Brain Technology in Augmented Cognition

Current and Future Trends

Suraj Sood

First edition published 2025

ISBN: 978-1-032-69296-8 (hbk)
ISBN: 978-1-032-69300-2 (pbk)
ISBN: 978-1-032-69298-2 (ebk)

Chapter 2

Electroence-phalography (EEG)

DOI: 10.1201/9781032692982-3

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

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2.1 FROM NEURAL ACTIVITY TO AUGMENTED COGNITION

How do we get from neurons to thought? There are at least three possibilities. One is that the nervous system and mind are identical. More specifically, the central nervous system (CNS), which consists of the brain (along with the spinal cord) would be identical with consciousness. The next possibility is that the brain enables the mind: without the brain, there would be no mind. This is a causal thesis that a biological entity (the brain) gives rise to a psychological one (the mind). Thirdly, the mind and brain are distinct, but they intersect at least enough to allow for an exploitable relation between them. This third possibility is perhaps the most tenable as far as neurotechnological augmented cognition goes.

It is also possible that the mind and brain have no relation. If this were true, cognitive neuroscience would be somewhat less intuitive as an interdiscipline. If cognition and neurology had no relation, what would be the point of studying them together? The only real answer to this could be pure curiosity.

What can the activity of neurons do to better our thoughts? Some—perhaps most—believe neurons are, indeed, the basic unit of thought. I do not necessarily conceive of them this way. It is still too early (at best) to admit such a claim about reality that cuts across two distinct research areas, viz. those of cognition and neurology. How could we tell if a neuron corresponded with a cognitive unit? The brain can be altered in ethically proper ways for consensual research,

DOI: 10.1201/9781032692982-3

FIGURE 2.1 Portable EEG worn by anonymized subject

and cognition could be measured afterward, but some aspects of cognition may remain obscure to researchers operating from a primarily physicalist (and non-mentalist) point of view. But if EEG can augment cognition, it is likely to augment a researcher's understanding of an EEG helmet-wearer's cognitive state (e.g., conscious).[1]

As a psychologist, I consider cognition purer a topic for psychology than I do neurology. Both cognition and neurology play large roles in psychological research, but when neural studies do, they always make a study neuropsychological, neurological, or neuroscientific. This book is not intended to be a philosophical study of the nature of reality, but some of my augmented cognition research is concerned with ontology (and—in a somewhat different sense than I have treated ontology—so is computer science). It is worth being clear about the subjects discussed.

It is well-known that electroencephalography (EEG) affords scans of broad brain activity. It is useful for studying regional rather than individual neural activity (where the latter is more the province of functional magnetic resonance imaging, i.e., fMRI). EEG has been used to study personality (see, e.g., Nardi, 2011). EEG consists of an electrode headset that is attached to the participant's scalp via cool, wet gel. EEG is of interest to augmented cognition insofar as it allows us to learn what different, very broad brain regions are up to, especially during tasks. These tasks vary in nature.

The group NeuroTechX has recently written a helpful primer for EEG (and BCI). EEG became accessible to the open-source community during the 1990s. Experimenter Hans Berger is credited with having invented EEG and coining its name in 1929. EEG is "a technique with over a hundred years of history, and while…originally used more strictly in the fields of psychology, medicine, and neuroscience…is widely used today in gaming, *human–computerinteraction* [emphasis added], neuromarketing, simulations, and beyond"

[1] A further consideration involved with EEG hardware includes properly placing the helmet onto the subject's head. Precision is important since the brain region activity measured depends on sensor placement.

(Farnsworth, November 20th, 2023). Revlin (2013) noted that EEG "is the oldest imaging method of all those currently employed" (p. 35).

EEG is described as being used to make relative measurements, in that electrical currents picked up are contrasted with a frame of reference. This frame is to be a place absent of the anticipated neural action. NeuroTechX (2023) stated further that "it is important to verify axis labels when viewing EEG graphs" (p. 12). Measured action could be spontaneous, evoked, or induced. EEG is largely utilized for researching the neural structure of cognition. NeuroTechX wrote that ERP is among the more utilizable functions of measurement via EEG. EEG offers lower spatial resolution than other brain-imaging technologies but good temporal resolution: EEG can pick up neural firing with a precision of one-thousandth of a second (1 millisecond). Studying electrical currents with EEG takes place in two phases: data acquisition and analysis. Acquiring data via EEG includes electrodes (which pick up signals), amplifiers (that "view and interpret" signals), and a computer (that consolidates signals) (p. 15).

