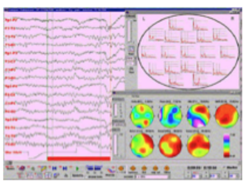
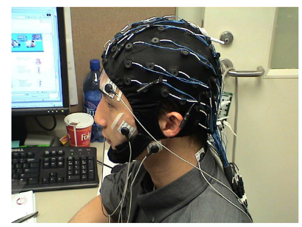
Electroencephalography

Throughout human history we have had electricity emanating from our brains through our skulls, scalps, and hair. It was not until the 1800s that attempts were made to measure these electrical signals. These attempts were refined over the last century to develop into the tools we now have to non-invasively measure neuronal signals in humans. In this chapter we will look at one of the most established ways to understand brain activity by measuring these electrical signals. This is done using a tool called an electroencephalograph (EEG) assembled from the words electro, encephalon, and graphō meaning to write brain electricity.

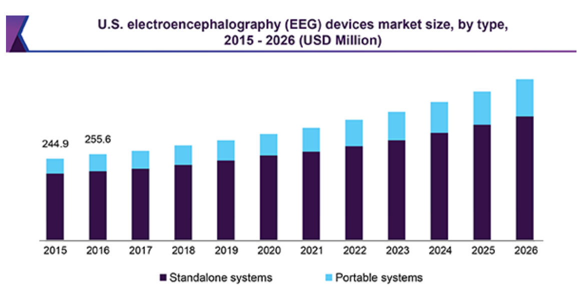
In every living animal the electrical (and magnetic) signals that the brain emits through



the scalp can be non-invasively recorded by sensors (electrodes) that function a bit like radio receivers, placed on the scalp. In EEG the scalp electrodes are connected via amplifier(s) to a computer that records and stores the electrical activity of the brain (mainly the outermost area called the cortex). By placing many electrodes on the scalp, we can gain an understanding of not only when but also where these electrical sources originate.



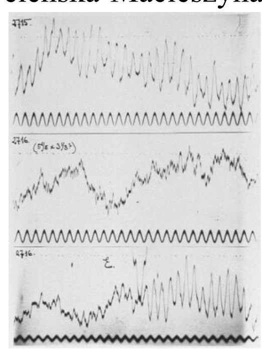
EEG has had a tremendous impact on our understanding of brain function largely due to its ubiquity and flexibility. EEG is used in thousands of research laboratories, hospitals and epilepsy centers across the world. In addition, EEG is a popular diagnosis method at hospitals for assessing neurological disorders such as epilepsy, stroke, ADHD, sleep disorders, and awareness. The massive amounts of data from an EEG recording session have benefited further from the processing power of modern computers, the improved EEG hardware, and recent improvements in analysis techniques. All these developments have catapulted the potential of EEG as one of the most popular tools to understand human brain activity non-invasively.



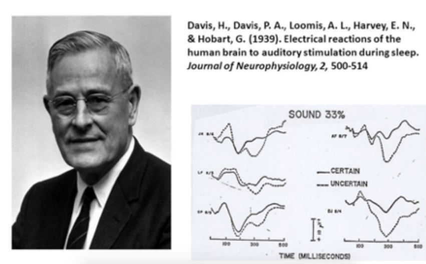
Some History of EEG:

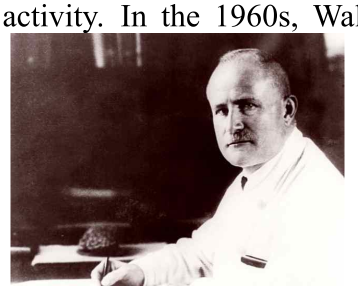
A British physician from Liverpool, Richard Caton was the first person to use a form of EEG on the exposed brains of rabbits and monkeys. He published a very brief summary of his findings in the British Medical Journal in 1875 called "The Electric Currents of the Brain". In one paragraph Caton explained that using his galvanometer he has measured electrical currents in every brain that he had tested. He concluded that the electric currents seem to have a relationship to function. He further wrote that impressions through the senses influenced particular cortical areas and that stimulating the retina with light activated contralateral areas of the brain related to eye blinks. The editor of the British Medical Journal introduced Caton's work by saying that "the most significant things are, at times, packaged in modest clothing". Following this, little note was taken of Caton's findings until Hans Berger realized their significance.

