Escape from labs: How to expand the territory of brain research?

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Abstract - *Brain activity is most often tested in laboratories, while participants sit and sometimes even lie down. Still, although such advanced techniques of studying brain activity as functional magnetic resonance imaging, positron emission tomography, magnetoencephalography or electroencephalography (EEG), help us understand how the nervous system works and what exactly is going on in the brain during many activities, from simple ones, such as hand movements, to highly complex, e.g., arithmetic calculations, they do not allow us to measure brain activity under natural conditions. Thus, there are attempts to build mobile devices, e.g., mobile EEG. In this chapter we show that such a mobile EEG as MindWave expands the territory of brain research – allows for mobile observation of brain activity outside laboratories and therefore in (ordinary) everyday spaces. Moreover, we demonstrate that MindWave is one of the simplest and cheapest mobile EEG, and, at the same time, a very reliable tool, already successfully used in scientific research. In conclusion, we encourage researchers to escape from laboratories (from time to time) and study brain activity in "natural" (not laboratory/artificial) spaces.*

Keywords - Brain waves, electroencephalography, MindWave, mobile EEG, power spectrum

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INTRODUCTION

In recent years, very advanced techniques of studying brain activity, such as functional magnetic resonance imaging (functional MRI, fMRI), functional ultrasound imaging (fUS), positron emission tomography (PET), single-photon emission computed tomography (SPECT), magnetoencephalography (MEG), transcranial magnetic stimulation (TMS), as well as electroencephalography (EEG), have been created and developed (Eysenck & Keane, 2015). These techniques help us understand how the nervous system works and what exactly is going on in the brain during many activities, from simple ones, such as hand movements (Potok et al., 2019; Przybylski & Kroliczak, 2017), to highly complex, e.g., arithmetic calculations (Klichowski & Kroliczak, 2017; 2020). However, brain activity is most often tested in laboratories, while participants sit (e.g., TMS and EEG) and sometimes even lie down (e.g., PET or fMRI), and, consequently, under conditions unnatural for the activities tested (e.g., for behaviour in some territory). Therefore, there are attempts to build mobile devices to measure brain activity under more natural conditions (Reiser et al., 2019). So far, however, mobile observation of brain activity is possible mainly through EEG, so it concerns the measurement of brain waves (it is difficult to even imagine mobile fMRI, but prototypes of mobile cortical stimulators are being developed, similar to TMS). The so-called mobile EEG can be used outside laboratories and therefore brain research can be carried out in widely understood everyday (ordinary) spaces, and neuroscientists can study real behaviour in different territories (not in simulations) (Aspinall et al., 2015).

In this chapter we discuss the MindWave – one of the simplest, and cheapest, mobile EEG, which is both very reliable and already successfully used in scientific research. In short, the purpose of this chapter is to encourage the use of mobile EEG machines (such as MindWave) in research on human activity in different new spaces, as well as territories.

MINDWAVE MOBILE EEG

Mobile EEG devices belong to a group of most modern tools used for mobile monitoring of various parameters of the human body (Serhani et al., 2016). They are a type of a sensor used to monitor electrical activity (waves) of the human brain (Sun & Yeh, 2017). Mobile EEG machines are not only portable, but also easy to use (electrode amplifiers eliminate the need for a special gel, while the rigid structure eliminates the need for a cap – required for a stationary EEG equipment) (Huang et al., 2020; Sawangjai et al., 2019). Such tools are therefore used not only in scientific research (Bleichner & Debener, 2017), but also in everyday life, e.g., for studying at school or for checking the fatigue level of truck drivers (Huang et al., 2020; Xu & Zhong, 2018). It is also possible to combine them in groups and study the interaction between several or even a dozen people, e.g., players on the field or students in the classroom (Dikker et al., 2017). And although such tools are not without some limitations (Huang et al., 2020; Ratti et al., 2017), they allow an ease, safe and, most important, basically everywhere to observe the work (waves) of the brain (Xu & Zhong, 2018). There are many mobile EEG equipment on the market (Huang et al., 2020; LaRocco et al., 2020; Minguillon et al., 2017; Sawangjai et al., 2019). It is worth mentioning such tools as:

– 72-Channel Dry EEG Headset (Cognionics),
– B-Alert X (Advanced Brain Monitoring),
– BR8 (Brain Rhythm Incorporation),
– ENOBIO 8 (Neuroelectrics), EPOC (Emotive),
– Muse (InteraXon),
– Nautiluswireless EEG acquisition system (g.tec),
– Quick-20 Dry EEG Headset (Cognionics).

However, the most popular is MindWave Mobile EEG (NeuroSky), developed since 2007 (Sawangjai et al., 2019; Xu & Zhong, 2018). The popularity is mainly due to the simplicity and low price (< 250 euro). As we show later, that is not all about prices. MindWave utilises a single electrode placed on the Fp1 position (see Figure 1) which is elementary for EEG research (Abo-Zahhad et al., 2016), i.e., the Brodmann area 10 (BA10). BA10 is part of the prefrontal cortex in the left hemisphere (Bludau et al., 2014). Of course, by receiving signals from Fp1, we do not just collect data from BA10, but basically from the whole brain. The reference electrode is, in turn, on the ear clip. The clip is attached in A1 position (see Figure 1), i.e., to the left ear lobe (Abo-Zahhad et al., 2016; Sawangjai et al., 2019). Figure 1 depicts the device design.

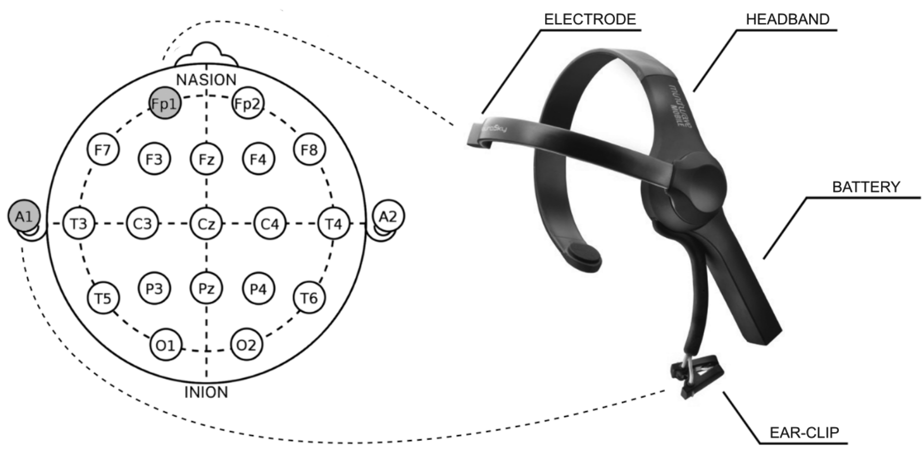

Fig. 1: MindWave Mobile EEG design. By using MindWave Mobile EEG, the single electrode is placed on the forehead, over the left eye, in the Fp1 position of the International 10-20 system for EEG (electroencephalography) recording. The reference electrode is on the clip fixed to the left ear (in the A1 position). The difference of the electric potentials recorded between these two electrodes is amplified, filtered, sampled, and finally analysed by appropriate algorithms. The device is powered with a battery, and the data registered is sent via Bluetooth to the researcher's computer or to a cloud such as Dropbox.

