Samen aanjagen van vernieuwing

Introducing Brain-Computer Interfaces for Education and Research

Reimagine the human-computer interactions, for better or for worse

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1. Introduction

Executive Summary

Brain-computer interfaces (BCIs) offer various applications from assisting in speech communication to controlling external devices like artificial limbs. The distinction between implantable and non-implantable BCIs is crucial, with implantable BCIs offering higher accuracy but posing certain risks. Despite the promising advancements, challenges such as data privacy and ethical considerations persist besides cybersecurity. However, the growing interest in BCIs, increasing availability on the market and ongoing research promise a potential future where BCIs become integrated into various aspects of daily life. But is this potential feasible, or desirable? One thing is for sure, it will still take some more decades.

Early 2023, Elon Musk's Neuralink announced they would start recruiting participants after approval from a hospital institutional review board. The approval meant Neuralink could perform an experimental brain implant to "grant people the ability to control a computer cursor or keyboard using their thoughts alone" (Neuralink, 2023). In January 2024, Neuralink implanted a chip into a participant's brain. The progress continues as Neuralink's first patient achieved a remarkable milestone. The 29-year-old, paralysed by a car accident, was reported to be able to play video games and make posts on X by only using his thoughts (Reuters, 2024). The approval of Neuralink's first-in-human clinical trial has earned significant attention from the media.

In this whitepaper, we will briefly examine the background of brain-computer interfaces (BCI) includingrecent developments, current and potential application areas, and its possible impact on education and research. We will touch upon ethical considerations related to BCIs, but our discussion will not delve deeply into this aspect. We gather insights from desk research and interviews with three experts:

- Anne-Marie Brouwer, senior scientist at TNO and professor at Radboud University on Mental State Monitoring;
- Jan Willem van 't Klooster, associate professor of monitoring and coaching technologies at the University of Twente;
- Mariska Vansteensel, assistant professor at the Department of Neurology and Neurosurgery of UMC Utrecht, and President of the BCI Society.

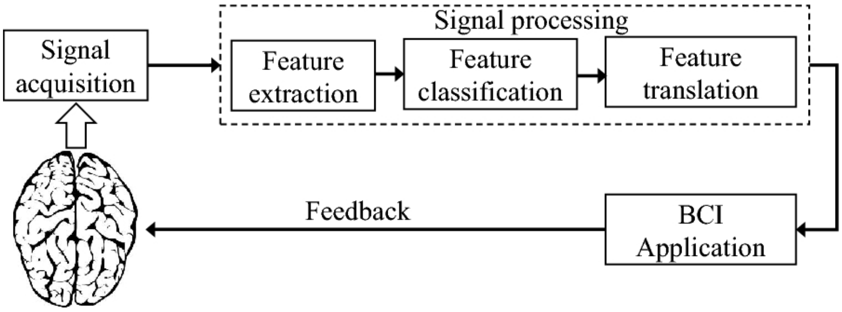
1.1 Background

Brain-Computer Interface is a system that collects brain signals, analyses them and translates them into commands to control an external device (Mullin, 2023). The starting point of brain-computer interfaces dates back to 1924. That year Hans Berger created a device that can measure brain activity using electroencephalography (EEG) (Ince, Adanir, & Sevmez, 2020). Five decades later the term 'Brain-Computer Interface' was introduced in 1973 by Jacques Vidal in his paper at the University of California. Vidal described BCI as "a link between the brain and a computer" (Vidal J. J., 1973). The brain continuously fires electrical signals that can be read out by sensors. These signals can be translated into commands to be used by a computer. In his publication, Vidal refers to a computer as "a prosthetic extension of the brain" (Vidal J. J., 1973). Vidal also completed the first scientific experiment using a 'non-implantable' BCI to move a cursor on a computer screen (Vidal J. J., 1977).