Wet-gel electrodes have been described. NeuroTechX also noted that "dry electrodes", which "leverage…flexible material, a stable structure, dry conductive surface…and a sophisticated algorithm" (p. 17) can be used. The algorithm is used to pull and detach signals via EEG from bio-environmental sources of static. Thus, dry electrodes could be used in lieu of wet ones to make the process of data acquisition cleaner. NeuroTechX also distinguished between *active* and *passive* electrodes. Active ones allow signals to be amplified right at the site of measurement (i.e., the top of the head), all prior to making it to the ordinary amplifier setup. Passive electrodes are usually used, as they are more cost effective. Amplifiers are used since EEG signals are small, measurable in millivolt, microvolt, or nanovolt units (*mV*, *μV*, and *nV*, respectively). Following amplification, signals become digitally rendered, such that they become processable and then viewable via computational monitor.

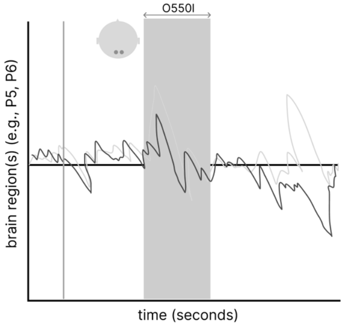

FIGURE 2.2 An example of an ERP reading

EEG signals are recorded via computers. Such computers could be either desktops or laptops—provided, NeuroTechX noted, that the computer in question possesses enough capability and agility to stay abreast of the huge volume of data fed via amplification. According to NeuroTechX, the majority of state-of-the-art EEG labs usually have two or three such laptops or desktops. Computer #1 shows, if experimentally necessary, stimulus usually in the form of either an audio or eye task; computer #2 is the signal recorder. It is crucial that computer #2 knows which stimulus it is being shown, and when. The possibility also exists, however, that recording and stimulus be synched via "time stamps" (p. 18). Programs are used to record data, storing EEG signaling. EEG signal analysis needs a certain kind of program to *preprocess* (a term familiar to any readers involved in machine learning) said signals, prior to any alteration of them. These programs exist in both industrial and open-source forms. For a comprehensive treatment of EEG signals, the reader is referred to Siuly, Li, and Zhang (2016).

EEG is used in augmented cognition research for eye-tracking (ET) (e.g., Xiang & Abdelmonsef, 2022) and classification (Wang & Wang, 2022; Rajabi et al., 2023). Rajabi et al. described that their EEG classifier was used "to perform binary classification on the EEG signals collected during the presentation of…face image[s] to the user to distinguish the images that attracted their attention" (Schmorrow & Fidopiastis, 2023, p. 33). Their classifier was "trained for each subject separately using their EEG data collected while performing a target face detection task". Rajabi et al. expected such classifying "to reveal images relevant to the target face from the subjects' point of view".

What makes EEG a human–computer interactive (HCI) technology is the use of software to analyze electrode inputs. A typical number of electrodes to use is between 12 and 64 (Willingham, 2007) to measure the "summed activity of millions of neurons" (p. 54). Different kinds of neurons fire at different rates, but even while resting, they fire. To control for neurons' constant firing, event-related potentials (ERPs) are measured, and "tens or hundreds" of similar trials are done (p. 55). The waves from these trials are averaged, smoothing them out. In my experience—having my EEG taken during a linguistic vocalization and identification task at the University of California, Los Angeles (UCLA)—I noticed Python scripts running at the beginning and end of my participation. I did not get a good look at the code. (This EEG-BCI intersection will be discussed more, close to the end of this book.)

For a better understanding of EEG, the research of LaRocco, Le, and Paeng (2020) is helpful. They list several "consumer EEG-based devices" such as "Neurosky MindWave, InteraXon Muse, Emotiv Epoc, Emotiv Insight, and OpenBCI". In LaRocco et al.'s study, each of these devices was listed as having reportedly enabled detection of drowsiness in people. This demonstrates the variety of consumer EEG devices that have been available to researchers and a focus on a specific application of them. This overlaps with a small cluster of AugCog research that focuses on the mental state of aircraft pilots, including their performance (Russo, Kendall, Johnson, Sing, Escolas, Santiago, Holland, Hall, & Redmond, 2005) and phenomenology.[2] EEG has been "used within augmented cognition systems [to] form situation awareness advisory tools that are able to provide real-time feedback to air-traffic control supervisors and planners" (Abbass, Tang, Amin, Ellejmi, & Kirby, 2014).