Until Hans Berger few physiologists recorded electrical signals from brains. Vladimir Vladimirovich Pravdich-Neminsky published the first evoked potential of the mammalian (dog) in 1912 and in 1914, Napoleon Cybulski and Jelenska-Macieszyna photographed EEG-recordings of experimentally induced seizures. It wasn't until 1924 when Hans Berger, inspired by Caton, was able to record for the first time alpha waves from the human brain. Berger had discovered a man with part of his brain exposed and managed to record the first human EEG via a silver wire inside a liquid filled rubber tube that he inserted under the scalp. He then used ordinary radio equipment to amplify the recorded electrical activity. Berger observed that the electrical signals from the brain changes when he stimulated cognition, sensation, or emotion. He coined this type of recording elektroenkephalogramm. By 1938 this method had become popular internationally and was used for diagnosis of brain diseases such as epilepsy.



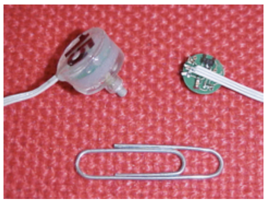
Since the days of Hans Berger EEG has improved tremendously. British researchers Adrian and Matthews verified that there are patterns of electrical signals from the human brain and identified regular oscillations around 10 to 12 Hz which they termed "alpha rhythm". Pauline and Hallowell Davis discovered that by averaging signals they could improve the signal to noise ratio substantially and invented the concept of event related potentials (ERPs). ERPs are an analysis technique of EEG which enables more signal and less noise and will be discussed in the next chapter. Before WWII, Alfred Loomis funded Pauline and Hallowell Davis to experiment with EEG and managed to advance the technology substantially, before shifting his focus to war-related radar development. In 1953 Grey Walter developed EEG Topography by recording from many electrodes simultaneously and using their location to map brain activity. In the 1960s, Walter and his team extended ERPs to look at many types of cognitive function. Later in the 1960s researchers started looking at attention in the brain. Attention became a popular research topic because you can investigate exactly the same stimulus in an identical way by only shifting where people direct their attention. Thus, you have the perfect control





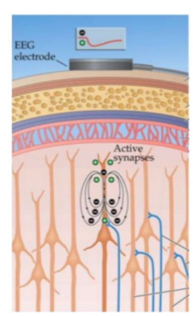
condition using attended and unattended versions of the exact same stimuli. The increased cortical activation should reasonably be linked to the directed attention to the stimulus and not to potentially confounding variables. Thus, attention became an effective concept to localize and understand brain function for many brain imaging tools.

EEG Technicalities:

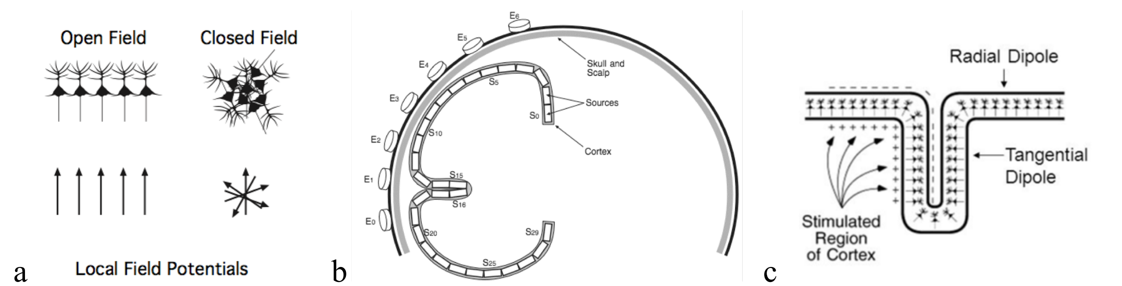


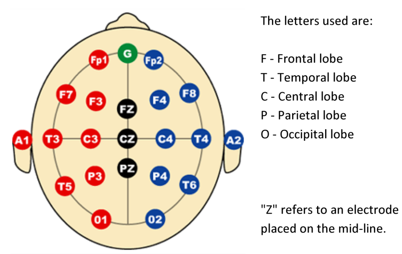
There are many types of EEG electrodes, and these have evolved significantly over the last decade. A simple EEG electrode is pictured to the right. These are commonly coated with silver-chloride (AgCl) for better recordings. More recently active electrodes (left) have become popular for several reasons. They contain electronic filters and an amplifier that ensure that the noise absorbed by the EEG cables are not magnified to the same extent, thus leading to cleaner signals. Some of these electrodes have spring loaded electrode tips that maintain an even pressure on the scalp facilitating fast and effective set up. In addition, some types of electrodes come with small diodes on the electrode itself that indicate if there is a good connection (low impedance) to the scalp with red, yellow, or green lights. To increase the signal to noise ratio between the electrode and the scalp further, gel can be applied. Active electrodes commonly need less gel while other types of electrodes have sponges that are dipped in a saline solution to lower the impedance. The viscosity of the solution determines how long recording can be continued; so saline solution electrodes might have to be dipped in the saline water again after 20 minutes, while more sticky gel can last for hours. Some (gel-free) electrodes do not use gel at all but are covered in a nano-coating that helps to establish a good connection without the mess that comes with electrode gel.

