STATE OF THE ART OF BRAIN COMPUTER INTERFACES FROM VOCATIONAL AND EDUCATIONAL TRAINING PERSPECTIVE

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ABSTRACT:

This article delivers a comprehensive overview of the functioning of Brain-Computer Interface (BCI) systems, elucidating the principal technologies employed in brain signal acquisition and activity monitoring, alongside their varied applications. Additionally, it identifies the most suitable technologies for integration into Vocational Education and Training (VET), detailing potential applications within this context. Lastly, the article delineates the optimal interfaces for VET use, highlighting their specific characteristics and functionalities.

KEYWORDS: Brain computer interfaces; BCI, EEG, neuroscience

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1. INTRODUCTION

Brain–computer interfaces (BCIs) are a rapidly evolving technology that has the potential to revolutionize how humans interact with computers. BCIs measure brain activity and translate it into commands for a computer or other device, allowing users to control machines and devices using only their thoughts (Peksa & Mamchur, 2023). The primary objective of developing these neurogadgets is to assist people with disabilities, such as those with limb paralysis or prosthetic limbs. However, neurogadgets are increasingly being used for other purposes, as controlling drones or controlling homes through signals of the brain (Akram, Alwakeel, Alwakeel, Hijji, & Masud, 2022).

Brain-computer interfaces are emerging as a revolutionary technology in various fields, and it is expected that future challenges will require professionals who master this technology. The goal of Basque vocational training is to address these future professionals' needs by preparing them to face these challenges with a solid foundation of personalized skills and knowledge. Integrating this technology into training programs is a strategic investment that can result in a more skilled, inclusive, and continuously innovative workforce.

1.1. How do they work

A typical BCI system consists of four components which are: signal acquisition, feature extraction, feature translation commands, and device output (Abdulwahhab, Myderrizi, & Mahmood, 2022). The operation of the interface typically follows a sequence. First, is the capture of raw signals, which are then processed to remove any noise, digitized, and filtered. Subsequently, the processed signal is analysed to identify corresponding features and patterns, often using various algorithms and artificial neural networks. The decoded command can then be sent to an external device to control it.

BCIs are generally categorized into unidirectional and bidirectional types based on the direction of information flow. Unidirectional BCIs either receive signals from the brain or send them to it, allowing the brain to control external devices, whereas bidirectional BCIs facilitate the exchange of information in both directions, Current research on feedback mechanisms is focused on creating technologies that convert external commands into electrical signals that can be transmitted through the nervous system. For instance, this technology could enable the electrical stimulation of leg muscles in individuals with spinal cord injuries, allowing them to regain mobility by controlling their movements through a device.