2.2 MEASURING INDIVIDUAL COGNITIVE DIFFERENCES

EEG answers the questions of where and when brain events happen. In cognitive research, it could inform an experimenter of when the brain registers stimuli. EEG has also been used in personality research. The benefit of this is to understand how the brains of different individuals work. Dario Nardi, a UCLA researcher, conducted a pilot EEG test to validate the popular Myers-Briggs Type Indicator® neuroscientifically. He was interested in finding distinct regional patterns in participants working on a variety of tasks, noting scattered versus whole-brain readings. Based on these, he classified each of the 16 Myers-Briggs personality types into distinct cognitive profiles based on existing theory in the area.

Personality research constitutes a small minority of augmented cognition research. Work like Nardi's, while not augmented cognition proper, could be thought of as an "extended" augmented cognitive study. I mean this in the sense that the reader leaves with an enriched understanding of cognitive neuroscience in a more neutral psychological area (as opposed to a clinical context—more so the province of BCI research). Nardi's findings were published in a more popularly geared book, *The Neuroscience of Personality*. This study to my mind is exemplary of how interesting EEG research can be, despite its status as the most popular (and accessible, compared to BCI) brain technology of those discussed here. Nardi's work shows how EEG can be used to understand personality at a more base level.

Cervera-Torres, Minissi, Greco, Callara, Ferdowsi, Citi, Maddalon, Giglioli, and Alcañiz (2023) proposed a model including socio-emotional virtual reality (VR) and measurement of emotional response. The latter includes

[2] Also worth exploring is Berka, Levendowski, Davis, Whitmoyer, Hale, and Fuchs' (2006) research on situational awareness and EEG (including "time-locked potentials…generated by neuronal networks").

EEG, which the authors proposed would be used to record emotional response "during the social-emotional and non-social VEs [virtual environments]" (Schmorrow & Fidopiastis, 2023, p. 323). Cervera-Torres et al.'s study consisted of a proposal to use EEG in this manner, as well as to study "emotional HBO [human body odor]" and affective valence (ranging from negative to positive). Their study is indeed unique within AugCog: not only for its hypothetical nature but also given the authors' interests in VR, body odor, and affect. The study also discusses social cognition and behavioral cues, making it more holistically psycho-neurotechnological. It is conceivable that this kind of study, if carried out, would open the door to more studies involving VR and our sensory apparatus. It is widely known that a limitation of current VR is its inability to elicit the faculties of taste or smell, and studies like these could eventually change this.

2.3 EEG IN GENERAL

EEG in general is used clinically to troubleshoot neurological issues like injury and abnormalities, including tumors and epilepsy. A good primer on the history of EEG in general is Giannitrapani and Liberson's (1985) book, available freely online. This book covers a good range of kinds of EEG studies focusing on mental ability. Also included are (regional) spectral analysis, brain function by area, factor analysis, and the function and age relativity of EEG frequency, as well as EEG hardware, conditions, and recordings. Skills needed to learn how to use EEG include properly placing the helmet, managing the signal-to-noise ratio (including noticing noise and lowering it), preprocessing of data (at least, in an EEG-based BCI system), and software engineering.

I have, perhaps, taken for granted up until this point that the reader of this book knows about EEG at a basic level. This includes EEG's function, or what it does. In her book *Quirk: Brain Science Makes Sense of Your Peculiar Personality*, author Hannah Holmes stated this thus: "EEG measures electrical changes in the brain" (p. 22). More technically, EEG is used for ERPs. The unit of EEG measurement of brain activity is the microvolt (μV), and the upper bound for the interested frequency of waves is around 30 Hertz (Hz) (Smith). Amplitude is the other dimension of measurement, showing the height of recorded brain waves. Brain waves show the "total electrical output of neurons near…[EEG] electrodes" (Revlin, 2013, p. 36), depicting "continuous brain activity" (Willingham, 2007, p. 54). NeuroTechX is more specific, having written that EEG allows for the recording of the brain cell action of over a thousand neurons as they fire in concert with one another: this allows for the measurement of broader, regional brain activity.

Holmes' is the most elegant framing I have come across. Yet she went further, noting that EEG measurement is conducted when people talk, solve mathematical problems, and view photography. Each of these is of interest for augmented cognition: discourse analysis could be augmented; mathematics is frequently taken up (sometimes innovatively, and often to great experimental effect) in augmented cognition; aesthetics is present in user interface (UI) work, which is a prominent part of the face, culture, and work of HCI. Based on our current understanding of the brain regions and their functions, hypothesizing which are active during a given task should be reasonably easy.