The signal recorded by MindWave is amplified 8000 times by this device, and then it is sent to a computer or cloud *via* a Bluetooth module. It is analysed only in a special application that can be installed on any computer (LaRocco et al., 2020). However, not only does MindWave measure the raw signal and power spectrum (alpha, beta, delta, gamma, theta). It also measures the attention level (mainly based on the beta wave: >14 Hz; this algorithm indicates the intensity of mental focus or focus on a cognitive task; the value ranges from 0 to 100) and meditation level (mainly based on the alpha wave: 8-14 Hz; that algorithm indicates, on the other hand, the level of mental calmness or relaxation; the value also ranges from 0 to 100) (Salabun, 2014). In both cases, the value from 0 to 20 means a significantly lowered level, from 20 to 40 – lowered, from 40 to 60 – neutral, from 60 to 80 – slightly increased, and from 80 to 100 – Increased (Przybyla & Klichowski, 2018; Salabun, 2014).

CORRELATION OF MINDWAVE MOBILE EEG RECORDS WITH BEHAVIOURAL DATA

MindWave Mobile EEG is a tool recognized as reliable (Hemington & Reynolds, 2014), and as demonstrated by Johnstone and collaborators (2012), measurements carried out with MindWave significantly correlate with those carried out by stationary EEG systems (complicated to use and very expensive), for example NuAmps (Compumedics Neuroscan). Of course, this also applies to many other (slightly more expensive and more difficult to use) mobile EEG devices (Hinrisch et al., 2020; Kam et al., 2019; Zerafa et al., 2018).

In addition, many studies (e.g., Chang et al., 2013; Enriquez-Geppert et al., 2017; Kosmyna & Maes, 2019; Nor et al., 2015; but cf. Hernandez et al., 2018) have shown that most of the data generated by mobile EEG is correlated with behavioural data, and therefore that they are not artefacts, but real characteristics of the participant. One of our most recent studies (Przybyla et al., 2021) shows that this also applies to the cheapest and simplest mobile EEG – MindWave. We carried out an experiment in which sixth-grade students participated. The aim was to measure the concentration parameter while performing tasks with MindWave. The training (control) task was to play a game in which the barrel displayed on the screen starts to burn when the concentration parameter increases. When the examined child reached a high level of concentration and held it for a while, the barrel exploded. The program recorded the time it took the participant to blow up the barrel. We treated this task as a control measurement, allowing us to obtain a parameter other than related to the experimental task, but showing in some sense the ability of the student to control their own concentration. In the final phase of the procedures, the students played a SpeedMath game, during which they had to perform simple mathematical calculations in memory and enter only the result on the keyboard. The programme analysed incorrect answers and the concentration parameter from MindWave. Then, we conducted a correlation analysis with other variables collected in the course of performing tasks and through a short interview with students, as well as their teachers. These were: mathematics grade (expressed in numbers) and teacher's assessment of student's mathematical concentration and competences (on a scale of 1 to 5). Figure 2 shows that the concentration parameter measured with MindWave is correlated with maths's grades from the previous semester and in particular with concentration assessed by the teacher and teachers' assessment of mathematical competences. It reveals that EEG measurements reflect other parameters related to the cognitive functioning of the student or parameters analogous, but measured differently. Therefore, reliable analysis of the information provided by MindWave can be effectively used in predicting selected behavioural data, for example the assessment of maths skills.

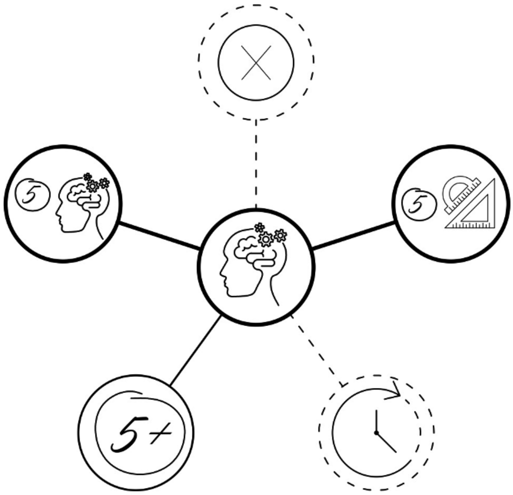

Fig. 2: Visualisation of the network of relationships between the concentration parameter from MindWave and other parameters related to the student's cognitive functioning

The concentration parameter is correlated with the concentration assessed by the teacher and teachers' assessment of mathematical competences, as well as with maths's grades from the previous semester. While it is not correlated with the number of mistakes made and the time of completing the control task. The thickness of the connections between the network nodes reflects the strength of their relationship.

