Towards Brain Research in a Pocket

Bringing EEG Research and Diagnostics out of the Lab

Jó Ágila BITSCH LINK [a,1], Roann RAMOS [b,c], Cassandra SEVERIJNS [a] and Klaus WEHRLE [a]

[a] *COMSYS, RWTH Aachen University, Germany*
[b] *College of Science, University of Santo Tomas, Philippines*
[c] *University Hospital, RWTH Aachen University, Germany*

Abstract.
Bringing brain research tools like EEG devices out of the lab into the pockets of practitioners and researchers may fundamentally change the way we perform diagnostics and research. While most of the current techniques are limited to research clinics and require excessive set-up, new consumer EEG devices connected to standard, off-the-shelf mobile devices allow us to lift these limitations. This allows neuropsychological assessment and research in mobile settings, possibly even in remote areas with limited accessibility and infrastructure, thus bringing the equipment to the patient, instead of bringing the patient to the equipment.

We are developing an Android based mobile framework to perform EEG studies. By connecting a mobile consumer EEG headset directly to an unmodified mobile device, presenting auditory and visual stimuli, as well as user interaction, we create a self-contained experimental platform. We complement this platform by a toolkit for immediate evaluation of the recorded data directly on the device, even without internet connectivity. Initial results from the replication of two Event Related Potentials studies indicate the feasibility of the approach.

Keywords. Mobile health; EEG; mobile experimentation platform

1. Introduction

Mobile information technology has fundamentally changed the way people interact with each other and their environment. The emergence of commercial wireless mobile electroencephalography (EEG) [1] promises to realize this potential also for neuropsychological research and health care. In this paper, we present our work on a mobile framework for allowing researchers and practitioners to bring their experiments and diagnostic tools out of the lab.

EEG measures electrical potentials on the human skull, a correlate of cognitive processes in the living brain. A subclass—the Event-Related Potentials [2]—measure the spatial and temporal response to specific stimuli or events. As such,

[1] Corresponding Author: Jó Ágila BITSCH LINK, RWTH Aachen University, Ahornstr. 55, 52074 Aachen, Germany; Email: jo.bitsch@cs.rwth-aachen.de

Table 1. Feature Comparison with Related Work.

Feature	*Laboratory system*	*Smartphone Brain Scanner*	*EEG for a Walk*	*Our System*
ERP Experiments	+	0	0	+
Source Reconstruction	+	+	-	-
Brain Computer Interface	+	+	-	-
Real-time Analysis	0	-	-	+
Mobile usability	-	+	0	+

they provide insight into brain function and health, making it an important tool for clinical research as well as health care. While experiments and diagnostics are currently mostly limited to clinical environments, requiring sophisticated set-up calibration in very controlled environments.

Using our mobile system neuropsychological assessment and research is possible in mobile settings, even remote areas with limited accessibility and infrastructure, bringing the equipment to the patient, instead of bringing the patient to the equipment. This could greatly benefit patients in rural areas, but also people with limited mobility or lack of access. Similarly, from an organizational and insurance point of view, it is much easier to perform screening in a school, then to bring all students of a class into a research clinic. Also, our approach opens up the possibility of new experimental contexts and novel paradigms.

2. Related Work

Making EEG systems suitable for mobile use is a growing research field. Validating the quality of currently available mobile EEG measuring devices, such as EEG headsets, in comparison to traditional laboratory equipment is an important aspect. Another challenge is the development of software platforms that allow for building various applications that can receive and process data from mobile EEG devices and support full mobility and real-time imaging and functionality. Here, we present some of the current findings and approaches on these topics.

In a study by Badcock et al. [3], the EPOC EEG gaming headset is used to measure auditory Event-Related Potentials. While other studies [4] suggest that gaming headsets are valid for measuring EEG activity while walking outside, this study aims specifically at testing the validity for measuring auditory ERPs. To do this, a traditional EEG system and the Emotiv EEG headset were placed on participants' head and EEG signals from both systems were recorded simultaneously while an auditory experiment was presented to the participant. With the use of intraclass correlations (ICC) for comparison, the calculated auditory ERPs for the traditional and the gaming system were shown to be similar. The Mismatch Negativity (MMN) waveform however, did not show a high level of similarity, with the proposed and confirmed explanation that the MMN itself was error prone for many participants. The analysis was restricted to measurements at the frontal cortex, which deliver the largest auditory ERP responses. Thus, it can be concluded that at least for measuring EEG and auditory ERP in this area the Emotiv headset is a valid tool.

Figure 1. Experiment set-up with a Study Participant. Note, the equipment is small, mobile and easy to transport.