The eminent theoretical physicist Michio Kaku discussed neurotechnology at some length in his popular book, *The Future of the Mind* (2014). He noted that EEG dates to 1924; only in recent times, though, could the computer be used to make comprehendible what the EEG measures through electrodes. Cutting-edge EEG, Kaku noted, consists of placing a hairnet with miniscule electrodes on top of the scalp. He described EEG as "strictly passive" (p. 26), in that with it, miniscule electromagnetism traverses the brain. This enables measurement of whole-brain patterns taking place as people sleep, focus, dream, and relax. Usually, EEG imaging shows the emission of gradual EMG currents when participants are awake. Kaku's most simple statement about EEG is that such imaging measures electric brain currents immediately. NeuroTechX (2023) wrote that EEG records such currents flowing as

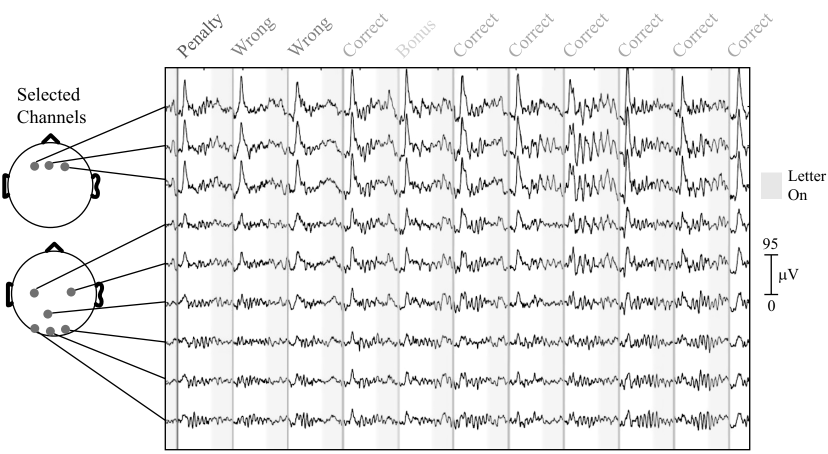

FIGURE 2.3 An example of an EEG readout outside of AugCog (University of California, San Diego, 2023)

the pyramidal neuronal layer is excited. EEG's largest boons (in addition to temporal resolution) are being both cheap and convenient.

Kaku also discussed EEG helmets and typewriters. Helmets are the most common implementation of EEG. A benefit of EEG typewriters, wrote Kaku, is their noninvasive nature (as compared with electrocorticogram, i.e., ECOG). EEG typewriters trade off precision and accuracy for being relatively easily accessible. The Austrian company Guger Technologies is an example of a company that has seemed to work successfully with this new kind of EEG.

Kaku introduced work done with magnetoencephalography (MEG). Kaku wrote that MEG could have complemented EEG sensor work. However, "true telepathy helmets" were still "many years away" (p. 71). He also provided a possible answer to the *binding problem* in memory research. Concerned with how our minds consolidate memories into singular experiences, Kaku proposed the partial answer through "the fact that there are electromagnetic vibrations oscillating across the entire brain at roughly forty cycles per second": such vibrations could be sensed via an EEG scan (p. 107).

A variant of EEG known as iEEG, or intracranial EEG, exists. Use of iEEG is more invasive than standard EEG; instead of electrodes being placed on the scalp, they are surgically inserted into the skull. iEEG's functions are twofold: it records electrical impulses from the cerebral cortex and stimulates the brain (NeuroTechX, 2023). iEEG leverages *neuromodulation*, targeting specific parts of the brain electrically or pharmaceutically to record signals and stimulate the brain. Neuromodulation is done for both practical and non-applied purposes. Another variant of EEG is sEEG, or stereoencephalography, which is actually a form of iEEG. NeuroTechX noted that sEEG went from being the most common kind of iEEG used in Europe to (most recently) the most commonly used worldwide. I have not come across these variants of EEG in AugCog, but they are worth noting in terms of the varieties of neurotechnologies that can be used.

Another variant of EEG is quantitative EEG, or qEEG. qEEG affords neural activity-tracking by the millisecond, which is converted into a colored map showing relative frequency in brain regions. Though qEEG is also usable to show inter-brain region communication and collaboration—even allowing for person-to-population comparison—its primary use is clinical. Van der Kolk (2015) noted the general, direct positive correlation between the number of problems a patient has and abnormalities in their qEEG measurement. qEEG is even used to train patients to take responsibility for behavioral problems by acknowledging their neural realities. qEEG does not seem to be used in AugCog, but it has potential given it shares inexpensiveness and portability with regular EEG.