AN EXAMPLE OF A MINDWAVE-STUDY IN NATURAL CONDITIONS

An example of a successful attempt to use MindWave Mobile EEG in natural conditions is our earlier study carried out as a part of the project on learning in CyberParks (Klichowski, 2017). It shows that such a simple and cheap device as MindWave can measure brain activity not only outside the laboratory, but also during movement.

The experiment was conducted in a park on our university campus. Sitting on a park-bench or walking along the paths the participants carried out several tasks on a smartphone, e.g., one-back task. This paradigm aimed at examining the effectiveness of processing information while memorising. The two-back task consists in showing several stimuli, one by one (words, numbers, pictures etc.). Every now and then, a picture is repeated. The participant's task is to react (for example, tap a button) when the picture currently displayed was also displayed exactly two pictures back (Klein et al., 2016; Konecky et al., 2017; McElree, 2001; Oberauer, 2001). Figure 3 shows the trial structure and timing in our two-back task.

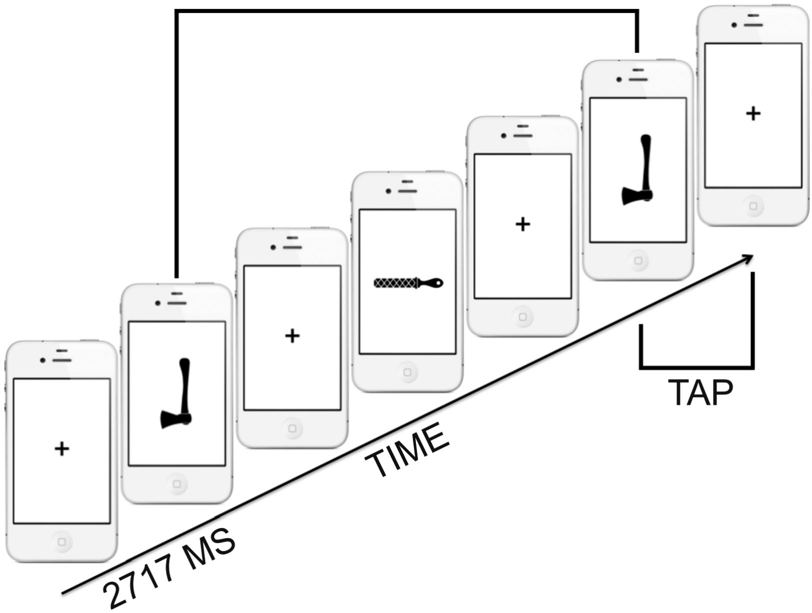

Fig. 3: The trial structure and timing in a two-back task of CyberParks-experiment. A point of fixation (+) was displayed on the smartphone screen for 2500 ms. Then, a picture of a tool was displayed for 217 ms. The participant had 2717 ms to tap. One block consisted of twenty-five pictures.

During the experiment, participants had the MindWave Mobile EEG fixed to their heads. Thus, we could observe what was going on in their brain (e.g., the level of attention and meditation) while performing tasks, millisecond by millisecond. Figure 4 visualises the dynamics of attention and meditation while carrying out two-back tasks, i.e., how their levels change in time. As we can see, the dynamics of attention is different when a two-back task is performed in a sitting position, compared to performing it while walking. This refers to slightly longer periods of lack of concentration during walking and to the fact that the dynamics of attention reflects the dynamics of the cognitive task during walking worse than during sitting. The case is similar as far as the dynamics of meditation goes: The profile for sitting is different from that of walking, and these differences refer to slightly longer and

