WHAT EEG CAN TELL US ABOUT LEARNING?

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Absztrakt

EEG felvételeken neuroncsoportok elektromos aktivitását tudjuk rögzíteni olyan időbeli felbontással, amely lehetővé teszi a kognitív folyamatok követését is. A neuronok elektromos aktivitása számos tényezőtől függ: az éberségi állapottól, attól hogy a szem nyitva vagy zárva van-e, az elvezetés alatt végzett feladat típusától, a figyelem mértékétől és az érzelmi állapottól. Attól függően, hogy az elektród a koponya mely részén helyezkedik el, más-más aktivitási mintázatot rögzíthetünk. Míg az EEG elvezetésben megjelenő, a kísérleti személy különböző állapotai közötti eltérések jól használhatók neuropedagógiai mérésekben, addig a genetikai különbségekből és a neuronális hálózat egyéni topográfiájából adódó eltérések megnehezíthetik az eredmények kiértékelését. Ebben a cikkben Emotiv EPOC EEG készülékkel készített méréseket hasonlítunk össze. A mérésekben az Eszterházy Károly Egyetem 7 hallgatója (3 fiú) vett részt. A résztvevők EEG aktivitását nyugalmi állapotban (zenehallgatás behunyt szemmel), egy akció-dús filmjelenet és olvasás alatt vizsgáltuk. A felvételek jelentős egyéni különbségeket mutattak a különböző feladatok alatti alfa aktivitás mértékében és az alfa csúcs frekvenciájában is. Míg a vizsgált személyek egy részében a frontális elektródok teljesítmény-spektruma is erőteljes alfa aktivitást jelzett, addig másokban még nyugalmi állapotban is alig emelkedett ki ez a frekvenciatartomány. A legalacsonyabb az alfa aktivitáshoz kapcsolódó tevékenység is egyénileg változott: ez lehetett a film vagy az olvasás is. A béta és a gamma aktivitás általában a film alatt volt a legmagasabb. Ezek az eredmények arra utalnak, hogy az EEG felvételek segíthetik a hatékonyabb tanulási folyamatok tervezését, de ehhez a résztvevők egyéni sajátosságait is fel kell tárni, csak ezek ismeretében értelmezhetők a feladatok során kialakult EEG változások.

Abstract

EEG data can help us to understand cognitive functions. The advantage of the EEG technique is that it measures neural activity directly with a good time resolution, and it is a relatively inexpensive, non-invasive technique. Brain electric activity depends on many factors, recordings reflect the position of the electrode, vigilance, engagement and emotions, and they also depend on individual features of the person like his/her genetic background or the topography of his/her neuronal connections. In this pilot experiment we measured the EEG activity during relaxation, movie watching or reading in 7 university students and compared their EEG spectra to reveal individual and task-dependent differences. The most reliable EEG wave, the alpha wave, showed considerable variability among participants, its several characteristics: amplitude, peak frequency, position and task dependency differed among the participants. Apart from individual variations common tendencies were also detected: the alpha band was the strongest in the recordings from the occipital sensor and it was the largest during relaxation. We concluded that individual characteristics of EEG recordings should be considered when we use EEG data to interpret cognitive processes.

Introduction

Recording and analyzing EEG data can help us to understand the cognitive functions relevant for learning and memory formation. EEG directly measures neural activity, with it we can monitor which brain regions are active during the different tasks. Although EEG cannot measure the electric activity of a single neuron, its time resolution is much better than of the brain imaging techniques (such as MRI or PET scanners). The electrical activity of the brain depends on many factors: it differs during wakefulness and the different sleep stages, changes when the eyes are open or closed and depends on the activity the person is doing (Barry et al., 2007; Klimesch et al., 1994). EEG activity thus reflects arousal, attention, engagement and also emotions. Because of its excellent time resolution EEG can capture cognitive processes in the time frame in which cognition occurs (Basar et al., 1999). Moreover EEG measurement is a noninvasive, relatively inexpensive method therefore it can be expansively used when pedagogical methods are tested (Ferrari, 2011). Its main limitation is that EEG activity displays large individual variations summing up from the genetic variance, the individuality of neuronal connections to the personal approaches to different tasks. This variability in EEG signals makes the analysis and the interpretation difficult.