It is debatable whether the study of emotion fits into augmented cognition. Some of my augmented cognition research has advocated for an expansion of topics to include augmented affect (the unconscious side to emotion). Certainly, both emotion and cognition are psychological topics: further, healthy affect lends itself to better-quality cognition (and perhaps vice versa). Emotion, or technically affect, is usually treated as part of cognitive psychology (though it is studied in other disciplines, like philosophy). Richard J. Davidson discusses at length in his book, *The Emotional Life of Your Brain* EEG in relation to emotion. The book offers a good history of EEG from a seasoned EEG researcher.

Less debatable for AugCog could be the use of EEG to study the brain's default mode network (DMN). The DMN has become one of the most prominent regions of study in neuroscience. Knyazev, Slobodskoj-Plusnin, Bocharov, and Pylkova (2011) studied the DMN using EEG, noting that positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) were more common and less controversial options for such. However, their work opens the door to AugCog researchers studying the DMN: this is especially relevant given the breadth of DMN's involvement in cognition: it is involved in "self-referential processing, interoception, autobiographical memory retrieval, [and] imagining [the] future" ("Default Mode Network", 2011).

EEG is also used in neurofeedback (e.g., "Who We Are | Brain Performance"). Brain Performance—a group of neurofeedback centers—advertises that they process "EEG brain maps" with a "research-based EEG normative database"; their methodology is "guided by neuroimaging". This company's goal is to enhance physiological processes responsible for maladaptive physical or behavioral symptoms. Though they do not seem as interested in augmenting cognition directly, treating clients' physiologies can lead to alleviation of maladaptive symptoms that block optimal cognitive functioning.

Within HCI, EEG enjoys broader use than just in AugCog. It has also been studied within engineering psychology and cognitive ergonomics, artificial intelligence (AI), and in the conference proceedings titled *HCI in Business, Government, and Organizations* (2023). Potentially relevant for augmented cognition—certainly so for the closely related area of positive computing—is Davidson's having measured prefrontal cortex (PFC) activity in relation to resilience (capital-R Resilience, for him). Resilience is here conceptualized in relation to positive and negative emotion and associated with "left-right asymmetry" (p. 202) in the PFC. Davidson also used EEG to study expert meditation (his participants included the famous Matthieu Ricard). He found that the brain's gamma patterns were stronger for participants while they meditated: so strong that they set a scientific record. Davidson also found that these gamma patterns endured after meditation for the eight monks, showing stable brain changes resulting from regular and disciplined meditation.

EEGs consist of a helmet used to record signals from a person's brain. Neural activity tracked this way is first cleaned, then analyzed using software.

The analysis of cleaned data consists of noting patterns in neural activity. Said patterns may be active while a participant carries out a task (usually while sitting, but not necessarily). Alternately, patterns of brain activity may be compared between individuals who are part of the same study.

REFERENCES

Abbass, H. A., Tang, J., Amin, R., Ellejmi, M., Kirby, S., Augmented Cognition using Real-time EEG-based Adaptive Strategies for Air Traffic Control, 2014. https://www.husseinabbass.net/papers/HFES2014Abbass.pdf

Berka, C., Levendowski, D. J., Davis, G., Whitmoyer, M., Hale, K., Fuchs, S., Objective Measures of Situational Awareness Using Neurophysiology Technology, Augmented Cognition Conference, 2006. https://www.researchgate.net/publication/236610901_Objective_Measures_of_Situational_Awareness_Using_Neurophysiology_Technology

Cerveras-Torres, S., Minissi, M. E., Greco, A., Callara, A., Ferdowsi, S., Citi, L., Maddalon, L., Giglioli, I. A. C., Alcañiz, M., Modulating Virtual Affective Elicitation by Human Body Odors: Advancing Research on Social Signal Processing in Virtual Reality. In: Schmorrow, D. D., Fidopiastis, C. M. (eds) *Augmented Cognition. Lecture Notes in Computer Science*, vol. 14019, Springer, Cham. https://doi.org/10.1007/978-3-031-35017-7_20

Davidson, R. J., *The Emotional Life of Your Brain: How Its Unique Patterns Affect the Way You Think, Feel, and Live—and How You Can Change Them*, Hudson Street Press, New York, 2012.

Default Mode Network, *The Neuroscience of Depression*, Default Mode Network - an overview | ScienceDirect Topics, 2021.