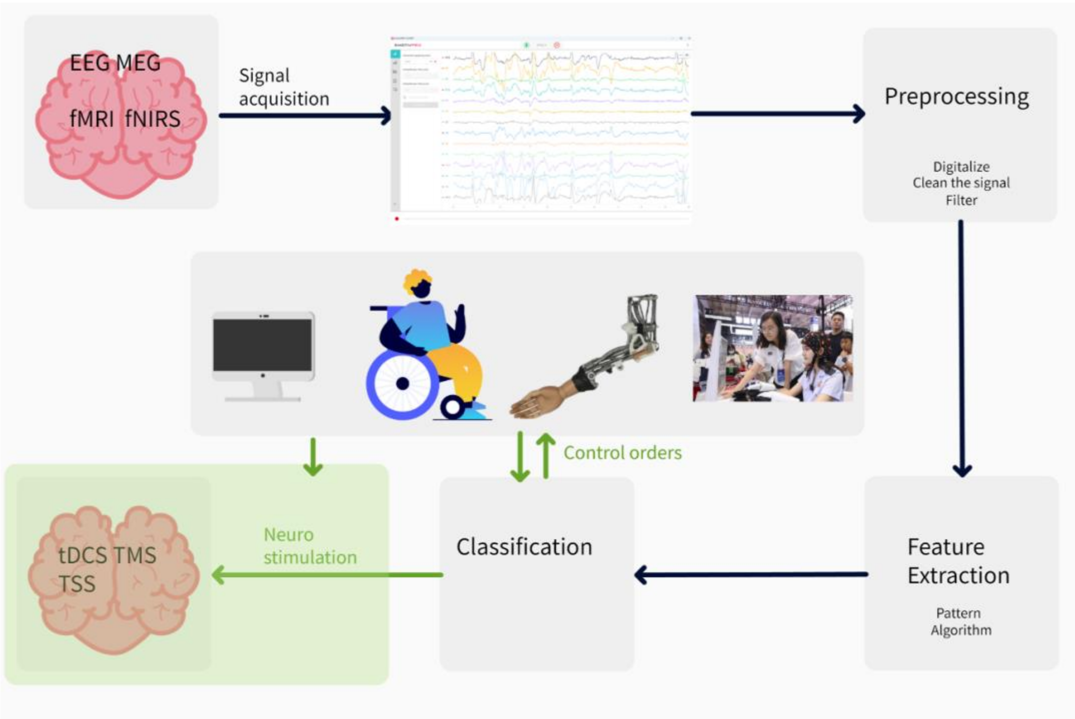

Figure 1. BCI system scheme

There are different types of neural interfaces depending on the degree of invasiveness. Invasive neural interfaces require surgery to implant electrodes into the human brain. Although they offer the highest efficacy, they also pose greater risks. Non-invasive neural interfaces analyse brain activity from the surface of the head using techniques such as electroencephalography (EEG), magnetoencephalography (MEG), or functional magnetic resonance imaging (fMRI). These methods do not require surgery. Semi-invasive brain-computer interfaces (BCIs) involve placing electrodes beneath the skull bone on the brain's surface, as in the case of electrocorticography (ECoG).

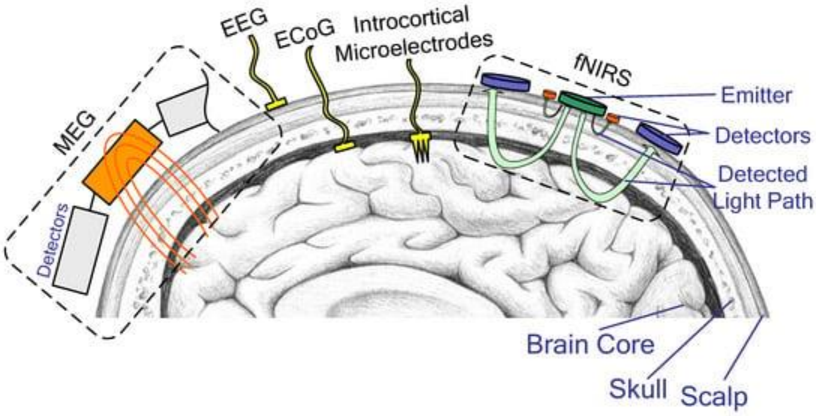

Figure 2. BCI sensors types (Peksa & Mamchur, 2023)

At present, invasive and semi-invasive interfaces are mainly used in medical contexts to improve the well-being of people with disabilities or to improve or prevent neurodegenerative diseases. In contrast, non-invasive neural interfaces have been gaining traction in the gaming industry, meditation, neuromarketing, and other fields. As more devices are developed and commercialized, these sectors may experience a major revolution. It is anticipated that in the future, it will be possible to mentally control different devices and perhaps read and control human thoughts.

2. BCI TECHNOLOGIES AND APPLICATIONS

2.1. BCI Technologies

Various technologies are employed in brain-computer interfaces (BCI), each providing different types of information. Some of these technologies are based on capturing electrical signals, such as electroencephalography (EEG), while others use brain imaging, like functional magnetic resonance imaging (fMRI), or measure blood oxygen levels, such as near-infrared spectroscopy (fNIRS). These technologies differ in terms of the spatial and temporal resolution they offer; for instance, fMRI provides high spatial resolution but low temporal resolution, whereas EEG offers the opposite. Additionally, each technology has specific applications, some are more suitable for medical diagnostics, while others are ideal for measuring concentration or assessing cognitive processes. The choice of the appropriate technology depends on the specific goals of the study and the particular needs of the user.

Below there is a brief description off different existing technologies, their main characteristics and advantages and disadvantages.

