Using Brain-Computer Interface to improve learning skills for students with disabilities: a rapid review

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Abstract –

Brain-Computer Interface (BCI) enables direct communication between the brain and an external device. BCI systems have become a popular area of study in recent years. These technologies can be utilized in various ways to assist people with disabilities and healthy individuals. Regarding substantial BCI advancements, we can say that these systems are on the verge of commercialization. This review has considered current trends in BCI research on inclusive education to assist students with disabilities in achieving improved learning outcomes for all students in an inclusive environment.

Keywords: Brain-computer interface, inclusive education, student with disabilities

1. Introduction

Over the past few decades, research on brain-computer interface (BCI) devices has become widespread. BCI enables a direct connection between the brain and an external device such as a computer, robot, neuro-prosthesis, exoskeleton, speech prosthesis, assistive technology, or wheelchair [1] [2]. Through several focus groups with persons with disabilities, we found an interest in using BCI technology to innovate new solutions and products [3]. These systems can be utilized for a variety of purposes. They are typically employed for clinical purposes but can also be used for entertainment, training, security, treatment, education, safety, communication, and control, among other applications [4][5]. Most BCI systems are separated into invasive and non-invasive approaches. The non-invasive technique is the most popular and most secure of these options. Even though numerous publications have been published and several actual applications have been developed, BCI systems still face numerous obstacles and restrictions.

Understanding how the brain functions to measure and interpret brain waves is crucial. The electrical and magnetic phenomena of neural function can be monitored during brain functioning. The most popular form of electrophysiological observation is electroencephalography [6], in which biosensors measure and record electrical signals generated by brain activity. Brain cells communicate by sending electrical impulses; the more impulses sent, the more electricity the brain generates. The pattern of this electrical activity can be measured by an electroencephalogram (EEG); these EEG data are often analyzed by a quantitative EEG (QEEG) approach, in which the frequency spectrum of the EEG signals is evaluated [7]. Figure 1 presents an overview of possible placement over the scalp to detect and monitor electrical impulses of brain activities [8].

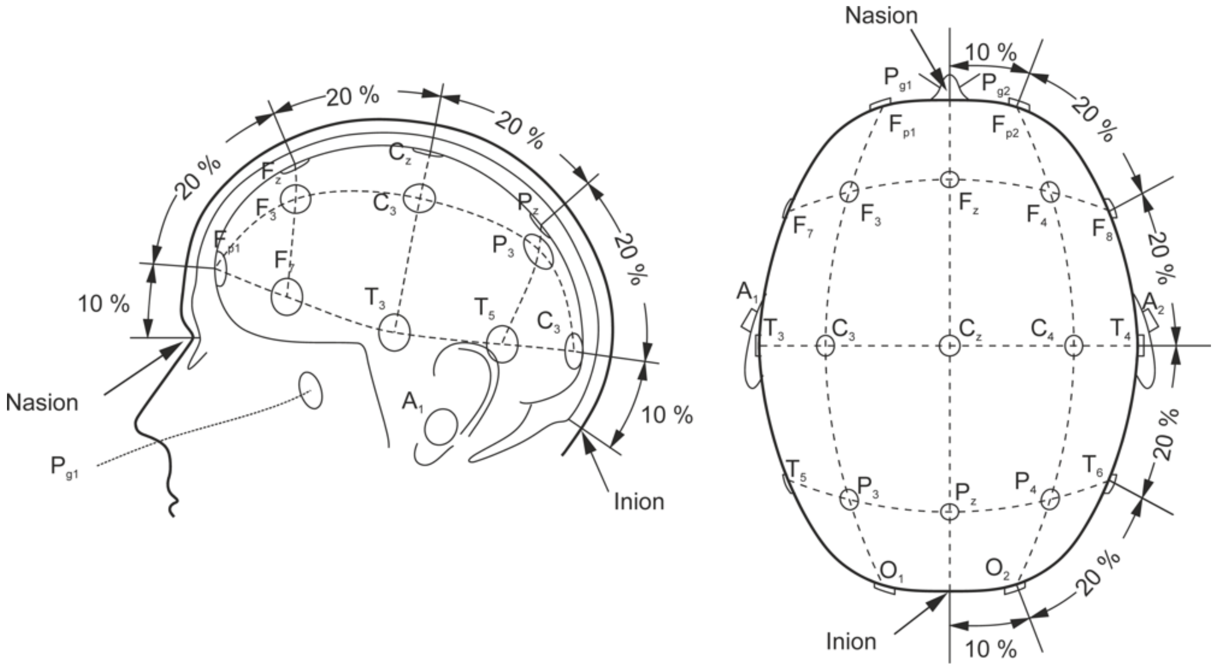

Figure 1. Possible Electrode placement over the scalp.