Farnsworth, B., "EEG Headset Prices – An Overview of 15+ EEG Devices", iMotions, November 20, 2023. https://imotions.com/blog/learning/product-guides/eeg-headset-prices/

Giannitrapani, D., Liberson, W. T., *The Electrophysiology of Intellectual Functions*, Karger, New York, 1985. https://archive.org/details/electrophysiolog00gian/page/n6/mode/1up

Holmes, H., *Quirk: Brain Science Makes Sense of Your Peculiar Personality*, Random House, New York, 2011.

Kaku, M., *The Future of the Mind*, Doubleday, New York, 2014.

Knyazev, G. G., Slobodskoj-Plusnin, J. Y., Bocharov, A. V., Pylkova, L. V., The Default Mode Network and EEG Alpha Oscillations: An Independent Component Analysis, *Brain Research*, 1402, 2011. https://doi.org/10.1016/j.brainres.2011.05.052

LaRocco, J., Le, M. D., Paeng, D. G., A Systemic Review of Available Low-Cost EEG Headsets Used for Drowsiness Detection, *Frontiers in Neuroinformatics*, 14, 553352, 2020. https://doi.org/10.3389/fninf.2020.553352 PMID: 33178004; PMCID: PMC7593569.

Nah, F., Siau, K., *HCI in Business, Government and Organizations (Part II)*, Springer, 2023.

Nardi, D., *Neuroscience of Personality*, Radiance House, 2011.

NeuroTechX, NeuroTechX – Slack Group for Neuroscience, Hive Index, 2023. https://thehiveindex.com/communities/neurotechx/

NeuroTechX, *The Neurotech Primer: A Beginner's Guide to Everything Neurotechnology*, 2023.

Rajabi, N., Chernik, C., Reichlin, A., Taleb, F., Vasco, M., Ghadirzadeh, A., Björkman, M., Kragic, D., Mental Face Image Retrieval Based on a Closed-Loop Brain-Computer Interface. In: Schmorrow, D. D., Fidopiastis, C. M. (eds) *Augmented Cognition. Lecture Notes in Artificial Intelligence*, vol. 14019, Springer, Cham, 2023, 26–45.

Revlin, R., *Cognition: Theory and Practice*, Worth Publishers, New York, NY, 2013.

Russo, M., Kendall, A., Johnson, D., Sing, H., Escolas, S., Santiago, S., Holland, D., Hall, S., Redmond, D., Relationships Among Visual Perception, Psychomotor Performance, and Complex Motor Performance in Military Pilots During an Overnight Air-refueling Simulated Flight: Implications for Automated Cognitive Workload Reduction Systems. In: Schmorrow, D. (ed) *Foundations of Augmented Cognition: Volume II*, Lawrence Erlbaum Associates Publishers, Mahwah, New Jersey, 2005, 174–183.

Schmorrow, D. D., Fidopiastis, C. M. (eds), *Augmented Cognition*, Springer, Cham, 2023.

Smith, E. J., EBME & Clinical Engineering Articles: Introduction to EEG, *ebme*. https://www.ebme.co.uk/articles/clinical-engineering/introduction-to-eeg

Siuly, S., Li, Y., Zhang, Y., *EEG Signal Analysis and Classification: Techniques and Applications*, Springer, 2016. L-8486706-e230c729d9.pdf (e-bookshelf.de)

University of California, San Diego, EEG / ERP data available for free public download, updated 2023. https://sccn.ucsd.edu/~arno/fam2data/publicly_available_EEG_data.html

Van der Kolk, B., *The Body Keeps Score: Brain, Mind, and Body in the Healing of Trauma*, Penguin Books, New York, 2015.

Wang, X., Wang, Z., CNN with self-attention in EEG classification In: Kurosu, M., et al. *HCI International 2022 - Late Breaking Papers. Multimodality in Advanced Interaction Environments*. HCII 2022. Lecture Notes in Computer Science, vol 13519. Springer, Cham, 2022. https://doi.org/10.1007/978-3-031-17618-0_36

Who We Are | Brain Performance, *Brain Performance: Neurofeedback Centers*, n.d. https://www.brainperformance.com/about-us

Willingham, D. T., *Cognition: The thinking Animal,* 3rd edn., Pearson Prentice Hall, New Jersey, 2007.

Xiang, B., Abdelrahman, A., Vector-based data improves left-right eye-tracking classifier performance after a covariate distributional shift, 2022. https://doi.org/10.1007/978-3-031-17615-9_44