Electroencefalogram (EEG)

The EEG recording shows different types of brain waves. These waves or oscillations are classified according their natural frequencies (alpha: 8–13 Hz, theta: 3.5–7 Hz, delta: 0.5–3.5 Hz, beta: 13–25 Hz and gamma: 30–70 Hz). Alpha rhythms are interpreted as an "idling rhythm" when the eyes are closed and the person is relaxed. Alpha rhythms are clearest in the occipital lobes, in the brain part responsible for seeing. Alpha oscillations also have another function: the so called functional alpha has been observed during sensory and cognitive processes (Schürmann and Basar, 1999). It has been demonstrated that functional alpha activity is correlated with working memory and probably with long-term memory engram formation (Basar et al., 1997; Klimesch et al., 1994). Alpha activity has a key role in optimal functioning, its enhancement has been shown during optimal cognitive and psychomotor performance, while poor performance, fatigue decreases the amplitude of alpha activity (Bazanova, 2012). Theta oscillations are related to cognitive processing and cortico-hippocampal interaction (Basar et al., 1997; Klimesch et al., 1994; Miller, 1991). Complex events, requiring frontal processing, induce large frontal theta response, as well as orienting, and selective attention (Basar-Eroglu et al., 1992). Delta responses occur not only during slow wave sleep but it is also related to signal detection and decision making (Basar-Eroglu et al., 1992). Beta waves are often seen in people who are awake, they are prominent in the frontal lobes, responsible for conscious thought and movement. Gamma oscillations seems to be important building-blocks of electrical activity of the brain, related to multiple cognitive functions including attention (Müller and Keil, 2004) and memory (Herrmann et al., 2004; Tallon-Baudry et al., 1998), and several findings suggest that they represent more than just perception (Jensen et al., 2007). Gamma oscillations may occur in different and distant structures and show phase locking, strong or weak time locking. Gamma oscillations possibly represent a universal code for central nervous system communication (Basar et al., 1999; Yordanova et al., 1997). In humans the two hemispheres show asymmetric cortical activity. Especially frontal asymmetry studied in details since it is linked to emotions (Harmon-Jones et al., 2010). Activity increase in the left (dominant) hemisphere is associated to positive emotions such as motivation or enthusiasm while avoidance and other negative emotions are accompanied by an increase in right hemispheric activity (Davidson, 1998).

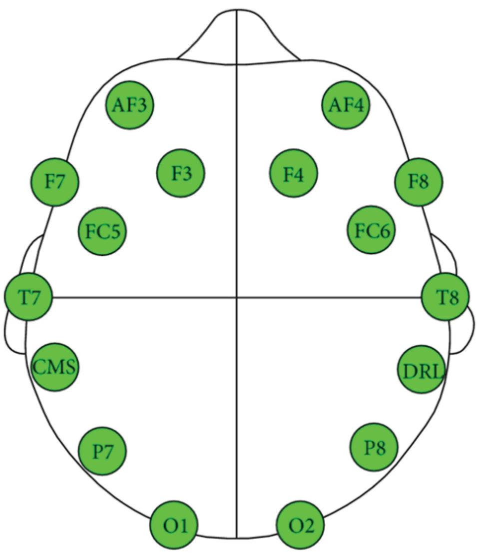
Aims of the study

Our study was aimed at exploring individual differences in EEG signals, especially in the alpha band. We measured the EEG during different tasks using Emotiv EPOC wireless EEG set. We wanted to compare data from the participants to reveal the extent of personal and task dependent features.

Methods

The Emotiv EPOC wireless EEG headset and accompanying software was used for data acquisition. The headset consists of 14 sensors positioned on the wearer's scalp according to the international 10–20 system (Fig. 1). Brain waves are measured in terms of amplitude (10–100 microvolts) and frequency (1–64 Hz).