Since Vidal's experiments, BCIs have advanced significantly in accuracy, speed, and usability, paving the way for new possibilities for applying them in various domains. In 2006, Leigh Hochberg's group demonstrated cursor control through a Brain-Computer Interface (BCI) implant, marking a significant advancement in the field (Hochberg et al., 2006) Over the years, subsequent research has showcased even more sophisticated forms of control. Notably, researchers have achieved impressive feats such as accurately and swiftly decoding speech using BCIs. This progress underscores the remarkable evolution in BCI technology and its potential to revolutionise communication and control interfaces for individuals with motor disabilities.

2 What is a Brain-Computer Interface?

BCIs strive to establish (direct) communication between the brain and a device. This device is usually a computer used for practical applications. These applications often focus on restoring lost body functionalities. The first developments were using BCIs to enable paralysed people to use a computer. A requirement for BCIs is having a closed feedback loop. This means that the actions triggered by the brain activity are noticeable to the end user, like moving a cursor on a screen.



From: Brain–computer interface: trend, challenges, and threats (Maiseli et al., 2023)

2.1 Techniques for reading brain activities

A clear distinction that can be made for BCIs is between implantable and non-implantable BCI. Implantable BCIs are surgically implanted in the body of the user close to the nervous system. Non-implantable BCIs are placed on top of the participants' skin and are removable (Kumar, 2021). These different technologies can extract information from the brain, allowing a device to use it. To give you an overview of techniques for reading brain activities we listed some of them in the following table.

Table 1 Overview reading brain activities techniques

BCI technique	Implantable /non-implantable	Description
ElectroEncephaloGraphy (EEG)	Non- implantable	Measures electrical signals from the brain by placing sensors on the scalp.
Magnetoencephalography (MEG)	Non- implantable	Detects the brain's magnetic fields produced by its electrical activity.
Functional Near-Infrared Spectroscopy (fNIRS)	Non- implantable	Measures BOLD (blood oxygen level dependent) signals, in essence the metabolism of the brain by placing sensors (or magnets) on the scalp.
Functional Magnetic Resonance Imaging (fMRI)	Non- implantable	Measures BOLD (blood oxygen level dependent) signals, in essence the metabolism of the brain by using a MRI scan.

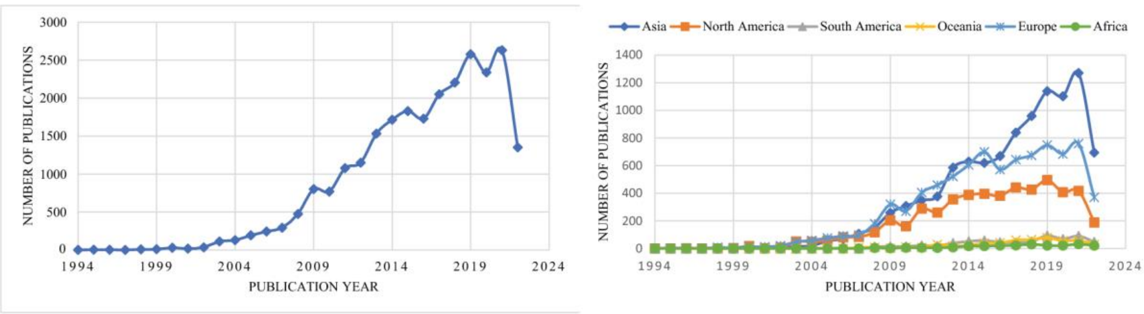
ElectroCorticoGraphy (ECoG)	Implantable	Measures electrical signals from the brain using sensors placed directly on top of the brain. Higher data quality of measurement compared to EEG. High temporal and high spatial resolution.
Intracortical multielectrode arrays (MEA)	Implantable	Tiny needles placed directly into the brain to record and stimulate neural activity
Stentrode	Implantable	inserted into blood vessels near the brain.
StereoElectroEncephaloGraphy (SEEG)	Implantable	Neurosurgical procedure that involves placing multiple depth electrodes into specific regions of the brain.

Brouwer points out the difference between active and passive BCIs. Van ‘t Klooster is making a distinction between direct and indirect BCI. Vansteensel acknowledges the complexity of BCI and mentions that the BCI Society is currently reviewing the definition of BCI as there is a broad interpretation currently of what is or is not considered to be a BCI.