Similar to our system, Stopczynski et al. propose the Smartphone Brain Scanner (SBS) [5]. This open source project provides a platform for building portable brain imaging applications to use with mobile neurosystems and focuses on real-time 3D reconstruction and prospects for neurofeedback-training. It can present time-locked audiovisual stimuli and capture the neuroimaging responses. Several experiments were done to initially test the validity of the framework, related to BCI motor control, embodied semantics and neurofeedback interfaces and in this context example applications were presented. The results validate the quality of real-time EEG recordings and the structure of the system allows for a range of enhancing applications and uses. While very similar in principal to our system, SBS requires specific patches to the operating system, requiring an expert to re-compile the operating system kernel. This limits the available range of devices significantly. Also, a lot of the analysis is done off-device, which limits the use of the system in completely mobile scenarios. See Table 1 for a feature comparison.

3. Design

We designed the system as an easy to use, easily transportable, self-contained set-up, as depicted in Figure 1. The only physical components are: (1) a mobile EEG headset, (2) the receiver dongle of the headset, and (3) a mobile device, such as a tablet or mobile phone.

We subdivide the application framework for the mobile EEG system into different logical components. As shown in Figure 2, it consists of three main parts: (1) EEG driver and recording facilities, (2) stimuli presentation and experiment management, and (3) local evaluation and result presentation. We design these components to be coupled loosely, facilitating the easy extension and and replacement of the different system components.

3.1. Recording of Data

The commercial EEG headset transmits EEG measurements with a sampling rate of 128 Hz via a proprietary wireless channel to a small USB dongle at the mobile device. A device driver service, implemented in Java as a standard user space

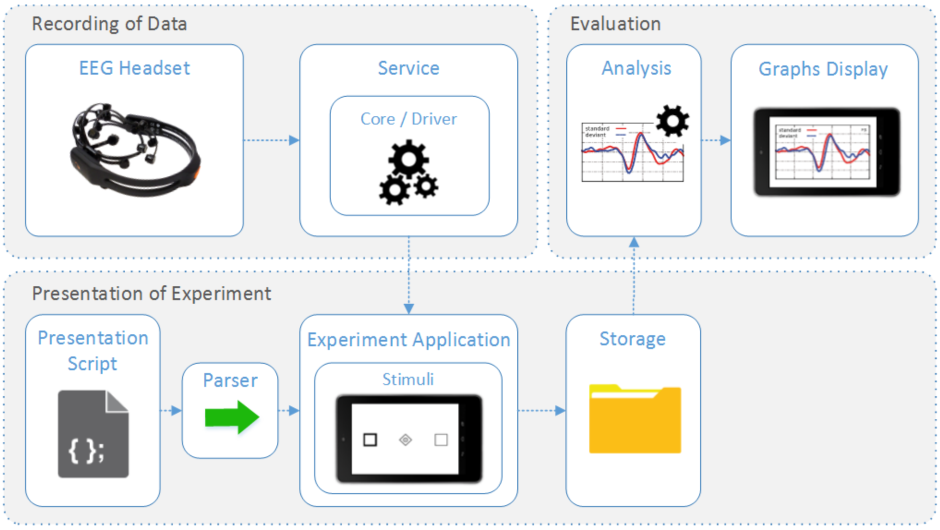

Figure 2. Overview of the framework's system architecture. The framework consists of three main components: (1) EEG driver and recording facilities, (2) Stimuli presentation and experiment management, and (3) local evaluation and result presentation.

application, receives and decodes the measurements and annotates them with the exact time stamp, as well as makes them available to other applications.

This allows other application developers to access the EEG data, possibly concurrently, without requiring them to write their own low-level driver code. This allows one client application to record EEG data for an experiment, while a completely different application monitors the signal quality and battery status.

3.2. Presentation of Experiment

This component presents auditory or visual stimuli to a user. To facilitate the creation of new experimental paradigms, we create a small shim layer, that reads *Presentation* files for presentation to the user. Using this file format, used by the *Presentation* program which is popular among clinical researchers, allows researchers not familiar with mobile application programming to create new experiment setups. Once they uploaded the presentation script to the mobile device, the file can be selected to be parsed. The experiment will then appear in a menu list of readily available experiments and the experiment can be displayed on the mobile device, the way it was designed.

During the run of an experiment, while a sequence of stimuli is presented to the user, the device records precisely, when a stimulus was presented, the exact EEG waveform as well as additional user interaction such as touch events to the screen or possibly video or audio recordings of the user.

3.3. Evaluation Pipeline

To perform mobile diagnostics, possibly in the absence of supporting infrastructure, automatic on-device evaluation would be useful. For this purpose, we implement a small toolbox of evaluation components, that allow (1) the extraction of stimulus time-locked epochs, (2) filtering out artifacts, (3) calculating averages over epochs, and (4) display of resulting graphs.