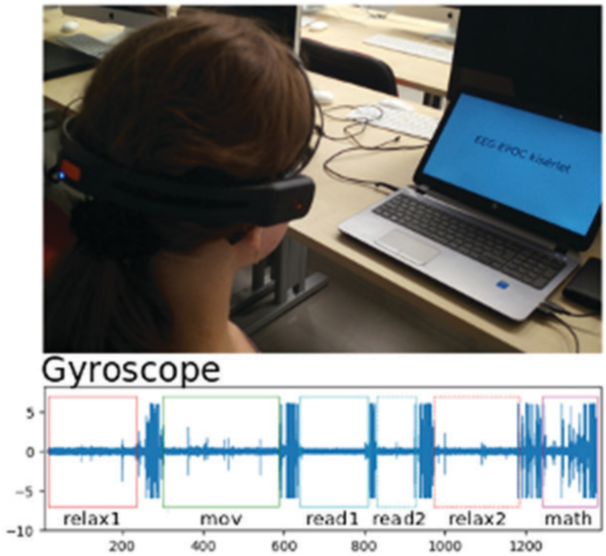
Figure. 1



Emotiv EPOCs electrode positioning, according to the 10–20 system, is used for EEG-signal recordings. The letters F, T, P and O stand for frontal, temporal, parietal and occipital lobes, respectively. There are four pairs of frontal electrodes, the most anterior and the one closest to the sulcus centralis named AF and FC, respectively. Even numbers (2, 4, 6, 8) refer to electrode positions on the right hemisphere, whereas odd numbers (1, 3, 5, 7) refer to those on the left hemisphere. CMS and DRL electrodes are the reference electrodes at P3 and P4 locations, respectively.

Seven right handed students from Eszterházy Károly University were recruited to participate. The age of the study participants was 21–29 years with 3 males, and four 4 females. The tasks during EEG measurement were presented on a laptop. First participants were listening to a relaxing music while their eyes were closed, then they watched a movie part they selected from our list. After the movie they had to read two different texts one about the biological basis of learning (an interesting topic for the participants) while the other was a dull legal text. After the reading they had another three minutes relaxation then they finished the experiment by doing a simple arithmetic exercise. Participants were asked to not move during the task, but they could reposition themselves between tasks (Fig. 2).

Figure 2.



Participants with the Emotiv EPOC EEG headset set next to a laptop presenting the tasks. They were asked to not move during the tasks. Gyroscope recording shows that the majority of movements occurred between tasks, participants stayed relatively motionless during the relaxing music (relax1-2) movie (mov) reading (read1-2) but during the mathematical (math) exercise they moved a lot.

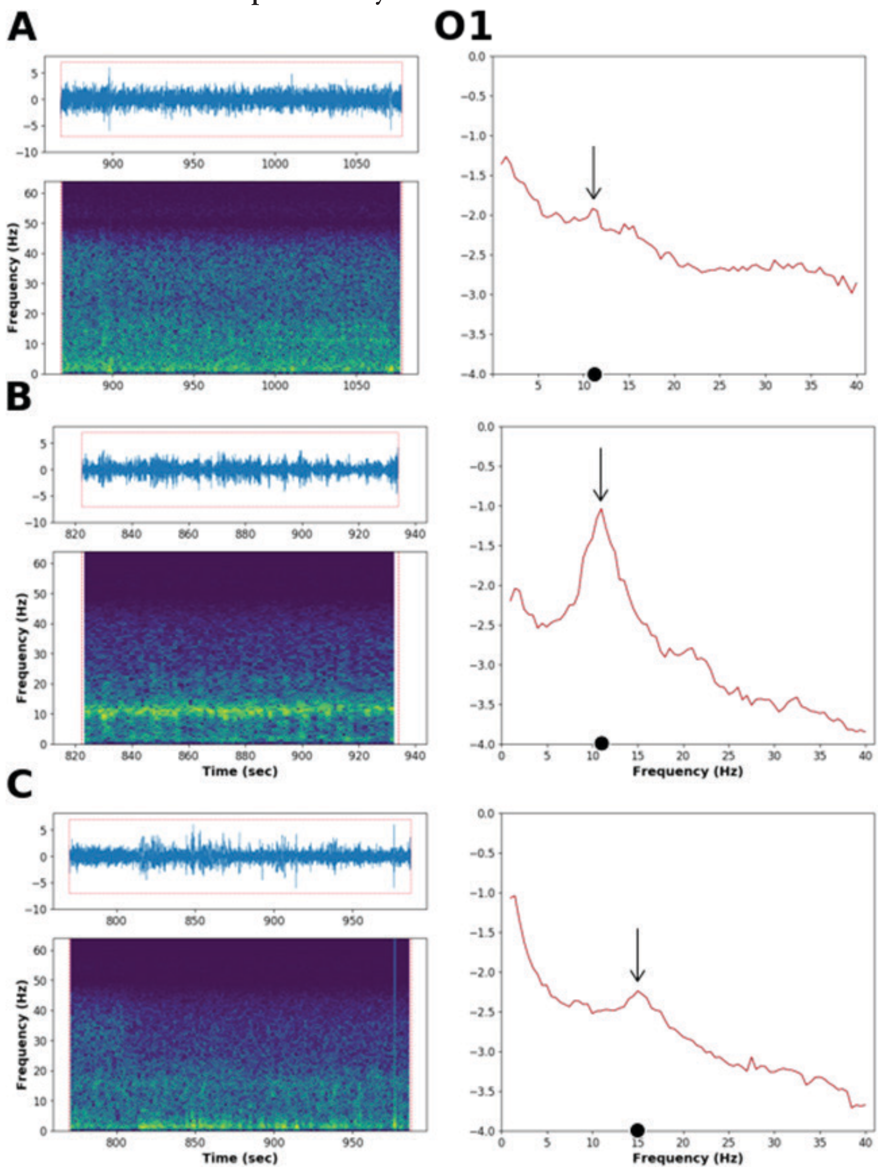
Recordings were offline analyzed in Python (Python software foundation, 2.7.12), using the 'scipy.signal' (0.17.0) and 'spectrum' (0.7.1) packages (Cokelaer, 2012–2017; Jones et al., 2001–2017). Raw data was high-pass filtered with 1 Hz cutoff frequency, then standardized to zero mean and unit standard deviation. To limit the effect of high peaks, we clamped the data to the [-6, +6] range. For spectral analysis we used a Tukey window of 2 seconds with a shape parameter of 0.25, 1 second overlap between segments, and segmentwise linear detrending.