We still have to improve our understanding of the functioning and structure of the brain. The more we know about the brain, the more possibilities we have for BCI (Becht & Committee on Legal Affairs and Human Rights, 2020) (Devlin, 2023). Despite technological advancements, Brouwer highlights challenges in interpreting brain activities and ensuring data quality, while van ‘t Klooster emphasises the impact of movement artefacts on data integrity and signal interpretation, which is mostly a problem by non-implantes BCIs. These obstacles underscore the complexity of developing reliable BCI systems.

2.2 Growing interest in BCI research

In recent years rapid progress has been made in BCI technologies. The number of papers on BCIs is rising, pushing the boundaries of what we can accomplish with BCIs (Maiseli, 2023). The rise seems to be due to a small increase in affordability, ease of use, accuracy and accessibility of the technology and the combination with technologies like machine learning (ML) and extended reality (XR) according to Van 't Klooster. Vansteensel acknowledges the advancements in this research area as AI/ML supports the processing of signals when it comes to interpretation or prediction. Despite the rise, there are a handful of people who use BCIs in their daily lives.
Vansteensel suggests that despite the increasing interest, there are limitations such as the overheating in some cases of currently used implants, with the challenge lying in developing new fully implantable systems to address this issue.



(a) Overall publication trend (b) Continental publication trend

From: Brain–computer interface: trend, challenges, and threats
Note: The decline observed at the end is likely a result of (for now) incomplete data.

While Elon Musk's Neuralink has predominantly captured media attention, an example of another media-attracting company is Meta. Meta has been working with a team of researchers from the University of California, San Francisco (UCSF) after Regina Dugan asked a provocative question: "What if you could type directly from your brain?" on the stage at F8 in 2017 (Meta, 2017). In 2020 Meta shared a vision of a hands-free interface: "*Imagine a world where all the knowledge, fun, and utility of today's smartphones were instantly accessible and completely hands-free*" (Meta, 2020). Since 2017, Meta made progress with UCSF and a milestone has been achieved in 2021 with project Steno by demonstrating the successful decoding of attempted conversational speech in real-time (Meta, 2021). However they tossed the program, which was no surprise to researchers, as their timeframe was too short (Regalado, 2021). But what if someone actually took the time and resources needed? It's important to note that numerous other companies are actively supporting research in the field of brain-computer interfaces and indeed investing their time and resources, albeit receiving less or no media attention.

3 From clinical trials to the consumer market

3.1 Maturity level of BCIs

There are estimated to be about 60 brain implants completed in the last two decades, most of them aren't in use anymore, but all of these BCIs are experimental and applied to certain cases. The number will most likely increase in the next few years with more technological advancements (Howard, 2022). The market value of BCIs is expected to grow as well. The market value in 2022 was worth 1.9 billion USD. The expectation is that it will rise to 8.9 billion USD in 2032 (Acumen Research and Consulting, 2023). The expanding prevalence and market value of BCIs highlight the necessity of exploring their diverse applications, showcasing the transformative potential of BCI technology in various fields.

3.2 Recent BCI research and application areas

3.2.1 Decoding (attempted) speech

There have been breakthroughs in enabling speech-impaired people to speak again. Multiple studies have been conducted to achieve neuroprosthetic speech.nUMC Utrecht was the first in the world to demonstrate that a fully implantable BCI can serve as a practical communication tool for individuals with severe motor and communication impairments (Vansteensel et al., 2016). Since then, researchers have heavily focused on decoding (attempted) speech from the brain (Berezutskaya et al., J Neural Eng 2023; and Moses et al.). Vansteensel explains that parts of the brain responsible for vocal motor function are read out, and these signals are processed and interpreted to generate real speech. AI is used for the interpretation of the neural signals, and prediction of the attempted speech. Moses et al. (2021) used a method of deep-learning algorithms to create calculations that figure out and categorise words by looking at patterns in brain activity. These programs helped them understand and complete sentences by predicting the next word based on what was said before. This example of neuroprostetic speech, showcases the intersection of neuroscience and artificial intelligence (Wang et al., 2023).