3.4. Additional Design Considerations

Our framework runs in a standard unmodified, unrooted Android device, such as a tablet, mobile phone, or TV set. We connect a commercially available wireless EEG headset [1] using a small USB dongle. While the requirement of running on unrooted devices presented minor implementation challenges, it makes hardware provisioning trivial, requiring only a simple calibration to be used on a new device class.

4. Initial results

In our initial prototype [6], we replicated the experimental set-up of two EEG studies, measuring the Event-Related Potential [2] of auditory [3] and visual [7] stimuli.

4.1. Replicating an Auditory Mismatch Negativity Study by Badcock et al. [3]

Users are presented with with an oddball paradigm of short auditory stimuli using in-ear headphones. There is a standard 1000 Hz tone played 85% probability, and a deviant 1200 Hz tone played with 15% probability. We replicated the exact stimuli and implemented the reproduced the evaluation pipeline in an Android application.

As shown in Figure 3, the initial results are promising. The wave forms we recorded visually closely match the results reported by Badcock et al. These results are very preliminary, as we only recorded data from ourselves. In a next step, we will need to confirm these results in a verification study with more participants.

4.2. Replicating a Visual Mismatch Negativity Study by Kimura et al. [7]

Instead of auditory stimuli, we present participants with visual stimuli on the screen of the mobile device. A stimulus is white line on a black background, where we vary the rotation of the line (in 30 degree steps) and the line cap (round or flat). The paradigm is then an oddball paradigm on the rotation of the line.

Participants were sitting in a comfortable chair about 50 cm from a Nexus 7 tablet and instructed to press the screen whenever they see a round cap (control condition).

While we were able to measure wave forms, we were not able to record visually matching ERPs. We are still investigating the exact reasons for this. Possible explanations include: (1) errors in the evaluation pipeline of this experiment, (2) statistical variation, as we performed the experiment only on ourselves so far, (3) inaccuracies in the recreation of the stimuli, and (4) environmental distractions during the experimental runs.

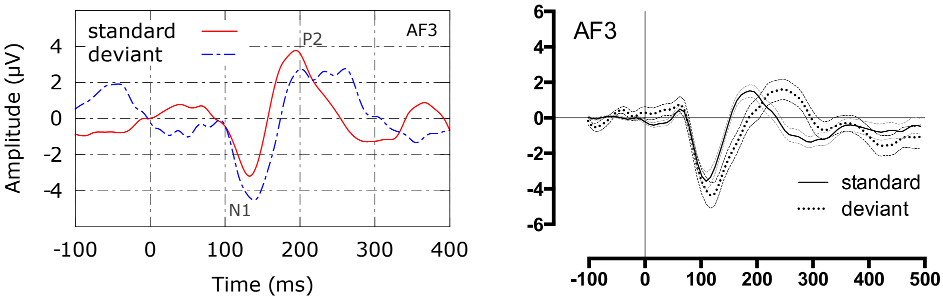

Figure 3. Event-Related Potentials from our replication (left) vs. the reported waveform [3] (right) of an auditory mismatch negativity study [3]. The wave forms visually match, indicating the initial feasibility of our framework. A verification study with more participants will need to confirm these initial results.

5. Conclusion

We presented our design and initial prototype for a mobile platform for EEG research and health-care assessment. Through the replication of the experimental set-up of an auditory Event-Related Potential study, we indicated the feasibility of our approach. The replication of a visual study reveal current limitations. Our next steps will be to consolidate the created framework and make its source code openly available to other researchers. Furthermore, we plan additional validation studies and eventually use the created tools in future studies for dyslexia research.

References

[1] Emotiv EEG;. Available from: `http://emotiv.com/epoc.php` [cited 2015-01-16].

[2] Coles MGH, Rugg MD. Event-related Brain Potentials: An Introduction. In: Electrophysiology of Mind: Event-Related Brain Potentials and Cognition. New York: Oxford University Press; 1995. p. 1 – 26.

[3] Badcock NA, Mousikou B, Mahajan Y, de Lissa P, Thie J, McArthur G. Validation of the Emotiv EPOC EEG gaming system for measuring research quality auditory ERPs. PeerJ. 2013;1:e38.

[4] Debener S, Minow F, Emkes R, Gandras K, de Vos M. How about taking a low-cost, small, and wireless EEG for a walk? Psychophysiology. 2012;49(11):1617 – 1621.

[5] Stopczynski A, Stahlhut C, Petersen MK, Larsen JE, Jensen CF, Ivanova MG, et al. Smartphones as pocketable labs: Visions for mobile brain imaging and neurofeedback. International Journal of Psychophysiology. 2013;91:54 – 66.

[6] Orlea D. A Framework for Mobile Brain Research in the Context of Neuropsychological Healthcare. RWTH Aachen University; 2014.

[7] Kimura M, Katayama J, Ohira H, Schröger E. Visual mismatch negativity: New evidence from the equiprobable paradigm. Psychophysiology. 2009;46(2):402 – 409.