Therapy Division, Keuka College

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This literature review was completed to provide foundational knowledge on the topic of brain computer interface (BCI), and to establish the need for a research study that would examine the functional use of BCI for individuals with severe motor impairment. There are a variety of conditions, injuries, accidents, and diseases that can lead to a severe loss of motor, bodily, and cognitive function, leaving an individual unable to functionally explore and interact within his/her environment. One option that is being explored to assist these individuals is the use of BCI. This relatively new technology uses a computer to acquire a certain type of brain signal, interpret the signal, and then turn it into a command or action to power the device they are using (Shih et al., 2012). Abiyev et al. (2016) break down the process into five main parts: signal acquisition, signal preprocessing, feature extraction, classification, and action (p. 2). This multi-step process is necessary to acquire, interpret and output the correct and desired command when controlling a wheelchair (Abiyev et al., 2016). The current research on BCI-controlled wheelchairs interprets a variety of different signals such as EEG waves, sensorimotor rhythms, Event-Related Potential (ERB) and fuzzy neural networks (Kaufmann et al. 2014; Herweg et al. 2016; Abiyev et al. 2016). This type of technology can assist individuals in regaining some functional abilities that they have lost.

These conditions that affect an individual's motor skills can have a tremendous impact on daily life and can greatly limit function. For example, individuals with impairments who need a power wheelchair may not always have enough physical strength or endurance to use adaptive switches including knobs, toggles, and/or touchpads on their wheelchair. BCI is effective as it uses signals from the brain to control the wheelchair in the way the user desires without requiring any physical movement. The question that needs to be answered is: can these new BCI-powered wheelchairs be used for everyday tasks and are they going to be able to increase a person's functionality and independence? As there is more research being focused on the technological side of BCI, there is a need for more research regarding the functional capabilities of BCI technology. The research dedicated to BCI shows promise of allowing more freedom for these individuals but has not yet been tested and studied in real-life environments or in functional tasks. This makes it difficult for practitioners to use the findings in order to refer a patient to BCI equipment as they have no knowledge of functional benefits.

The purpose of this proposed study is to explore the functionality and feasibility of using BCI technology in power wheelchairs for everyday use. As new technology is being introduced, practitioners need to be aware of how it can be implemented and used effectively with certain populations. Occupational therapists have to be aware of how the brain can now be used to operate many innovative technological devices to increase their patients' independence. The literature review served to identify what current research on BCI technology is focusing on, as well as how well it works and what still needs to be researched. It has also identified what advances have been made since the introduction of BCI technology, as well as certain devices and systems that have not worked well in practice.

The majority of the research currently published on BCI technology consists of small group, non-randomized, repeated measure designs that focus on all age levels and use a combination of able-bodied and motor-impaired individuals as well as a mix of real and simulated(virtual reality) environments. They are level III and IV studies that were generally published within the last couple of years by engineering and medical researchers in laboratory settings mainly throughout the United States and Asian countries. Based on the current research relating to this proposed study, the following chapter will be based on these key topic areas: 1. functional impacts of motor disorders, injuries, and dysfunction, 2. overview of BCI technology, 3. current outcomes of BCI technology, 4. functionality of BCI technology, and 5. limitations of current BCI research.

Functional Impacts of Motor Disorders, Injuries, and Dysfunction

BCI technology can give some independence and functionality back to individuals who have sustained severe motor injuries. Rebsamen (2009) explains how there are nearly two million people across the United States who have impaired neural pathways secondary to issues such as amyotrophic lateral sclerosis (ALS), brainstem strokes, spinal cord injuries (SCI), cerebral palsy (CP), muscular dystrophy, and multiple sclerosis (MS). Although this is not an all-inclusive list, these are some of the many disorders that could make individuals good candidates to use a BCI-controlled wheelchair. For example, an individual with a C4 or higher SCI would not have adequate use of their upper extremities to control a power wheelchair with a joystick (Bashar & Hughes, 2018). Schultz-Krohn et al. (2018) also explain how diseases that affect the central nervous system such as ALS or MS may have significant motor declines that can leave them unable to be functionally mobile. Of these individuals, some will see cognitive declines and some will not (Schultz-Krohn et al., 2018). However, there is a chance that an individual could only have mobility declines and no significant cognitive declines (Schultz-Krohn et al., 2018). Individuals who have sustained these types of injuries or been diagnosed with these disorders could be good candidates for a BCI-powered wheelchair if they are evaluated and deemed cognitively able to safely and functionally operate one.

Overview of BCI Technology

BCI technology has advanced greatly since its beginning many years ago. BCI technology works by completing four basic steps: signal acquisition, feature extraction, feature translation and device output (Shih et al., 2012). In the published literature, there are a variety of different types of signal acquisition that are being used. There are also specific hardware and software differences that vary from device to device.