EEG:

- Sensors measure electrical activity produced by neurons
- Non-invasive technique
- Good temporal resolution
- Relatively inexpensive and portable
- Detects changes within milliseconds
- Well-suited for BCI due to portability
- Sensitive to noise and artifacts
- Difficult feature extraction
- Requires efficient classification algorithms
- Needs intuitive user interfaces
- Algorithms must adapt to individual users
- System reliability over time

fNIRS:

- Uses light to measure changes in oxygenated haemoglobin
- Good spatial resolution
- Monitors multiple brain areas simultaneously
- Weak signals affected by noise
- Limited spatial resolution
- Low temporal resolution
- High cost
- Potential eye safety risks

MEG:

- Records magnetic fields produced by brain activity
- Very high temporal resolution
- Excellent signal-to-noise ratio
- Detects subtle changes in neuronal firing patterns
- Very expensive equipment

- Limited spatial resolution
- Long acquisition times
- Interference from head movements

ECoG:

- Electrodes placed directly on the cortical Surface
- Excellent temporal and spatial resolutions
- Direct contact with cortical neurons
- Risks from invasive surgery (infection, bleeding)
- Complex signal acquisition and interpretation
- Safety and ethical considerations

PET:

- Imaging technique using radioactive tracers to measure metabolic brain activity
- Good spatial resolution
- Useful for studies of brain metabolism and blood Flow
- Low temporal resolution
- Use of radioactive tracers
- Expensive and non-portable
- Requires specialized facilities

fMRI:

- Measures changes in blood flow related to neural activity using magnetic fields and radio waves
- Excellent spatial resolution
- - Non-invasive
- Low temporal resolution
- Expensive and non-portable
- Sensitive to head movements
- Requires controlled environment and specialized equipment

2.2. BCI APPLICATIONS

Within Brain-Computer Interfaces (BCIs), various technologies exist across different stages of development and fields such as medicine, neuroscience research, education and training environments, human-computer interaction, neuromarketing, military applications, and even gaming and entertainment. These technologies enable users to control virtual objects solely through their thoughts, without the need for any physical movement.

Neuroprosthetics: BCIs enable individuals with physical disabilities to control devices like wheelchairs and robotic arms using brain signals. The BCI systems records neural activity to command external devices. This field aims to restore communication for those affected by injury or illness and enhance control of prosthetic limbs. Applications include brain-controlled robotic arms for users with spinal cord injuries or amputations and restoring communication for those with conditions like ALS. Neural implants in neuroprosthetics combine biological and artificial components for faster responses.

Communication: BCIs develop new ways for people with paralysis or similar conditions to communicate. They detect users' intentions from brain signals, converting them into text or speech. This tech helps people unable to speak or write. BCI applications in communication include typing on keyboards and voice commands. Future tech may allow generating language through thought alone.

Meditation: BCIs enhance meditation by providing real-time feedback on brain activity, helping achieve deeper meditative states. EEG headsets measure brain activity, offering feedback through sounds or visuals. Users can track progress and personalize their meditation practices. The technology helps manage stress and anxiety by recognizing brain state changes. BCI-assisted meditation aims to improve mental health and well-being.

Sleep: BCIs improve sleep quality and diagnose psychiatric and neurodegenerative diseases by analysing sleep stages. EEG-based systems measure brain activity during sleep, tracking REM and non-REM cycles. BCIs treat insomnia with neurostimulation therapies like tACS. Combining tACS with cognitive therapy enhances sleep treatments. Sleep BCIs offer insights into sleep and provide personalized interventions for better sleep health.

Neuromarketing: BCIs study consumers' brain responses to advertising stimuli, offering insights into preferences and behaviours. BCIs record brain activity during ads to improve marketing strategies. They evaluate product and packaging effectiveness, optimizing designs for consumer appeal. Neuromarketing with BCIs helps create targeted campaigns. As tech advances, BCIs will offer more precise consumer behaviour insights.

Education: BCIs enhance learning by providing real-time cognitive feedback, helping students focus better. They aid special needs students in controlling movements and communicating. BCIs improve engagement and motivation in learning. They teach abstract concepts through direct experience. BCIs reduce stress and personalize learning by tailoring lessons based on brain activity data.

Gaming: BCIs in gaming allow interaction with virtual environments using thoughts. For example, EMOTIV EPOC + Neuroheadset improves the users' gaming experience and to give them new and more intuitive game controlling, as well as a way to play videogames, using brain signals (Zając & Paszkiel, 2020). Research explores BCIs in virtual reality gaming. BCIs offer new gameplay experiences by tapping into emotions and thoughts. Advancements may make BCIs a significant part of gaming.

Mental Health: BCIs treat mental health conditions like depression, anxiety, and addiction by monitoring brain activity. They assess cognitive processes, detect emotional changes, and provide therapy feedback. BCIs help manage symptoms through self-regulation techniques. Portable EEG systems offer real-time monitoring. BCIs could revolutionize mental healthcare by enabling early intervention and personalized treatments.