The reason EEG can record signals given off by neurons using electrodes placed on the scalp is because at the outermost part of the cerebral cortex the neurons are 'open field' meaning they are all lined up such that their synapses are faced outward. A 'closed field' is where the neurons are faced in multiple directions' which will create a poor signal, as then individual signals can cancel each other out. A useful analogy is to imagine you had a handful of speakers all facing one way compared to them all facing each other, at a distance you would probably hear the speakers better if they were all faced towards you compared to towards each other. The open field neurons at the end of the cortex are arranged perpendicular to the surface and are called pyramidal neurons because of their pyramidal shape.



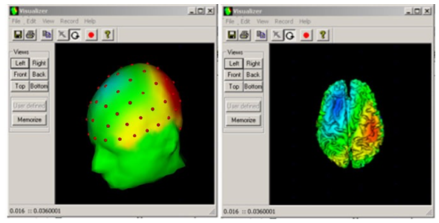
What is it Really Measuring? The tiny signals that we are measuring come from summated activation from a large number (100,000s) of similarly oriented pyramidal neurons in the cortex. As can be seen in the picture to the right the electrode is placed on the scalp and detects the voltage differences from synchronous activity across groups of cells. The signals we record, reflect summed post synaptic activity of large groups of cells. These cells have to be aligned in open fields to summate the electric field into a recordable dipole . Dipoles are voltage fluctuations that create a positive and a negative pole. If neurons are arranged like a closed field the positive and negative polarities cancel each other out and don’t emit a recordable signal. When you look at the folding of the cortex and the placement of electrodes in b and c below you can see that the summation of signals that happen when they are aligned along the scalp happens in some parts of the folded cortex, but not others. We mainly record from the gyri (peaks) and not the sulci (valleys) of the cortex. Subcortical, such as the hippocampus, areas are not commonly aligned in parallel and are further away from our electrodes. Thus, they are contributing much less to the EEG recordings.

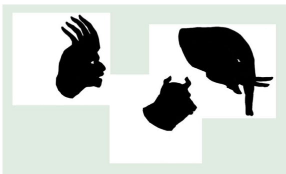




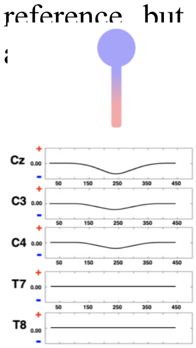
The electrodes are located on the scalp according to the international 10-20 system. The "10" and "20" refer to the fact that the actual distances between adjacent electrodes are either 10% or 20% of the total front–back or right–left distance of the skull. Modern systems with higher electrode numbers still use the principle as their baseline, but then add in more electrodes in between. We measure the distance sagittally (from front to back) from the nasion to the inion. The nasion is the indented point on top of the nose and the inion is a small bump on the back of your head (the external occipital protuberance). We measure coronally (from side to side) from the tip of one ear to the other. Each electrode site has a letter to identify the lobe of the brain and a number to identify the hemisphere location. The frontal, temporal, central, parietal, and occipital regions are labeled with the letters F, T, C, P and O respectively. (Note that there is no central lobe in the brain; the "C" letter is used only for EEG purposes.) The numbers (2,4,6,8) are even over the right hemisphere and odd (1,3,5,7) over the left hemisphere. The "z" stands for zero and refers to electrodes on the midline. Electrical signals always have to be measured in relation to a reference and they are commonly grounded. Technically, EEG compares the difference between a recording electrode connected to the ground and a reference electrode connected to the ground and amplifies that voltage as a channel output. The reference and ground electrode locations can vary depending on system and era. Some of the reference locations used include the average of electrodes on both mastoid bones (behind ear), nose tip, and global field power (an average of all electrodes). Some of the more modern EEG systems have automatized this so that the researcher doesn’t have to think much about it.

Localizing EEG: Based on the recordings from many electrodes we can create a picture of where activity happens called a scalp topography (see right). EEG commonly records from 40 or 64 electrodes, but sometimes as many as 256, 512, or even 1024. There is a diminishing rate of return for more electrodes that starts to plateau somewhere around 60-100 electrodes (Ryynänen, Hyttinen, & Malmivuo, 2004). One reason why EEG has worse spatial resolution (2-4cm) than FMRI is due to something called the inverse problem. The electrical signal underneath the electrode has to travel from its location through brain, skull, scalp and hair tissue to reach the electrode. Since it disperses through all these media we can only get an approximation of the underlying neural generators, but we can't be certain of their exact number and location. If there are several neural generators underlying our recordings we can try to estimate how many there are, but we can never be totally sure. That is called the inverse problem. It is a little like the shadow hand figures to the left. We can never be totally sure how many hands actually contributed to the elephant projection, but we can have an educated guess. The inverse problem exists in many fields and has been defined as the process of calculating from a set of observations the causal factors that produced them: for example, calculating an image in computer tomography (CT), source reconstructing in acoustics, or calculating the density of the Earth from measurements of its gravity field. Despite the difficulties, we can get a fairly good understanding of the neural generators and can cross verify it by using many participants, reproducing published studies and verifying our results with complementary technologies such as Functional Magnetic Resonance Imaging (FMRI) and single cell recordings. EEG should always be interpreted in the context of the literature.