3.2.2 Attention and mindfulness

Another application of BCI is the area Brouwer looks into: attention span and memory. BCIs are entering the consumer market to tap into people's urge to monitor/quantify themselves. An application with EEG is intended to assist users during meditation by reading their neural activity and using other measurements, like physical movement and an optical heart rate monitor. This information is processed in mobile apps to give users feedback on their focus during meditation sessions (Muse, 2024). Another example is a tracking device that helps create awareness around stressful situations. Integrating BCIs into consumer products underscores their potential to impact daily life.

3.2.3 Collaborative work

BCIs have also been incorporated into a so-called brain-to-brain interface. Next to reading brain signals, behaviour is also influenced by stimulation of certain brain regions. A recent example is the BrainNet project by researchers at the University of Washington (Jiang, 2019). Three participants were asked to play a Tetris-like game. A brain-to-brain network was established between three people - who couldn't speak to, hear, or see each other - to receive and send information using their brains to solve a task. Five groups of three participants had an accuracy of 81% to perform the task. The BrainNet project used both EEG and rTMS techniques for this brain-to-brain interface. This example showcases the importance of how BCI technology can enable direct brain-to-brain communication and collaboration, showcasing interdisciplinary progress and practical applications.

3.2.4 Immersive virtual reality

In the potential future, supporters of 'neural nanorobotics' envision BCIs being applied in various ways. These applications may include: fully immersive virtual reality that closely resembles reality, augmented reality displaying real-world information, real-time translation of foreign languages through auditory means, and access to diverse forms of online information. Additionally, there's a concept of experiencing the lives of willing individuals globally through non-intrusive 'Transparent Shadowing' in fully immersive, real-time episodes (EMOTIV, n.d.). The Social Creative Technologies Lab of Wageningen University is also conducting experimentation in this area. The application of BCIs in immersive virtual reality shows promises to reshape how we perceive and interact with the digital world.

3.2.5 Device control

BCIs can also be used to control external devices to support us in our daily lives with tasks, according to Vansteensel. An example is moving a cursor on a screen, or controlling an artificial limb (Collinger et al., 2018). With improved BCIs you could use your neural activity to control smart devices. Currently, research projects are looking into combining BCI with augmented reality to control devices (Zhang et al., 2022).

4 What if…

BCI's primary function has been reading out brain information to translate this into certain commands on a computer (closing the feedback loop). Next, we try to imagine a few situations of the potential of BCI in our daily lives.

4.1 The perfect non-invasive learning environment

BCIs have been used less in education at the moment, but this is changing. A very recent example is the University of Twente's recent experiment conducted among 20 students to measure alertness levels while completing tasks. Such data could be used as measurable feedback to the teacher, who could react to this information to improve the quality of the provided education (University of Twente, 2024).

Imagine there wouldn't be a teacher in this situation and it was an online learning environment. Imagine also the students using an XR device and the system immediately adapts to the current mental state of the students to provide the ultimate learning experience for each student. With more technological advancements over the next years, the use of BCIs could become more common. A BCI could be used to measure attention levels, mood, or the amount of information being obtained by a student. Looking at the accessibility and affordability of the BCI technologies, and current research activities by various universities and the R&D labs in the tech industry, this might not be a too far future.

4.2 Ultimate life hack

BCIs are used to monitor attention, as mentioned in the previous chapter. Imagine, you are working under great pressure and you have to remain focused. A BCI measures alertness and gives you a warning when you tend to doze off. In a less stressful environment, a BCI can give you all sorts of benefits in combination with automation. Think about controlling your home or office environment just by using your thoughts, like when you think about taking a break and the coffee machine already made you a cup of coffee when you reach the machine. Imagine when it senses you might need something, like adjusting the light and the climate in a meeting room to keep your attention.

4.3 Competitive regions in the race for BCI

BCIs might complicate fundamental (human) rights such as privacy, integrity, and protection against self-incrimination. Because of ethical considerations and risks, the European Commission has a strict regulation concerning emotional AI and BCI technologies to protect civilians (European Parliament, 2023). The potential misuse of BCIs for unintended purposes is a legitimate concern. Without adequate regulations, these technologies could be exploited undermining societal values and norms, posing significant ethical and societal risks.