Types of Acquisition

EEG signals are popularly used in BCI technology due to their transferability, ease of acquisition, and price (Fernández-Rodríguez et al., 2016). Do et al. (2013) used an EEG cap to acquire EEG signals. When gathering these types of EEG signals, a cap may be the easiest and most universal way to acquire them, but large wearable devices such as a cap can be cumbersome and not feasible for certain populations. Taherian et al. (2017) studied participants who wore a large headset that interfered with any sort of head or neck support on wheelchairs that the individuals needed. The authors of “Devices can Turn Thought Into Action” (2020) and Herwig et al. (2016) used more flexible, sticker-like, tactile stimulators that were placed on the legs, abdomen, and/or lower neck that were able to detect the participants EEG signals. Since the individuals who will be using this technology will require the use of a wheelchair and may have many supports on the chair, these more flexible, lower-profile devices may be more suited to their needs. Ang et al. (2011) had their participants either tap their fingers or use motor imagery techniques to imagine tapping their finger to produce certain EEG signals that could then be translated into movements for the device. Other studies instructed participants to imagine pushing a block or a picture on a screen to the left or the right (Taherian et al., 2017). All of these techniques used to provide feedback to the participants gave them a better understanding and a visual that was able to validate their actions in the experiment.

Hybrid Approach to BCI

Another feature that BCI research has touched upon is using a hybrid approach to BCI to help predict the users' moves when operating a powered wheelchair. Deng et al. (2020) proposed a "shared control approach" which uses both user and robotic controls with the ultimate goal of increasing user efficiency in powering the wheelchair. Similarly, Tang et al. (2018) explain how a cooperative robotic/human model can use technology such as lasers and scanners to identify obstacles and environmental data within the room to safely avoid obstacles which may pose a problem if incorrect BCI commands are sent. These systems are not all-encompassing, self-driving machines. They work in collaboration with the user, who maintains control of movements, to double check and correct or enhance their movements when controlling the BCI wheelchair (Tang et al., 2018). Results of using a shared control model as compared to a basic BCI system show that users significantly improved their completion time in tasks($p<0.005$) and they reported a better experience with the shared control system (Deng et al., 2020). Overall, a shared-control system can increase efficiency and decrease stress and user effort by working with the user to complete the task at hand. If BCI users are using a shared control system, the computer can step in before the false command is sent, eliminating the need to correct before moving on to the next command or movement. Overall, BCI technology has advanced rapidly in recent years and there have been great strides in the proven effectiveness of the new technology's accuracy, safety, and usability.

Current Outcomes of BCI Technology

The current research shows results that encompass simple outcome measures such as accuracy, time to complete, success/error rates, and number of commands used. There were minimal studies located that report statistical data along with their findings. The most commonly reported outcome was accuracy.

Findings on Accuracy of BCI

Both Liu et al. (2020) and Herwig et al. (2016) reported that with training, the accuracy of using the BCI technology significantly improved across the sessions of their studies, using both online and offline tests. Herwig et al. (2016) also reported that their participants were all able to reach at least a 95% accuracy level by the end of the study. These data findings show that this type of technology works as it is supposed to and individuals with little to no experience can safely and effectively use it with the correct training. Deng et al. (2020) defined success rate as completing the course under a certain amount of time and with no collisions. However, Tang et al. (2018) defined success rate as "the rate of a successfully completed test" (p. 15). This lack of consistency across studies can lead to confusion as Tang et al. (2018) reported a 100% success rate. If other studies have stricter criteria for success rates, they may not have as high a success rate and the technology could possibly be viewed as inferior. Attention to how key reported results are defined is imperative when analyzing studies and data on new technology.

Some studies, such as Zhang et al. (2017), provided data with little context. They reported the time the patients took to complete the experiments as well as the number of false commands sent. Zhang et al. (2017) also report on the number of false commands, but they were able to conclude that the number of commands sent across the four sessions decreased statistically significantly ($p<0.001$).

As seen in many articles looking at this new technology, little to no comparison is reported on. Similar to how key findings are defined, it is important to know what the findings of this technology mean. Moving forward, studies must aim to find a common ground to define results to promote reliability across research.

Reported Experiences

Throughout the literature search, participants reported feeling satisfied with the reliability and control of the wheelchair but indicated they felt some anxiety and nervousness when using the technology (Kaufmann et al., 2014; Deng et al., 2020). Both Kaufmann et al. (2014) and Deng et al. (2020) used a five-item questionnaire that evaluated satisfaction and workload. Lastly, Zhang et al. (2017) used the NASA Task Load Index to determine participants' workload estimates in the areas of mental, physical, and temporal demands, as well as performance, effort, and frustration. The results were within the normal range for all areas except for the temporal demands of experiment two (Zhang et al., 2017). Overall, these questionnaire results validate the findings on accuracy and reliability in the studies. These studies can report on the effectiveness of their technologies; however, to move to a more functional viewpoint, there is a need to obtain the user's experiences and thoughts when using the systems.

Functionality of BCI Technology

Many researchers have been able to prove that BCI can support wheelchair mobilization; however, it has been difficult for researchers to determine the functionality of this technology for users in their natural environments.