Results and discussion

Alpha frequencies

According to Gasser et al. (1985), the alpha rhythm is the most reliable EEG band. Evidence from animal models supports the view that alpha wave frequency is a result of the cortical network tuned by the thalamus, and it depends on T-type $Ca2^{+}$ channel activity (Lüthi and McCormick, 1998; Steriade and Timofeev 2003). The literature also shows that alpha rhythm is not a unitary phenomenon it demonstrates considerable variation depending on age, mental state, location of the recording electrode, as well as the cognitive task being performed (Basanova, 2012). During relaxation, when the eyes are closed, it is the most prominent activity. An especially strong signal can be picked up by the occipital electrodes (O1-2). The EEG recordings of our participants during the relaxation task showed alpha activity with different powers (Fig. 3), some of the recordings demonstrated a hardly visible alpha peak in the EEG power spectra graphs (Fig. 3A) while in the graphs of the others the alpha peak was prominent (Fig. 3B).

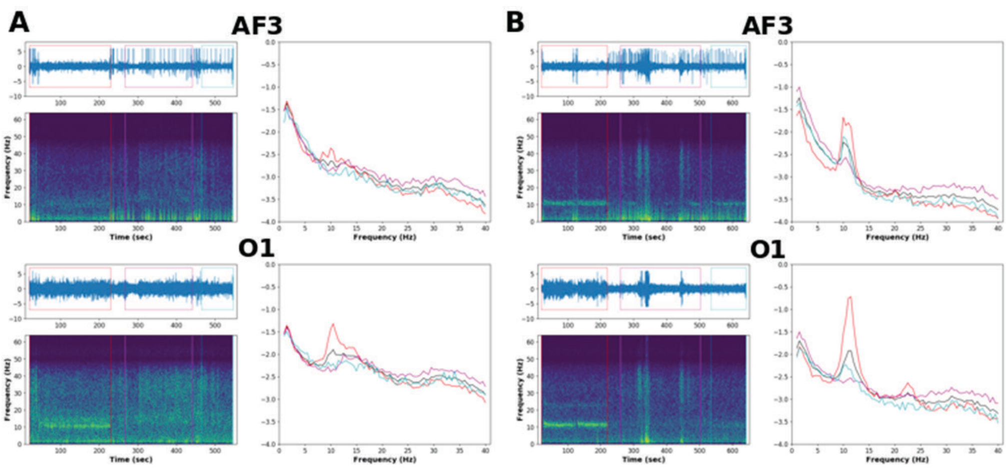
Figure 3. Variabilities in alpha activity.