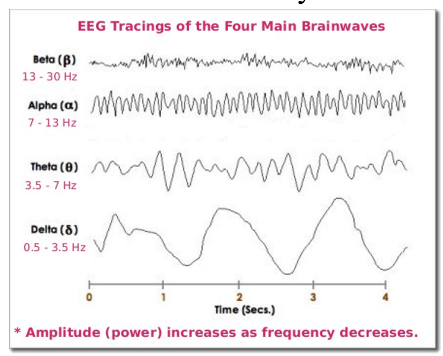


Every EEG electrode picks up an amalgamation of signals from all active sources underneath it. Some of these sources can be quite distal from an electrode. All the simultaneously active sources summate and make up a composite field which is measured on the scalp. The number of these simultaneously active sources, their direction, the strength, and how they summate all play into the composite recordings picked up by the electrodes. If a source is proximal to several electrodes, its signal can be picked up in several electrodes and analysis methods based on covariance can help localize the underlying source. In addition, fluctuations in the reference electrode influences all recording electrodes. This is usually accounted for by the recording software. The selection of the reference electrode(s) and its location (behind ear, tip of nose, composite) has been greatly debated and matters quite a bit for the EEG signals. There is no perfect reference, but it should ideally contain all the global fluctuations of the electrical field [illegible] local EEG potentials.



Localization of sources involves trying to find their contributing dipoles. These dipoles are directional originating from the source. Locating dipoles using EEG can be difficult, but there are several approaches that can help. Covariance between adjacent electrodes suggests that the source must be underneath them. The electrodes with the strongest activation are probably closest to the source. For example, in figure XX we can assume that the source must be to the right of the midline as electrode C4 activates more strongly than C3. Also, if the source is closer to the surface the activation is likely stronger. However, many factors come into play when localizing dipoles. Particularly new types of analyses have enabled much more precise localization. We will discuss these closer in chapters 4 and 14.

EEG and Wavebands: One physiological function that could be consistently measured at an early stage of EEG research were the stages of sleep. Characteristic oscillatory patterns were observed when people were sleeping such as alpha ([7-13Hz]), beta ([13-30Hz]), theta ([3.5-7Hz]) and delta ([0.5-3.5Hz]) waves (right). Sleep became a popular research area for EEG because it shows these quite characteristic signals at different stages of the sleep cycle. However, other cognitive functions were quite difficult to record with the early systems. The signals measured are quite small and are impacted by a lot of factors such as eye blinks, electrical noise, skin potentials, movement, electrode wire sway, muscle activity and even the EEG itself depending on the study. For sleep, however, rhythmic oscillations were observed in different wavebands that were prevalent at different stages during sleep. These wavebands could be easily separated by a mathematical transformation (Fourier transformation) to measure and compare activation by wavebands. That way we can simply quantify how much activity exists in each waveband over specific areas of the brain. When we are awake we show random, fast, low-voltage oscillations. When we become drowsy more rhythmic alpha waves appear over posterior areas. Stage one sleep emits theta waves and stage two sleep shows sleep spindles and k-complexes, transient high frequency or high amplitude bursts. Delta sleep displays high amplitude rhythmic oscillations detected in deep sleep and REM sleep consists of low-amplitude, fast waves with random saw-tooth shapes. Gamma waves (slow [30-70Hz] and fast [>70Hz]) are linked to cognitive processing in the cortex. In general the amplitude of the wave increases as the frequency decreases.