5 Wrapping-up

The development of BCI technology is in full swing. The progress in BCI technology shows great potential for enhancing both the lives of disabled individuals and overall human capabilities. With careful consideration of ethical concerns and privacy issues, BCIs have the potential to revolutionise fields as research and education and empower individuals in unprecedented ways. By fostering transparency and responsible usage, we can ensure that BCIs contribute positively to society, unlocking new possibilities for human-computer interaction and promoting greater well-being. However, there is plenty to be discovered and researched about our brains. There are still technological difficulties regardless of ethical considerations. A few of those considerations are cybersecurity and stability and usability of BCIs. One might also wonder: “What is the major benefit of having BCIs in our daily lives when there are other technologies to consider?”.

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References

Acumen Research and Consulting. (2023, 10). *Brain Computer Interface Market Size - Global Industry, Share, Analysis, Trends and Forecast 2023 - 2032*. Retrieved from Acumen: Maiseli, B., Abdalla, A.T., Massawe, L.V

ANT Neuro. (2023). Retrieved from https://www.linkedin.com/feed/update/urn:li:activity:7129904241179029505/

Bacher D, Jarosiewicz B, Masse NY, et al. Neural Point-and-Click Communication by a Person With Incomplete Locked-In Syndrome. Neurorehabilitation and Neural Repair. 2015;29(5):462-471. doi:10.1177/1545968314554624

Becht, O. & Committee on Legal Affairs and Human Rights. (2020). *The brain-computer interface: new rights or new threats to fundamental freedoms?* (Doc. 14814, Reference 4435). Committee on Legal Affairs and Human Rights. Geraadpleegd op 1 april 2024, van https://pace.coe.int/en/files/28722/html

Berezutskaya, J., Freudenburg, Z. V., Vansteensel, M. J., Aarnoutse, E. J., Ramsey, N. F., & Van Gerven, M. a. J. (2023). Direct speech reconstruction from sensorimotor brain activity with optimized deep learning models. *Journal of Neural Engineering*, *20*(5), 056010. https://doi.org/10.1088/1741-2552/ace8be

BrainRobotics. (2024, January 9). *BrainRobotics Hand - BrainRobotics*. https://brainrobotics.com/brainrobotics-hand/

Brueck, H. (2022, 11 10). *A man with ALS who can't use his hands got a brain implant that lets him text, shop online, and play games — just by thinking. It could be a game-changer.* Retrieved from Insider: https://www.insider.com/brain-computer-interface-what-is-it-how-does-it-work-2022-9

Collinger, J. L., Gaunt, R. A., & Schwartz, A. B. (2018). Progress towards restoring upper limb movement and sensation through intracortical brain-computer interfaces. Current Opinion in Biomedical Engineering, 8, 84-92.

Cleveland Clinic. (2022). *Transcranial Magnetic Stimulation (TMS)*. Retrieved from Cleveland Clinic: https://my.clevelandclinic.org/health/treatments/17827-transcranial-magnetic-stimulation-tms

Company, F., & Meta. (2019, November 7). F8 2017: AI, Building 8 and more technology updates from day two. *Meta*. https://about.fb.com/news/2017/04/f8-2017-day-2/

Devlin, H. (2023, 05 1). *AI makes non-invasive mind-reading possible by turning thoughts into text*. Retrieved from the Guardian: https://www.theguardian.com/technology/2023/may/01/ai-makes-non-invasive-mind-reading-possible-by-turning-thoughts-into-text

Eisenstein, M. (2024). Seven technologies to watch in 2024. In Nature (Vol. 625, p. 844). https://media.nature.com/original/magazine-assets/d41586-024-00173-x/d41586-024-00173-x.pdf

Eliaz, N. (2019). Corrosion of Metallic Biomaterials: A Review. Tel-Aviv University, Department of Materials Science and Engineering, Ramat Aviv. Retrieved from https://www.mdpi.com/1996-1944/12/3/407