Taking an EEG requires sophisticated, expensive, extensive, and immobile equipment; however, technological advancements have enabled mobile EEG biosensor-based embedded devices for new applications, including entertainment, control devices, and education. In these applications, a BCI establishes the relationship between the EEG-observed brain activity and the generated function [9]. Advanced BCIs include biosensors and modern signal processing units, are less expensive and more portable due to their simple design, and are as accurate as clinical EEG equipment [10]. Table 1 presents a summary of different methods.

Table 1. Summary of neuroimaging methods.

Neuroimaging method	Activity measured	Direct/Indirect Measurement	Temporal resolution	Spatial resolution	Risk	Portability
EEG	Electrical	Direct	~0.05 s	~10 mm	Non-invasive	Portable
MEG	Magnetic	Direct	~0.05 s	~5 mm	Non-invasive	Non-portable
ECoG	Electrical	Direct	~0.003 s	~1 mm	Invasive	Portable
Intracortical neuron recording	Electrical	Direct	~0.003 s	~0.5 mm (LFP) ~0.1 mm (MUA)	Invasive	Portable

Table 1. Summary of neuroimaging methods.

Neuroimaging method	Activity measured	Direct/Indirect Measurement	Temporal resolution	Spatial resolution	Risk	Portability
				~0.05 mm (SUA)		
fMRI	Metabolic	Indirect	~1 s	~1 mm	Non-invasive	Non-portable
NIRS	Metabolic	Indirect	~1 s	~5 mm	Non-invasive	Portable

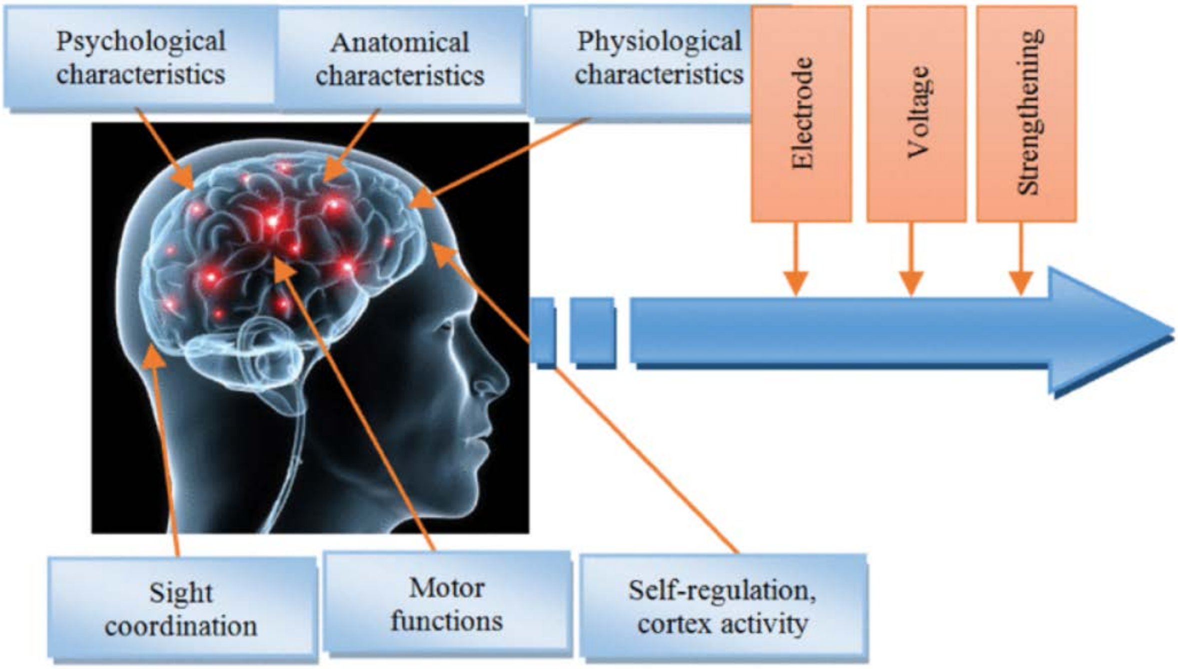

Figure 2. Sample illustration: a model of bioelectric signals.

Education research demonstrates that active student participation facilitates acquiring and retaining new information more effectively than traditional lecture-based instruction [11]. Moreover, when this active engagement is group-based as opposed to individual-based, students' problem-solving, written, and speaking skills, as well as their learning and cooperative skills [12].