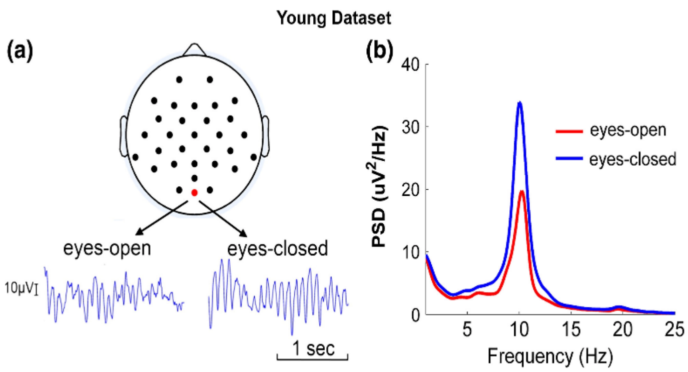


Alpha activity is a type of brain activity that can be measured using spontaneous EEG. It is characterized by oscillations in the brain's electrical activity with a frequency of around 8-12 Hz and is often most prominent over the occipital (visual) region of the brain. Alpha activity is typically highest during periods of relaxation and decreased arousal, and is often suppressed during periods of active task engagement or visual processing. The eyes open/eyes closed paradigm is a commonly used method for studying visual alpha activity. In this paradigm, a participant is seated comfortably and asked to keep their eyes open while looking at a blank screen or a static visual stimulus. The participant is then asked to close their eyes and relax. By comparing the EEG activity recorded during the eyes open and eyes closed conditions, researchers can investigate the effects of visual processing on alpha activity. When the eyes are open and the participant is actively processing visual stimuli, alpha activity is typically suppressed. When the eyes are closed and the participant is not actively processing visual stimuli, alpha activity is typically increased. (See Figure X)

Table HP-1-B1:EEG Patterns and Behavioral States

EEG Pattern	Behavioral/Psychological State
Alpha	Awake, non-focused, relaxed, drowsy, or non-vigilant; low level of environmental stimulation (e.g. eyes closed).
Beta	Awake, alert, focused attention and problem solving; dream/REM sleep; high level of environmental stimulation (e.g. eyes open).
Theta	Visual imagery, hypnagogic/hypnapopic imagery; light sleep.
Delta	Deep, restful sleep; vague dream states.

From: https://www.rsu.edu/wp-content/uploads/2015/06/TheElectroencephalogramEEGCorticalArousal.pdf



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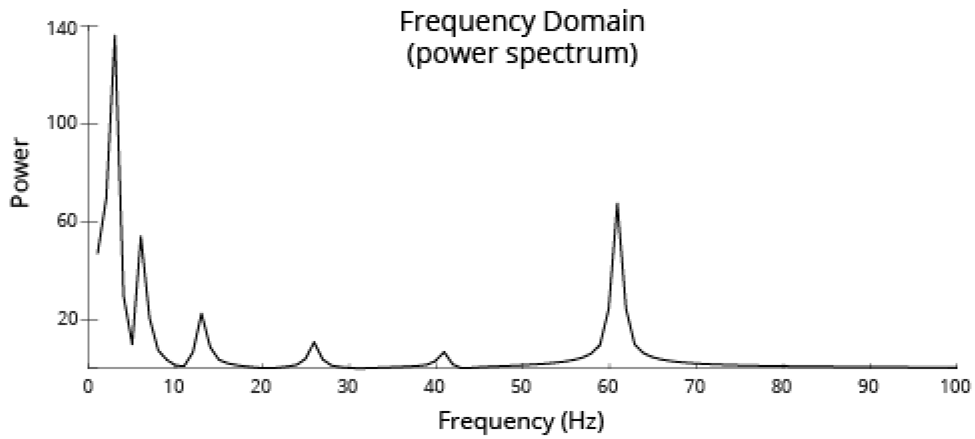

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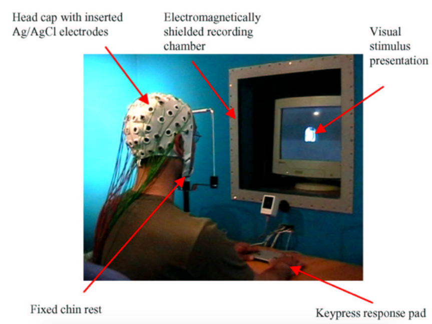
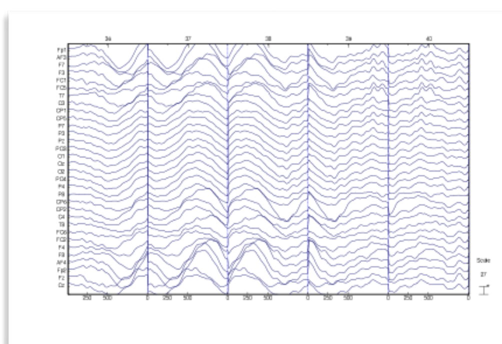
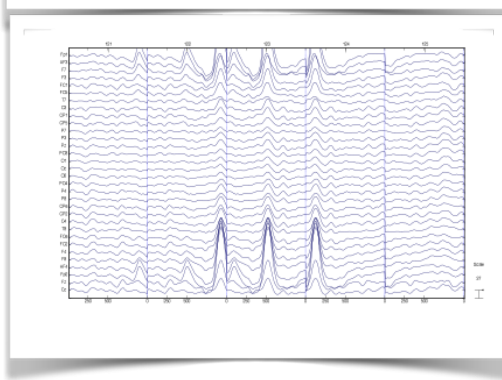
Practical EEG Recording