Military Enhancement: BCIs enhance soldiers physical and mental capabilities on the battlefield. They monitor soldiers' mental states, improving efficiency and reducing errors. BCIs integrate with AR systems for real-time tactical information. Soldiers can control devices and vehicles mentally. BCIs promise increased military effectiveness and new tech integration on the battlefield.

3. BCI IN VET

3.1. BCI Technologies used in VET

The most commonly used platform for BCI research and especially in education is electroencephalography (EEG). EEG measures the electrical signals produced by neurons in the brain through electrodes placed on the scalp, providing researchers, developers, or students with detailed information about neural activity associated with different cognitive functions.

The choice of technology depends on various factors and criteria, including equipment cost, usability, and learning curve. EEG is the most commonly used due to its low cost and portability. In terms of characteristics, it offers good temporal resolution but lacks spatial resolution, making it less suitable for certain applications. fMRI, on the other hand, provides a non-invasive option with higher spatial resolution than EEG but has lower temporal resolution.

EEG records activity mainly from the outer layers of the brain (i.e., has low spatial resolution). With a single sensor, it is impossible to identify the source of the activity. Recording with a large number of channels can allow mathematical reconstruction of the source, but it is still limited in identifying deep sources. Functional magnetic resonance imaging (fMRI) is better suited to answer questions such as “Which part of the brain is related to changes in attention?”

The electroencephalogram (EEG) is a widely utilized tool for monitoring the brain's electrical activity. EEG signals, which visually represent the brain's frequency activity, are commonly employed as inputs for brain-computer interface (BCI) systems. EEG has been instrumental in diagnosing and treating neurological disorders, monitoring sleep patterns, and investigating cognitive processes such as attention and memory. Due to its non-invasive data collection and relatively straightforward signal interpretation, EEG remains one of the most prevalent BCI techniques today.

Technological progress has resulted in EEG sensors that are smaller, lightweight, user friendly and affordable while maintaining high accuracy and reliability compared to traditional systems. Many modern EEG systems incorporate dry electrode designs, eliminating the need for conductive gels previously required for proper functionality. Additionally, the advent of portable devices allows users to record their own EEG signals without needing to visit a clinic, often utilizing Bluetooth connectivity to wirelessly transmit data directly to computers for analysis. All the characteristics make EEG a suitable and easily integrable technology for VET studies.

The overall quality of EEG signals is influenced by both the number and placement of electrodes. Increasing the electrode count can enhance spatial resolution, enabling more detailed analyses. Furthermore, a higher number of electrodes facilitates better noise reduction techniques such as averaging or interpolation. However, increasing the electrode count also raises the cost and complexity of the recording equipment. Therefore, it is essential to balance the benefits of improved accuracy with the additional hardware requirements when selecting an optimal sensor configuration.

Most commercial EEG headsets utilize the international 10-20 system for electrode placement. This system is a standardized technique to place the electrodes across the scalp, and this technique is performed according to the 10–20 international system (Dadebayev, Goh, & Tan, 2022). The "10" and "20" refer to the actual and nominal percentages of the distance between specific landmarks on a subject's head. The 10-20 system ensures a consistent and replicable framework for EEG electrode placement across different subjects, which is crucial for obtaining consistent and comparable results across various EEG studies.

3.2. Possible BCI applications in VET

Automation and Home Automation Projects

Control of home devices: Develop systems that allow controlling appliances, lights, and other domestic devices through brain signals, making the lives of people with reduced mobility easier.

Rehabilitation and Medical Assistance Projects

Development of brain-controlled prostheses: Students can work on the design and programming of limb prostheses that respond to brain signals, helping people with amputations regain mobility.

Communication systems for people with paralysis: Create interfaces that allow people with severe motor disabilities to communicate using their thoughts, such as virtual keyboards controlled by the mind.

Entertainment and Games Projects

Mind-controlled video games: Develop video games where players can interact and control the game using only their thoughts, creating an immersive experience.

Virtual reality applications: Integrate BCI into virtual reality environments to offer more interactive and personalized experiences.

Projects in the Field of Education

Personalized learning tools: Create educational applications that adapt to the student's needs in real time, analysing their state of concentration and adapting educational content accordingly.