Effective acquisition of practical engineering skills is possible through problem-based learning (PBL) [13], team-based learning [14], and project-based learning (PjBL) [15]. Engineering strongly emphasizes the ability to apply information in the real world.

2. BCI as an Assistive Technology

Significant advances have been made in the research of BCI control [16] [17]. It can be used in different use cases such as and not limited to:

- Control of external devices, such as limbs prostheses [18]
- Smart home environments [19]
- Robots and Exoskeletons [20]
- Robotic hand [21]
- Hearing prostheses [22]
- Wheelchairs [23]
- Computer programs [24]
- Virtual reality, avatars, and metaverse [25]
- Virtual environment and smart cities [26]

BCI's most important use is to give individuals intuitive control over overreaching and grasping movements using their paralyzed limbs [27]. Additional possible applications include communication [28]. One of the biggest challenges is restoring and replacing motor function or communication for people with physical disabilities.

3. BCI control in Educational and Serious Games

All kids rely heavily on play for their learning and growth. Both neurotypical and neurodiverse children gain more from engaging in activities that keep them interested, engaged, and offer embedded learning opportunities [29]. However, current BCI software focuses on basic, utility-driven applications, such as spelling grids and cursor movement. While valid, such applications are limited in their appeal for sustained use, particularly for young BCI users. Evidence suggests that enhancing engagement in BCI through gamified learning may result in a broader acceptance of the technology while aiding in the dissemination of BCI control schemes.[30]. A growing trend across BCI research endeavors reveals that more engaging. User-friendly activities may promote a variety of tangible boons in BCI use—both in short-term task learning and long-term BCI accuracy [31]. Therefore, there is an obvious need to support the development of more engaging, accessible BCI software that includes key play components in pediatric BCI.

BCI systems provide the new potential for both virtual plays (e.g., videogames and digital media) and physical play (e.g., manipulation of toy robots, cars, et cetera). Using the non-muscular properties of BCI, such technologies may enable previously excluded populations to explore and learn through play. BCI systems provide potential for both virtual play (e.g., videogames and digital media) and physical play (e.g., manipulation of toy robots, cars, et cetera). Using the non-muscular properties of BCI, such technologies may enable previously excluded populations to explore and learn through play. Previous research has demonstrated mediums as essential for continued learning and rehabilitation in children with disabilities.

Advancements in BCI research furthering the interaction between BCI systems and play thus represent a promising untapped potential for pediatric BCI end-users.

4. The outcome of learning activities using BCI

BCI can play a vital role in closing the knowledge gap and improving educational skills in students with disabilities [32]. The primary learning outcomes of these courses are that students with disabilities can:

- Classify systems based on their properties and understand and exploit the implications of linearity, time invariance, and stability;
- Determine and use Fourier transforms and other signal analysis methods;
- Understand the application of control methods, proportional–integral–differential algorithms, and properties of a control;
- Understand and analyze the design implications and interconnections of physical and control systems;
- Develop mathematical models for real physical and control systems and produce block diagram implementations of the mathematical models and control methods.

BCI can present an alternative technology to control and take online courses during crises [33].

5. Conclusion and future work

In general, BCI connects the brain and external devices. BCI is suitable for the improvement and facilitation of the life of everyone. BCIs can be used in many areas and inclusive education. Overall, findings show that BCI is a topic being closely studied by scientists worldwide. This study also demonstrates that BCI technology was commonly used for medical objectives. In education, BCI can be used in remote learning to control the computer for students with physical disabilities. The technology is still under development and can achieve excellent results with impact in the future.

References

[1] M. Zabcikova, Z. Koudelkova, R. Jasek, and J. J. Lorenzo Navarro, “Recent advances and current trends in brain-computer interface research and their applications,” *Int. J. Dev. Neurosci.*, vol. 82, no. 2, pp. 107–123, 2022, doi: 10.1002/jdn.10166.

[2] Lahiri, Anirban, Achraf Othman, Dena A. Al-Thani, and Amani Al-Tamimi. "Mada Accessibility and Assistive Technology Glossary: A Digital Resource of Specialized Terms." In *ICCHP*, p. 207. 2020.

[3] Al Thani, Dena, Amani Al Tamimi, Achraf Othman, Ahmed Habib, Anirban Lahiri, and Shahbaz Ahmed. "Mada Innovation Program: A Go-to-Market ecosystem for Arabic Accessibility Solutions." In *2019 7th International conference on ICT & Accessibility (ICTA)*, pp. 1-3. IEEE, 2019.