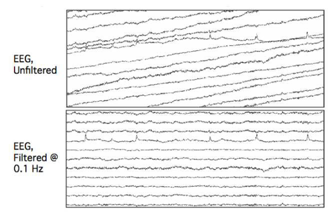


Recording EEG and ERPs is a science and an art. Researchers commonly use between 32 and 256 electrodes, though there are systems that apply even more. As we have learned we are recording very small brain potentials (microvolts) so it is important that there is a good connection between the electrode and the scalp. That's why we remove anything that can cause noise and apply a special gel to the electrodes. It can take up to an hour to apply electrodes depending on the system and number of electrodes. Different types of gels have different viscosity and conductivity, and it takes some experience figuring out what works best.

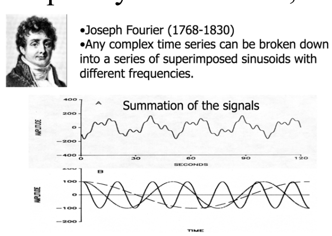


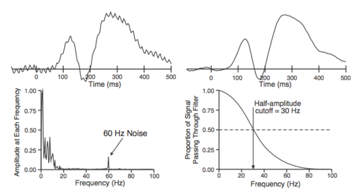


EEG recordings look like the images to the right, which also show the two types of common artifacts (noise), movement (top) and three eye blinks (bottom). The eye blinks are strongest around FP1 and FP2, which are frontal electrodes close to the eyes. They also create noise in the visual cortex in the occipital lobe. Lots of other things can create noise in the recordings including: electrical noise, skin potentials, electrode wire sway, air-conditioning, muscle activity, and even the EEG itself depending on the study. Some ways to prevent noise is to have good EEG preparation, proper collection procedures, error detection and discarding of that data. Since muscles produce much stronger electrical signals than the signals of interest from the brain, we need people to sit very still and not move a muscle. You can also see from the picture on the right that eye blinks create large oscillations. That is because those muscles are very close to our electrodes on the scalp, especially frontal electrodes such as FP1 and FP2. The mouth and tongue also have large muscles in close proximity to the brain. Thus, for our recordings we have to get participants to relax. It is not always easy, and we try to help participants relax by trying to make them sit very comfortably, but not too comfortably because then they might fall asleep and that causes beta and other interference! As mentioned above it is a science and an art to balance this right to get good EEG recordings.

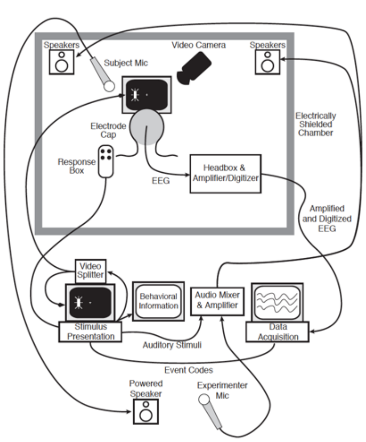


There are many ways to improve the recordings by post-hoc processing. Firstly, by subtracting each recording electrode from a reference, artifacts expressed in all electrodes can be removed. The signals can be filtered with low pass and high pass filters. This means that high frequency and low frequency oscillations, that we know are not of interest, can be removed. Top right you see a picture of recordings with a low frequency noise, where a very long slow wave has interfered and made the recordings skewed. We can also do a band-pass filter, which removes noise according to a specific wavelength. The French mathematician Joseph Fourier came up with a clever way to separate any signal into its many component waveforms, which allows us to look at specific frequency bands like they do for sleep studies. That enables us to remove specific wavebands such as the 60Hz (55Hz in Europe) noise we commonly see from the electrical sockets in most buildings in the US. Improving the signal computationally has much potential and we will discuss some of its potentials in chapter 14.