EMOTIV. (n.d.). EmotivBCI | Built for Insight, EPOC+ and EPOC X headsets. https://www.emotiv.com/products/emotiv-bci

EU AI Act: first regulation on artificial intelligence | Topics | European Parliament. (2023, August 6). Topics | European Parliament. https://www.europarl.europa.eu/topics/en/article/20230601STO93804/eu-ai-act-first-regulation-on-artificial-intelligence

FocusCalm | EEG Headband Technology. (2023, December 14). FocusCalm.

https://focuscalm.com
Henderson, E. (2022, 05 14). *'Foreign body reaction' to implants can be reduced by incorporating drug into silicone coating*. Retrieved from News Medical: https://www.news-medical.net/news/20220314/e28098Foreign-body-reactione28099-to-implants-can-be-reduced-by-incorporating-drug-into-silicone-coating.aspx

Hiraki, M. A. (2020). *Passive Brain-Computer Interfaces for Enhanced Human-Robot Interaction.* Retrieved from https://www.frontiersin.org/articles/10.3389/frobt.2020.00125

Hochberg LR, Serruya MD, Friehs GM, Mukand JA, Saleh M, Caplan AH, Branner A, Chen D, Penn RD, Donoghue JP. Neuronal ensemble control of prosthetic devices by a human with tetraplegia. Nature. 2006 Jul 13;442(7099):164-71. doi: 10.1038/nature04970. PMID: 16838014. Howard, K. (2022, 09 08). Science & Tech Spotlight:. Retrieved from GAO: https://www.gao.gov/products/gao-22-106118

Ince, R., Adanir, S. S., & Sevmez, F. (2020, 03 05). *The inventor of electroencephalography (EEG): Hans Berger (1873–1941).* Retrieved from Springer Link: https://link.springer.com/article/10.1007/s00381-020-04564-z

Jiang, L. S. (2019). *BrainNet: A Multi-Person Brain-to-Brain Interface for Direct Collaboration Between Brains.* Retrieved from https://www.nature.com/articles/s41598-019-41895-7

Kumar, S. (2021, 04 13). *The Pros and Cons of Invasive and Non-Invasive BCIs*. Retrieved from Scilogic: https://scifilogic.com/invasive-vs-noninvasive-brain-computer-interface-bci

Maiseli, B. A. (2023). *Brain–computer interface: trend, challenges, and threats.* Retrieved from https://braininformatics.springeropen.com/articles/10.1186/s40708-023-00199-3

Mayo Clinic. (n.d.). *EEG (electroencephalogram)*. Retrieved from Mayo Clinic: https://www.mayoclinic.org/tests-procedures/eeg/about/pac-20393875

Mayo Clinic. (n.d.). *Transcranial magnetic stimulation*. Retrieved from Mayo Clinic: https://www.mayoclinic.org/tests-procedures/transcranial-magnetic-stimulation/about/pac-20384625

Meta. (2020, March 30). *Imagining a new interface: Hands-free communication without saying a word*. https://tech.facebook.com/reality-labs/2020/3/imagining-a-new-interface-hands-free-communication-without-saying-a-word/

Meta. (2021, July 14). BCI milestone: New research from UCSF with support from Facebook hows the potential of brain-computer interfaces for restoring speech communication. https://tech.facebook.com/reality-labs/2021/7/bci-milestone-new-research-from-ucsf-with-support-from-facebook-shows-the-potential-of-brain-computer-interfaces-for-restoring-speech-communication/

Moses, D. A., Metzger, S., Liu, J. R., Anumanchipalli, G. K., Makin, J. G., Sun, P., Chartier, J., Dougherty, M., Liu, P. M., Abrams, G., Tu-Chan, A., Ganguly, K., & Chang, E. F. (2021). Neuroprosthesis for Decoding Speech in a Paralyzed Person with Anarthria. *The New England Journal of Medicine*, *385*(3), 217–227. https://doi.org/10.1056/nejmoa2027540

Mullin, E. (2023, 09 19). *Everything We Know About Neuralink's Brain Implant Trial*. Retrieved from Wired: https://www.wired.com/story/everything-we-know-about-neuralinks-brain-implant-trial/).