[4] P. Aricò, G. Borghini, G. D. Flumeri, N. Sciaraffa, and F. Babiloni, “Passive BCI beyond the lab: current trends and future directions,” *Physiol. Meas.*, vol. 39, no. 8, p. 08TR02, Aug. 2018, doi: 10.1088/1361-6579/aad57e.

[5] C. S. Nam, A. Nijholt, and F. Lotte, *Brain–computer interfaces handbook: technological and theoretical advances.* CRC Press, 2018.

[6] C. D. Binnie and P. F. Prior, “Electroencephalography.,” *J. Neurol. Neurosurg. Psychiatry*, vol. 57, no. 11, pp. 1308–1319, 1994.

[7] L. S. Prichep and E. R. John, “QEEG profiles of psychiatric disorders,” *Brain Topogr.*, vol. 4, no. 4, pp. 249–257, 1992.

[8] L. F. Nicolas-Alonso and J. Gomez-Gil, “Brain Computer Interfaces, a Review,” *Sensors*, vol. 12, no. 2, Art. no. 2, Feb. 2012, doi: 10.3390/s120201211.

[9] L.-D. Liao *et al.*, “Biosensor Technologies for Augmented Brain–Computer Interfaces in the Next Decades,” *Proc. IEEE*, vol. 100, no. Special Centennial Issue, pp. 1553–1566, May 2012, doi: 10.1109/JPROC.2012.2184829.

[10] A. Andrews, “Integration of Augmented Reality and Brain-Computer Interface Technologies for Health Care Applications: Exploratory and Prototyping Study,” *JMIR Form. Res.*, vol. 6, no. 4, p. e18222, 2022.

[11] M. Prince, “Does Active Learning Work? A Review of the Research,” *J. Eng. Educ.*, vol. 93, no. 3, pp. 223–231, 2004, doi: 10.1002/j.2168-9830.2004.tb00809.x.

[12] J. Katona and A. Kovari, “A Brain–Computer Interface Project Applied in Computer Engineering,” *IEEE Trans. Educ.*, vol. 59, no. 4, pp. 319–326, Nov. 2016, doi: 10.1109/TE.2016.2558163.

[13] M. C. LaPlaca, W. C. Newstetter, and A. P. Yoganathan, “Problem-based learning in biomedical engineering curricula,” in *31st Annual Frontiers in Education Conference. Impact on Engineering and Science Education. Conference Proceedings (Cat. No. 01CH37193)*, 2001, vol. 2, pp. F3E-16.

[14] S. Honeychurch, I. Ikegwuonu, and M. Fletcher, “Team-Based Learning: Optimising active and Collaborative Learning in a blended model of learning and teaching”.

[15] M. Kószó, “Projects on environmental education as means and methods to develop abilities used in the training of lower primary teachers,” in *Proc. Projects Environ. Educ.*, 2013, pp. 136–142.

[16] Luu, Trieu Phat, Yongtian He, Sho Nakagome, and Jose L. Contreras-Vidal. "EEG-based brain-computer interface to a virtual walking avatar engages cortical adaptation." In *2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, pp. 3054-3057. IEEE, 2017.

[17] Hong, Xin, Zhong Kang Lu, Irvin Teh, Fatima Ali Nasrallah, Wei Peng Teo, Kai Keng Ang, Kok Soon Phua, Cuntai Guan, Effie Chew, and Kai-Hsiang Chuang. "Brain plasticity following MI-BCI training combined with tDCS in a randomized trial in chronic subcortical stroke subjects: a preliminary study." *Scientific reports* 7, no. 1 (2017): 1-12.

[18] Buccino, Alessio Paolo, Hasan Onur Keles, and Ahmet Omurtag. "Hybrid EEG-fNIRS asynchronous brain-computer interface for multiple motor tasks." *PloS one* 11, no. 1 (2016): e0146610.

[19] Minguillon, Jesus, M. Angel Lopez-Gordo, and Francisco Pelayo. "Trends in EEG-BCI for daily-life: Requirements for artifact removal." *Biomedical Signal Processing and Control* 31 (2017): 407-418.

[20] Frisoli, Antonio, Claudio Loconsole, Daniele Leonardis, Filippo Banno, Michele Barsotti, Carmelo Chisari, and Massimo Bergamasco. "A new gaze-BCI-driven control of an upper limb exoskeleton for rehabilitation in real-world tasks." *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 42, no. 6 (2012): 1169-1179.