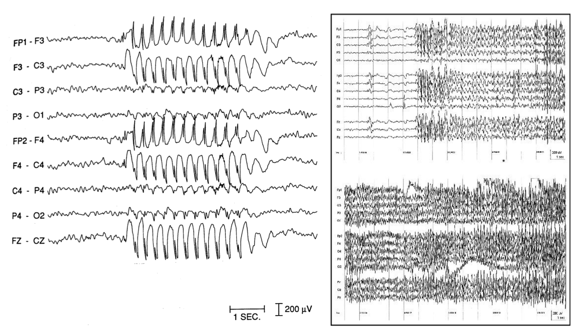
Typically, there is a testing booth for EEG recordings to reduce any external noise that could influence the recordings. However, some of the newer EEG systems, especially with active electrodes, do not require testing booths. The booth consists of a small electrically shielded room with a screen, speakers and sometimes a microphone and camera. The participant sits inside of this room with the electrodes on their head. Tasks are usually presented on a screen or through loudspeakers in front of the participants. In our lab we have foot pedals so that the participants can respond to the task without moving muscles close to the head. The data from the EEG is transmitted to a data acquisition computer and the data from the stimulus presentation computer is recorded separately. Testing usually takes around 30-60 minutes and includes breaks to keep the participants alert. Much effort needs to be devoted to setting up effective experiments. It is important that the



participants understand the task, pay attention throughout, avoid ambiguity, ensure that participants respond etc. We will discuss the nuances of effective experimental design in chapter 15. Much of the brain imager's time goes into understanding what experiments other people have done and designing clever tests that eliminate alternative interpretations. Some things we need to take into account are that the subject must sit still, they must not be moving their eyes, they should not blink too much (serial killers apply here), we need two very similar conditions to compare, and there need to be random intervals between stimulus presentations, so people don't automatically respond at regular intervals (expectancy bias). Many of these experimental considerations are a large part of the process of obtaining interesting data using any brain imaging tool.

The process of recording EEG starts with preparing all the materials for the experiment including getting approval to conduct the study from the internal review board and producing the experiment and instructions. Participants have to sign an informed consent that acknowledges that they understand what the experiment is about and that they can withdraw from the experiment at any point without consequences. The second step is to apply the electrodes to the participant. This includes cleaning the locations where electrodes will be in contact with the skin and putting on the electrode cap. Conventionally the head length and width is measured to gain a more precise fitting of the cap. Subsequently, gel is applied to each electrode until impedance is lower than a specific value (usually <5 kOhms) before the experiment can commence. The experiment is usually preceded by a pilot experiment, which is a trial run of your proposed research study and used to gather information about the feasibility, potential issues, and potential outcomes of the full-scale study.It also helps to ascertain that the participants understand the task.

Applications of EEG: EEG is used to monitor a lot of cognitive states such as alertness, coma, brain death and brain function. It is also important for localizing areas of damage following head injury (stroke, tumor, etc.); testing afferent nerve pathways (by evoked potentials); monitoring cognitive engagement (alpha rhythm); giving biofeedback; controlling anesthesia depth; and investigating epilepsy and locating its seizure origin. To the right you see two examples of brain abnormalities after a stroke, where brain waves first are calm and then go very active with high-frequency waveforms. Each line represents the recordings of one electrode named based on its location on the head. EEG is used in many different environments for example in sleep labs, clinical settings (e.g., to detect epilepsy), brain-computer interfacing, computer games, biofeedback and to test cognitive function particularly using ERPs, which we will talk about further in the next chapter.



There are many ways to extract meaningful information about brain activity from EEG. Commonly, specific behavior is correlated with brain signals. For example, participants can perform a specific task which is correlated with activity in relevant brain regions. Looking at visual stimuli activates the visual cortex and reading activates language specific areas of the cortex. We can also use EEG to see if there are more global brain differences e.g., after taking sedatives. The pharmaceutical industry uses EEG to see if specific treatments activate or suppress activity in specific waveforms.

	Changes in the amplitude of EEG spectral components					
Treatment (Dose $mg \cdot kg^{-1}$)	Delta (1–4 Hz)	Theta (4–8 Hz)	Alpha (8–12 Hz)	Beta-I (12–18 Hz)	Beta-II (18–30 Hz)	Gamma (30–50 Hz)
Vehicle	NC	NC	NC	NC	NC	NC
Dose comparisons						
Vortioxetine (0.1)	NC	↑	↑↑	↑	NC	NC
Vortioxetine (1)	↑↑*	↑	NC	NC	↓	NC
Vortioxetine (3)	↑	↑	NC	NC	NC	NC
Vortioxetine (5)	↑↑*	↑↑*	↑	NC	NC	↑↑**
Vortioxetine (10)	↑	↑↑*	↑	NC	NC	↑↑*
Clinical comparisons						
Vortioxetine (5)	↑↑*	↑↑*	↑	NC	NC	↑↑**
Escitalopram (2)	↓	NC	NC	NC	NC	NC
Duloxetine (10)	↓	↓↓	↓↓*	↓↓	↓↓	NC
Mechanism of action comparisons						
5HT-3 antagonist Ondansetron (0.3)	↑↑	↑↑*	↑	↑↑	↑	↑
5HT-7 antagonist SB-269970 (10)	NC	↑↑	↑↑	↑↑	↑	↑
5HT-1A agonist Flesinoxan (2.5)	NC	↑↑	↑↑	NC	↑↑*	↑↑**
Combination 5HT-1A receptor agonism comparisons						
Vor (1) + Fles	NC	NC	↑↑*	NC	↑↑*	↑↑**
Vor (3) + Fles	↑↑**	↑↑*	↑↑	↑↑	↑↑**	↑↑**
Vor (5) + Fles	↑↑	↑↑*	↑↑	NC	↑↑*	↑↑**
Vor (10) + Fles	↑↑	↑↑↑**	↑↑↑**	↑↑*	↑↑↑**	↑↑↑**

