# The brain's response to everyday sounds: A smartphone-based system to capture high-quality auditory ERPs

[Daniel Hölle[1], Sarah Blum[2,3], Sven Kissner[4], Stefan Debener[2], Martin G. Bleichner[1]]

[[1]Neurophysiology of Everyday Life Group, Department of Psychology, University of Oldenburg, Oldenburg, Germany]
[[2]Neuropsychology Lab, Department of Psychology, University of Oldenburg, Oldenburg, Germany]
[[3]Cluster of Excellence Hearing4all, Germany]
[[4]Institute for Hearing Technology and Audiology, Jade University of Applied Sciences, Oldenburg, Germany]

How many of the sounds that surround us do we perceive? How many go unnoticed? How strongly do people differ in their awareness to everyday sounds? With mobile, smartphone-based electroencephalography (EEG), we have a technology that allows us to study brain processes in everyday life and promises to answer these questions. We are specifically interested in relating the ongoing EEG activity to naturally occurring sounds that surround us. However, relating brain activity to events in the environment is challenging, as both the EEG data and the event data need to be precisely synchronized and stored together on one smartphone. Here we describe how we use two Android smartphone apps that we developed, AFEx and Record-A, to record audio features and EEG simultaneously with high temporal precision. We show how to use this approach to study event-related potentials (ERPs) in relation to everyday sounds. We relate audio features in the form of spectral information, loudness, and onsets to brain activity.

Our setup uses three apps: the AFEx app that provides the audio features, the Smarting app which is a commercial software that provides the EEG data, and the Record-A app that records the former two data streams to file. Figure 1 depicts this flow of information. In detail, the AFEx app provides audio features in a privacy-protecting way. The incoming audio signal, recorded with a microphone, is dissected into acoustic features. These features are loudness (RMS), spectral power (PSD), and sound onsets (e.g., start of a clap). All features are stored and processed in a way that speech, for instance, cannot be reconstructed from them. The Record-A app is a generic app that allows to record any kind of LSL data stream into one .xdf-file. With the LSL framework, different datastreams with different sampling rates can be recorded simultaneously. Each datastream has its own time information in reference to a master clock and upon import, they are time corrected and thereby synchronized.

For neural validation of the system, we conducted three brief auditory perception tasks to show that the setup allows to study ERPs. One participant was equipped with a mobile EEG amplifier (24 channels, 250 Hz sampling rate; Smarting, mBrainTrain, Belgrade, Serbia), an EEG cap (24 channels; easycap GmbH, Germany), and microphones at the ears. EEG and audio features were recorded concurrently on a smartphone (Google Pixel 3a). In the first task, a piano player played one note frequently (80% of all) and one note infrequently (20%) at regular intervals (~1 per second). The participant had to count the infrequent tones. This task is an analogue version of the well described auditory oddball paradigm used in many studies. In the second task, the freeplay condition, the participant listened to freely played piano notes that varied in speed and loudness. Finally, in the office condition, the participant listened to a pre-recorded home office soundscape. This soundscape included sounds such as working on a computer (mouse, keyboard, notification sounds), stapling, walking around, or moving dishes.

The data analysis was carried out in Matlab (The Mathworks Inc., Natick, MA, USA). The data was low-pass filtered at 25 Hz and high-pass filtered at 0.1 Hz. We cleaned the data by using artifact subspace reconstruction.

For all experiments, the sound features were recorded by the smartphone, turned into event codes (for sound onsets), and saved together with the EEG exclusively on the smartphone. To compute ERPs, we cut our continuous EEG data with our event codes and then averaged over these epochs using MATLAB. For all conditions, the expected auditory evoked potentials (P1, N1, P2) could be computed based on the sound onsets (see Figure 2). Using spectrum information, frequent and infrequent tones could be separated in the oddball paradigm. ERPs in response to infrequent tones showed a clear P3 component. In the office condition, we assigned the corresponding RMS value to each sound onset. We then computed ERPs for high RMS (loud) and low RMS (quiet) sound onsets. A higher N1 response is clearly visible in the high RMS ERP compared to the low one.

In sum, we showed that this setup allows to record audio and EEG with sufficient temporal synchrony to compute ERPs. With the setup presented here, we can now record participants' EEG and environmental sounds while they are, for instance, working in their office. Importantly, the system is not specific to auditory research, but additional smartphone sensors of interest (e.g., motion parameters to study gait patterns) can also be easily integrated into the system. Taking the step beyond the lab allows us answer to questions posed in the opening that help us to learn more about sound processing of the brain in the real-world.