[21] Cho, Jeong-Hyun, Ji-Hoon Jeong, Kyung-Hwan Shim, Dong-Joo Kim, and Seong-Whan Lee. "Classification of hand motions within EEG signals for non-invasive BCI-based robot hand control." In *2018 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, pp. 515-518. IEEE, 2018.

[22] Van Eyndhoven, Simon, Tom Francart, and Alexander Bertrand. "EEG-informed attended speaker extraction from recorded speech mixtures with application in neuro-steered hearing prostheses." *IEEE Transactions on Biomedical Engineering* 64, no. 5 (2016): 1045-1056.

[23] Chen, Xin, Yang Yu, Jingsheng Tang, Liang Zhou, Kaixuan Liu, Ziyuan Liu, Siming Chen et al. "Clinical Validation of BCI-Controlled Wheelchairs in Subjects With Severe Spinal Cord Injury." *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 30 (2022): 579-589.

[24] Gannouni, Sofien, Kais Belwafi, Mohammad Reshood Al-Sulmi, Meshal Dawood Al-Farhood, Omar Ali Al-Obaid, Abdullah Mohammed Al-Awadh, Hatim Aboalsamh, and Abdelfettah Belghith. "A Brain Controlled Command-Line Interface to Enhance the Accessibility of Severe Motor Disabled People to Personnel Computer." *Brain Sciences* 12, no. 7 (2022): 926.

[25] El Ghoul, Oussama, and Achraf Othman. "Virtual reality for educating Sign Language using signing avatar: The future of creative learning for deaf students." In *2022 IEEE Global Engineering Education Conference (EDUCON)*, pp. 1269-1274. IEEE, 2022.

[26] Kohli, Varun, Utkarsh Tripathi, Vinay Chamola, Bijay Kumar Rout, and Salil S. Kanhere. "A review on Virtual Reality and Augmented Reality use-cases of Brain Computer Interface based applications for smart cities." *Microprocessors and Microsystems* 88 (2022): 104392.

[27] Brandman, David M., Tommy Hosman, Jad Saab, Michael C. Burkhart, Benjamin E. Shanahan, John G. Ciancibello, Anish A. Sarma et al. "Rapid calibration of an intracortical brain–computer interface for people with tetraplegia." *Journal of neural engineering* 15, no. 2 (2018): 026007.

[28] Herweg, Andreas, Julian Gutzeit, Sonja Kleih, and Andrea Kübler. "Wheelchair control by elderly participants in a virtual environment with a brain-computer interface (BCI) and tactile stimulation." *Biological psychology* 121 (2016): 117-124.

[29] Kelly, D., Floreani, E. D., Jadavji, Z., Rowley, D., Zewdie, E. T., Anaraki, J. R., Bahari, H., Beckers, K., Castelane, K., Crawford, L., House, S., Rauh, C. A., Michaud, A., Mussi, M., Silver, J., Tuck, C., Adams, K., Andersen, J., Chau, T., . . . Kirton, A. (2020). Advancing Brain-Computer Interface Applications for Severely Disabled Children Through a Multidisciplinary National Network: Summary of the Inaugural Pediatric BCI Canada Meeting. *Frontiers in Human Neuroscience. https://doi.org/10.3389/fnhum.2020.593883*

[30] Powers, J. Clark, Kateryna Bieliaieva, Shuohao Wu, and Chang S. Nam. "The human factors and ergonomics of P300-based brain-computer interfaces." *Brain sciences* 5, no. 3 (2015): 318-354.

[31] Faller, Josef, Jennifer Cummings, Sameer Saproo, and Paul Sajda. "Regulation of arousal via online neurofeedback improves human performance in a demanding sensory-motor task." *Proceedings of the National Academy of Sciences* 116, no. 13 (2019): 6482-6490.

[32] Khribi, Mohamed Koutheair, Achraf Othman, and Aisha Al-Sinani. "Toward Closing the Training and Knowledge Gap in ICT Accessibility and Inclusive Design Harnessing Open Educational Resources." In *2022 International Conference on Advanced Learning Technologies (ICALT)*, pp. 289-291. IEEE, 2022.

[33] Tlili, Ahmed, Natalia Amelina, Daniel Burgos, Achraf Othman, Ronghuai Huang, Mohamed Jemni, Mirjana Lazor, Xiangling Zhang, and Ting-Wen Chang. "Remote Special Education During Crisis: COVID-19 as a Case Study." In *Radical Solutions for Education in a Crisis Context*, pp. 69-83. Springer, Singapore, 2021.