Changes in power in conventional frequency bands (delta, theta, alpha, beta, and gamma) in response to drug treatments are categorically summarized as follows: NC, no change (<10%); ↑, increase <25%; ↑↑, increase >25%; ↑↑↑, increase >75%; ↓, decrease <25%; ↓↓, decrease >25%. Statistical significance: *$P < 0.05$, **$P < 0.01$, one-way ANOVA with LSD *post hoc* analysis.

In hospitals EEG is applied to diagnose brain disorders such as brain tumors, brain trauma, encephalopathy, encephalitis, stroke, sleep disorders, and to determine levels of consciousness. Patients with epilepsy can be monitored with EEG for days waiting for a seizure to occur. During this time the patient wears an EEG and often simultaneous video is recorded to better be able to link seizure-related brain activity to external symptoms of the seizure(s).

As you can see EEG is a quite dynamic tool that can be applied in many ways. The main advantages of EEG include its high temporal resolution, its low cost, and its non-invasiveness. Low cost is particularly beneficial if a research paradigm needs to be improved after some piloting, which is commonly necessary. It makes running extra participants or repeating the experiment quite doable. Other advantages include its flexibility, that it is quiet, that it can detect covert processing, its ability to elucidate processing stages, and that we have a good understanding of the EEG signal. Disadvantages include its poorer spatial resolution (it needs very large populations of cells to activate and there is signal distortion by the skull and brain tissue), its reduced ability to record subcortical activations, set-up time, and its signal to noise ratio. In newer EEG systems the set-up time and signal to noise ratio have improved drastically. As a comparison, older systems could have 1-2h set up time per participant, while modern systems it can be down to 10 minutes.

Effective EEG recordings need good hardware that reduces noise in the recordings, software that accounts for known variables and filters signals effectively, skilled researchers that apply the tool in the right way, and thoughtful interpretation within the context of existing literature. Applied in the right way EEG is an effective research tool that can help us understand human brain function for many years to come. It is a great starter tool to enter the world of non-invasive neuroimaging in humans and much of the lessons learned transfer to the tools that we will discuss in the coming chapters.

Summary:

EEG is a powerful tool to look at brain function non-invasively. It has been around for over 100 years and the tool has improved tremendously. Current EEG benefits much from an increased number of electrodes, improved data collection methods, and powerful analysis techniques. EEG measures electrical signals from the cortex directly and is therefore directly measuring brain activity. Many analysis techniques have made EEG have made EEG a very powerful tool as we shall see in the next chapter and chapter 14. An hour of EEG recording at 1000 Hz (some systems record up to 100,000Hz) collects 3.6M data points per electrode. This means that there is still much room for analysis improvements for this tool, so we are likely to see further improvements.

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Of interest…

One of the things my students are the most curious about is EEG's efficacy as a lie detector. Can the EEG read our minds despite us wanting to keep something secret? The answer is that it is complicated. Currently the EEG does not work well as a lie detector though that may change as our knowledge of the tool increases. The United States and the EU have forbidden lie detectors as evidence in courts due to a lack of rigorous scientific evidence. However, a court in Mumbai, India, recently used neuroscientific evidence to commit a suspect to life in prison. A court in Iowa accepted a technique called "Brain finger printing" but was forced by the Iowa Supreme court to reverse its ruling. There are many commercial companies and experts that use both EEG and FMRI for lie detection despite the dearth of credible scientific support. One related method we know works is via ERPs. ERPs for objects we recognize activate the cortex differently from objects we don't recognize. This mechanism can serve as a backbone for an ERP-based lie detector. It would, as of yet, not be very accurate though. Firstly it's hard to have experts agree on what this measure of familiarity is. Secondly, the error rate is high. What works in a controlled laboratory setting might not work as well for detecting familiarity in the real world. This technique produces an error rate of 15-30% despite the items triggering the familiarity being presented many times. Thus, the jury is still out on this one, but maybe some day the accuracy will be good enough for courtrooms. That day is not today.