EEG signals recorded by the left occipital electrodes in three participants during relaxation with closed eyes. The recordings of the O1 electrodes (left upper trace), color-coded time-frequency spectograms (left bottom): warmer colors denote higher power, and the power spectra graphs (right) of the EEG activity are shown.

A) A participant displaying very weak alpha activity. The alpha band only visible at the end of the relaxation period, and no clear peak (arrow) appears at the power-spectra graph. **B)** A participant showing strong alpha activity and a clear peak (arrow) in the alpha band. **C)** Another participant with weak alpha activity. The power-spectra graphs shows that the alpha peak (arrow) frequency is around 15Hz (black circle), while in the other two individuals peak frequencies were lower, ~10Hz.

Figure 4. Changes in EEG activity with the position of the sensor and the task performed.



The peak frequency varied too, it was usually ~10 Hz (Fig. 3A-B) but in one participant the alpha peak frequency was close to 15 Hz (Fig. 3C). During the different cognitive tasks alpha activity decreased (Fig. 4), but the extent of this decrease displayed high individual variations among the participants. Some of them showed the lowest alpha activity during the reading (Fig. 4A) while others during the movie (Fig. 4B). In resting condition alpha activity reflects resting-state arousal level (Barry et al., 2007), while during cognitive tasks it increases with engagement (Haegens et al., 2014). With the position of the electrode the amplitude of the alpha peak changed, the power spectra graphs showed the highest peak when they were calculated from occipital recordings (O1, O2) while the frontal electrodes (AF3-4 F3-4 F7-8 FC5-6) recorded weaker alpha activity (Fig. 4). The difference in alpha peak could be prominent (Fig. 4A) or could be alpha activity being nearly as strong in frontal recordings as in occipital ones (Fig 4B). Identical positions at the two hemispheres showed similar alpha peaks (not shown).

The alpha activity in frontal lobe recordings was less prominent (AF3) than in the occipital recordings (O1). **A)** Some of the participants showed hardly visible alpha peak at frontal recordings (AF3), while the alpha activity was salient in the occipital recording (O1) especially during relaxation (red). During the other tasks alpha activity decreased in both locations, this participant showed the lowest alpha peak during reading (green) and the highest beta or gamma activity during the movie (purple). **B)** Another participant showed strong alpha peak in all recording. The frontal alpha peak indicated two different alpha frequencies. The lower and higher bands were prominent during relaxation (red). When alpha peak decreased during the different tasks the lower frequency band was reduced more robustly than the higher frequency band. In this participant during the movie (purple) alpha activity was the lowest while beta and delta activities were the highest.

Beta and gamma frequencies

Beta waves are associated with alertness, active task engagement, and motor behavior (Neuper and Pfurtscheller, 2001) while gamma waves are believed to facilitate feature binding in sensory processing (Skinner et al., 2000; Tallon-Baudry, 2003). During our tasks these frequencies were not prominent, although when participant watched the movie (visual as well auditory stimuli) higher beta and gamma activities were recorded than either during relaxation (auditory stimulation only) or during the reading (Fig. 4).

Conclusions

We studied variability in individual alpha activity both within and across participants, in the occipital and frontal cortex under different experimental conditions. In our recordings even the alpha activity, the most reliable activity of the EEG spectrum (Gasser et al., 1985) showed considerable variability. The alpha frequency displayed inter-subject variability reflecting the genetic background of the participants as well as their overall cognitive performance. Moreover it showed intra-subject variability reflecting fluctuations in their performance. Therefore knowing the range within which the alpha rhythm operates both between and within subjects, will be crucial in order to interpret results that try to explain performance differences in terms of alpha activity modulations.

The alpha system is known to support the selective modulation of cortical activity through thalamic gating mechanisms (Steriade and Timofeev, 2003). The changes in the temporospatial organization of the EEG in this range is believed to reflect adaptive mechanisms of the brain plasticity (Llinas et al., 1998; Putz et al., 2006), which are important in several cognitive functions as it was shown in several psychological investigations (Bazanova and Aftanas, 2008).

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