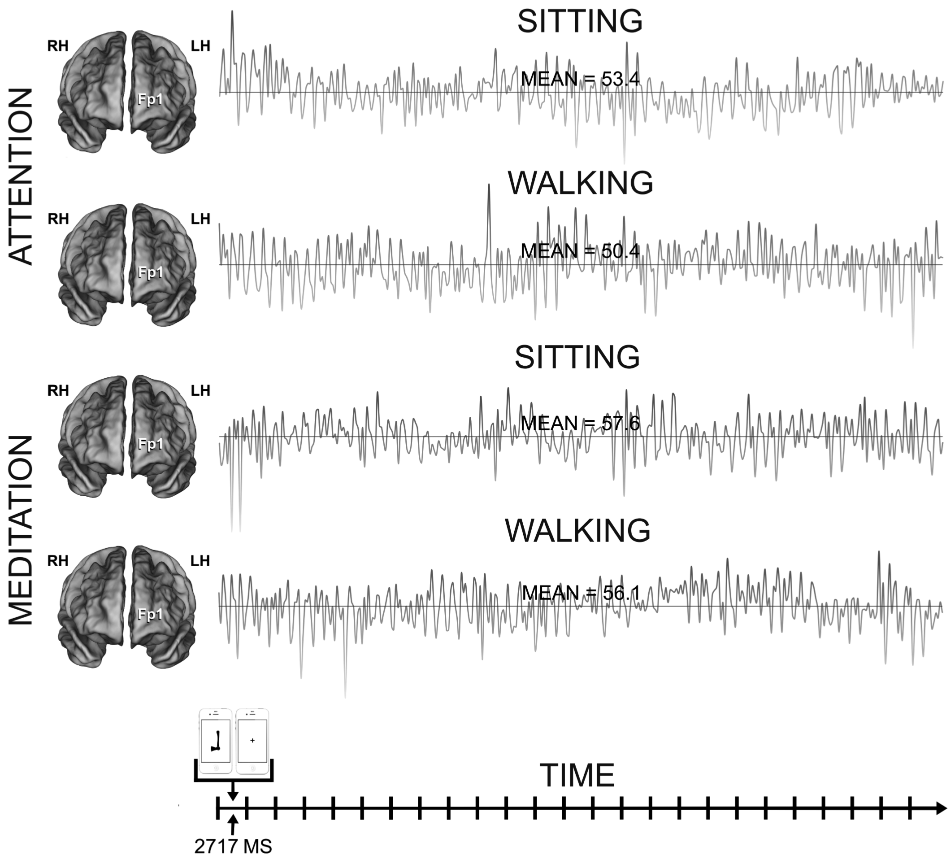

Fig. 4: The dynamics of attention and meditation during two-back tasks measured with MindWave Mobile EEG. We observed slightly longer periods of lack of concentration and slightly longer and stronger periods of stress during walking, as compared to sitting. LH – left hemisphere, RH – right hemisphere.

stronger periods of stress during walking. This allows us to conclude that when learning in CyberParks (e.g., using a smartphone), one should sit, not walk. We would not be able to make such observations in a laboratory and, consequently, educational activities with the use of smartphones during walks in parks would still be encouraged (for a full review of these issues, see Klichowski, 2017, and Klichowski & Patricio, 2017).

CONCLUSIONS

Although we have excellent laboratories to study the activity of the human brain, we increasingly see the need to escape from them. Why? Because sometimes it is impossible to simulate natural conditions in a lab. Then mobile tools measuring brain activity become helpful. For now, they can mainly measure the brainwave (mobile EEG), but perhaps soon, we will have more mobile neurotools. In this chapter we have shown that mobile EEG devices such as MindWave are not only cheap and easy to use, but also very reliable and already used in science with success. Thus, we encourage (from time to time of course) to escape from our labs and expand the territory of neuroscience to outdoor spaces. This is the only way to really understand the territory we are exploring.

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