Functional Outcome of BCI Technology

Ang et al. (2011) describe in their findings the benefits that BCI can provide to a person, such as accurate motor movements in upper extremities, but the actual functional effects of using

BCI are “beyond the scope of this study” (p. 257). Similarly, Liu et al. (2020) expanded upon their study concluding that there is a need to assess “whether the users can carry out the [BCI technology] in the real environment” (p. 13). Both were able to support that BCI is an effective and feasible solution when it comes to upper extremity mobility; however, both report that more research is needed in order to prove the functionality aspect of this technology. Similarly, Do et al.’s (2013) study was able to provide enough evidence that BCI was effective for individuals with an SCI, but they explain that there needs to be more research conducted in future studies that test how functional this system can be in order to aid the SCI population.

In an attempt at a functional approach, Zhang et al.’s (2017) study used patients with SCIs in real-life scenarios to manipulate multiple types of devices including household electrical appliances, a nursing bed, and an intelligent wheelchair using BCI control. In the future, these researchers plan to further integrate other devices including a robotic arm in order to increase functionality of their system. Other researchers have taken it a step further by trying an approach through the use of virtual reality and 2D simulated training environments in order to successfully simulate a real-life feel (Liu et al., 2020; Zhang et al., 2017; Herwig et al., 2016). Many leave a disclaimer stating that future studies should test and evaluate the effectiveness of real-world wheelchair control to expand upon the fact that BCI is effective in a controlled environment. More research is needed to support the effectiveness in real-world environments to ensure proper usability and user safety.

United States Research Efforts

There are also many universities in the United States and around the world who have taken interest in BCI research and continued to build on the potential benefits of this technology. For example, the University of Michigan has developed a direct brain interface laboratory that has a main goal of advancing BCI technology toward clinical availability. Their upcoming research is aimed at using BCIs closely with assistive technologies, identifying various features of BCI and supports that could be utilized to increase independence of people with physical impairments, identifying different design preferences of potential BCI users, and more ("Direct Brain Interface Laboratory," n.d.). The team at Michigan is made up of associate investigators who specialize in physical medicine and rehabilitation, biomedical engineering and biostatistics. The backgrounds of these professionals will be beneficial as they begin new research into the functionality component of BCI as they will be able to dig further into the medical side of this technology. The connections they make will be coming from a therapeutic standpoint and these researchers will be able to take in the considerations of the populations likely to use BCI technology rather than simply the usability of the technology on its own. There are many other universities taking up interest in BCI research from a medical perspective including University of California Berkeley, University of Pittsburgh, and the College of Engineering at the University of Utah, to name a few ("North American BCI Research Programs," n.d.).

Limitations of Current BCI Research

BCI is a fairly new and emerging topic for researchers where the logistics of the technology are being tested but only with fairly limited populations and narrow settings leading to a variety of limitations as seen in the literature. One consistent limitation found throughout the literature is that many of the studies had a small sample size. As Lui et al. (2020) acknowledge in their study, they used an extremely small sample size, which makes it difficult to generalize the findings, and a narrow age demographic with no control group. Herweg et al. (2016) acknowledge that their study also had a small sample size and narrow age range making it difficult to generalize the findings to the broader population, yet again. As the researchers of multiple studies pointed out, it is difficult to find subjects who are willing to participate in these emerging studies (Fernández-Rodríguez et al., 2016). Many BCI-related studies require prior knowledge and manipulation of BCI technology, which makes it difficult to recruit participants. Many of the studies found in the literature had a total number of participants of fewer than 10. The studies that were conducted were mainly repeated measures studies, meaning that they repeatedly recorded scores from the same participant and had no control group to compare but rather they compared the subjects to themselves throughout the study. These factors make the research hard to generalize to the public and especially to the potential populations using this type of technology.

Another limitation commonly found throughout the literature is that researchers had been conducting the studies in simulated environments. Many studies use a simulated environment or virtual reality systems in a laboratory that are similar to real-life environments, but these cannot capture the essence of a real-life environment. A simulated scenario is easier to control, more convenient, and is less expensive compared to testing in a real-life environment; however, this can lead to misleading results (Liu et al., 2020). Just because a BCI wheelchair can work functionally in a controlled environment does not mean that it will work just the same in a real-world, uncontrolled environment (Herwig et al., 2016). This disparity plays a role in the overall functionality of these systems and how they may affect the user.

Yet another limitation that was found frequently throughout the literature was the use of able-bodied test subjects. It is convenient to test the BCI technology on able-bodied individuals who have their physical abilities intact, but the end result for this technology is to ultimately assist with populations who don’t have all these abilities. Many researchers concluded that the validation of their research may vary because their participants were physically healthy and did not require dependence on the BCI technology (Kaufmann et al., 2014). Considering there is sufficient evidence to support BCI feasibility, there now needs to be more research with end-user populations who can truly benefit from BCI so that it can be more universally accepted and accessible.

Conclusion

BCI research is becoming a more popular topic for researchers and there is ongoing research being conducted in order to evaluate the potential functional benefits BCI may have. There are many studies that support the feasibility of BCI technology and how scientists are able to track the brain waves as people are able to control mechanisms with their mind, however; now there need to be more studies focused on real populations and in real life situations. In order for BCI to reach the stage of universal acceptance, it needs to take into account the differences between all potential users, and researchers must seek a way to make the technology flexible so that it can ensure effective usability for all users.

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