Projects related to Brain-Computer Interfaces (BCIs) in vocational training can significantly improve student motivation and help create motivational challenges. Integrating BCIs into the curriculum provides students with the opportunity to work with cutting-edge technologies, which increases their interest and enthusiasm for learning. These projects allow them to see the direct and tangible impact of their efforts, such as the development of devices that improve the quality of life of people with disabilities. Additionally, by facing complex challenges and solving real problems, students gain a sense of achievement and purpose. The innovative and multifaceted nature of BCI projects, which span areas such as neurorehabilitation, automation, and entertainment, offer a dynamic learning environment where students can explore their interests and develop technical and creative skills, keeping them constantly motivated and engaged

3.3. BCI Headsets for VET

NextMind: The NextMind is a brain computer interface device designed to allow users to control digital devices using their thoughts. It is an EEG headset that allows to detect neural signals from visual cortex. Additionally, NextMind provides Software Development Kits

(SDKs) for developers, enabling them to create custom applications and integrations that leverage this innovative technology. The NextMind neurogadget has been acquired by Snapchat's parent company, Snap Inc., on 2022 and the standalone product is no longer available for purchase.

Emotiv Epoc: The Emotiv Epoc is a high-resolution, multi-channel EEG system with 14 EEG channels and 2 reference channels. It comes with EmotivPRO software for data acquisition and analysis, and it offers an API for developers to create custom applications. The Epoc is suitable for research, advanced BCI applications, and educational purposes due to its comprehensive features and robust data quality.

Emotiv Insight: The Emotiv Insight is a sleek, lightweight, 5-channel EEG headset designed for real-time brain activity monitoring. It is accompanied by the Emotiv App for mental state tracking and cognitive training. Developers can use an API to integrate the Insight with custom applications. Its user-friendly design and educational tools make it ideal for classroom settings and personal cognitive development.

NeuroSky: NeuroSky offers affordable, user-friendly EEG headsets like the MindWave, featuring single-channel EEG sensors. The NeuroSky App Store provides various apps for education, meditation, and entertainment. NeuroSky also supports a Unity SDK, enabling developers to create custom applications. Its simplicity and affordability make it well-suited for educational purposes, particularly in introductory neuroscience and cognitive science courses.

Muse: The Muse headband, designed for meditation and mindfulness, features 4 EEG sensors and comes with the Muse App for real-time feedback and progress tracking. While Muse primarily focuses on consumer wellness, it offers SDKs for integration into custom applications. Muse is increasingly used in educational settings to teach mindfulness and stress management techniques.

OpenBCI Ultracortex: The OpenBCI Ultracortex is a customizable, open-source EEG headset supporting up to 16 channels. It includes OpenBCI software for data analysis and visualization. Its flexibility and open-source nature make it highly suitable for educational environments, from high school projects to advanced university research.

Unicorn Hybrid Black: The Unicorn Hybrid Black is a portable, 8-channel EEG headset designed for both professional and personal use. It comes with Unicorn Suite software for comprehensive neurofeedback and cognitive training applications. A Unity SDK is available, allowing developers to create custom applications. Its ease of use and robust functionality make it a good choice for educational settings, particularly in higher education and specialized training programs.

Neurosity: The Neurosity Notion headset is an 8-channel EEG device designed to improve productivity and focus. It includes the Neurosity Crown software for real-time brain activity tracking and optimization. The headset offers a free SDK for developers to create custom cognitive applications. Neurosity's focus on cognitive enhancement makes it suitable for educational environments, particularly for courses and workshops on neurofeedback and productivity enhancement.

3.4. Our Approach in Basque VET

In Basque vocational training, the first project employing BCI technology was initiated in 2021. This project involved controlling a Tello drone using the NextMind neurogadget, with a proprietary development utilizing NextMind libraries for Unity. Following this, another development was carried out in Unity using NextMind to send commands to a smart home via the MQTT protocol. Currently, efforts are underway to replicate this functionality using the Unicorn Black headset from g·Tech, as NextMind has been discontinued since 2022.

The integration of BCI technology in vocational training represents a strategic investment in building a more skilled, inclusive, and continuously innovative workforce. By embracing these advanced tools, we are preparing professionals to meet future challenges with a robust foundation of personalized skills and knowledge. This forward-thinking approach ensures that vocational training programs remain at the forefront of technological advancement, fostering an environment where innovation thrives.

4. CONCLUSION

In this article, we have outlined what Brain-Computer Interface (BCI) systems entail, their various applications, and the technologies used to capture brain signals or activity at a general level. Additionally, we have identified the most suitable technology for use in vocational training and discussed potential applications and the neurogadgets best suited for this purpose.

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