Muse. (2024). *Muse: the brain sensing headband Store with Worldwide Shipping | Muse™ EEG-Powered Meditation & Sleep Headband*. Muse: The Brain Sensing Headband. https://choosemuse.com/

Neuralink. (2023, 09 19). *Neuralink's First-in-Human Clinical Trial is Open for Recruitment*. Retrieved from Neuralink: https://neuralink.com/blog/first-clinical-trial-open-for-recruitment/

neurotech Edu. (n.d.). *Consumer EEG Headsets*. Retrieved from neurotech Edu: http://learn.neurotechedu.com/headsets/

NeuroTech Tree - View-only. (n.d.). https://foresight.org/ext/ForesightNeurotechTree/

Pedersen, T. (2021, 12 13). *All About Functional Magnetic Resonance Imaging (fMRI)*. Retrieved from PsychCentral: https://psychcentral.com/lib/what-is-functional-magnetic-resonance-imaging-fmri#f-mri-vs-mri

Psychology Today. (n.d.). *Brain Computer Interface*. Retrieved from Psychology Today: https://www.psychologytoday.com/us/basics/brain-computer-interface

Reuters. (2024, March 21). Musk's Neuralink shows first brain-chip patient playing online chess. Reuters. https://www.reuters.com/business/healthcare-pharmaceuticals/neuralink-shows-first-brain-chip-patient-playing-online-chess-2024-03-21/

ScienceDaily. (2023, 08 28). *Brain signals transformed into speech through implants and AI*. Retrieved from ScienceDaily: https://www.sciencedaily.com/releases/2023/08/230828130347.htm

Social Creative Technologies Lab @ Wageningen University. (2023, December 15). *Social Creative Technologies Lab @ Wageningen University on LinkedIn: #bci #vr #xr #3d #metaverse* [Video]. https://www.linkedin.com/posts/sct-lab_bci-vr-xr-ugcPost-7141419229605482496-Fxw5/?utm_source=share&utm_medium=member_desktop

Stanford Enclopedia of Philosophy. (2016, 2 10). *Neuroethics*. Retrieved from Stanford Enclopedia of Philosophy: https://plato.stanford.edu/entries/neuroethics/#EthiNeur

Steinert, H. D. (2021). *Real-World fNIRS Brain Activity Measurements during Ashtanga Vinyasa Yoga.* Norwegian University of Science and Technology, Department of Mechanical and Industrial Engineering. Trondheim: TrollLABS. Retrieved from https://www.mdpi.com/2076-3425/11/6/742

S. Zhang, Y. Chen, L. Zhang, X. Gao and X. Chen, "Study on Robot Grasping System of SSVEP-BCI Zhang, S., Chen, Y., Zhang, L., Gao, X., & Chen, X. (2022). Study on robot grasping system of SSVEP-BCI based on augmented reality stimulus. *Tsinghua Science and Technology*, *28*(2), 322-329.

University of Twente. (2024, February 15). No more soporific lectures. Universiteit Twente. https://www.utwente.nl/en/news/2024/2/1354519/no-more-soporific-lectures

Vidal, J. J. (1973). *Toward direct brain-computer communication.* Los Angeles: University of California. Retrieved from https://www.annualreviews.org/doi/pdf/10.1146/annurev.bb.02.060173.001105

Vidal, J. J. (1977). *Real-time detection of brain events in EEG.* IEEE. Retrieved from https://ieeexplore.ieee.org/abstract/document/1454811

Waldert, S. (2016, 06 27). *Invasive vs. Non-Invasive Neuronal Signals for Brain-Machine Interfaces: Will One Prevail?* Retrieved from Frontiers: https://www.frontiersin.org/articles/10.3389/fnins.2016.00295/full

Wang, J., Wang, T., Liu, H., Wang, K., Moses, K., Feng, Z., ... & Huang, W. (2023). Flexible Electrodes for Brain–Computer Interface System. Advanced Materials, 35(47), 2211012.