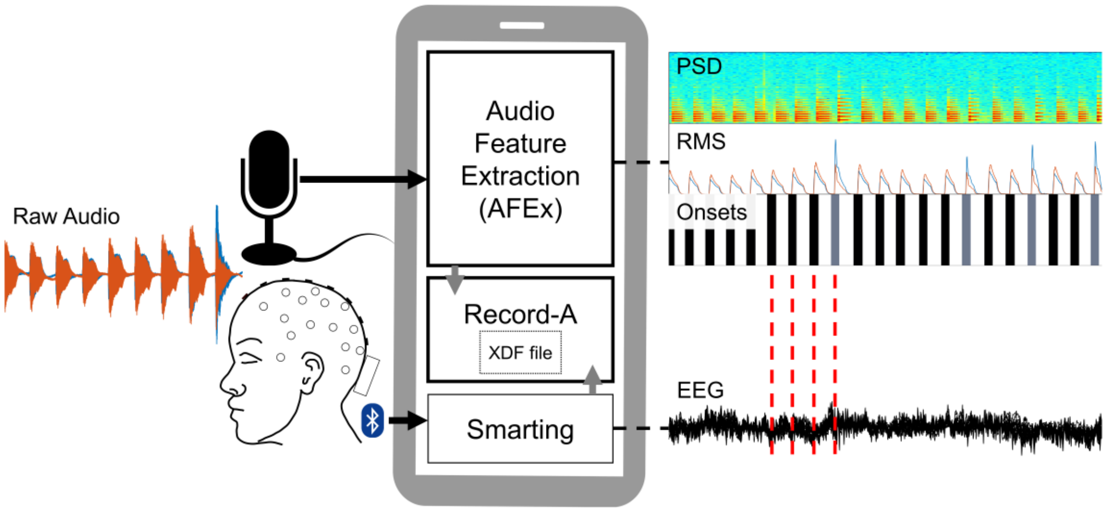


*Figure 1 Schematic of recording setup. The participant was equipped with a mobile EEG and listened to audio. The EEG data stream was generated by the Smarting app that received the data from the amplifier via Bluetooth. The sound features were computed by the AFEx app which received the audio data via a microphone connected to the smartphone. All data streams were recorded with the Record-A app and written in an xdf-file. With the sound onsets, we can epoch the EEG data and compute ERPs.*

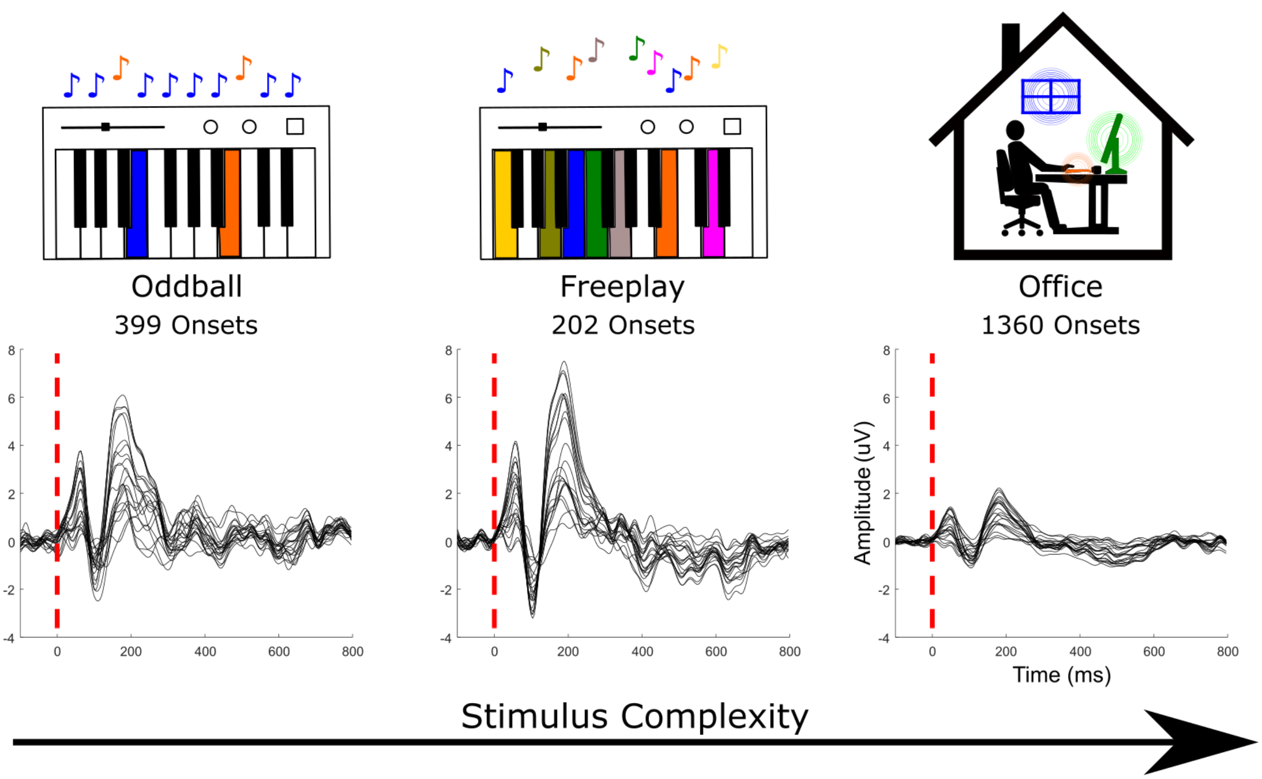


*Figure 2 Grand average ERPs of all sound onsets for each condition. In the oddball condition, the participants listened to frequent and infrequent tones that were played live on a piano. Infrequent tones had to be counted. In the freeplay condition, the participant listened passively to freely played piano tones. In the office condition, the participant listened passively to a pre-recorded home office soundscape. Note that all sound onsets for each condition were averaged here, i.e. in the oddball condition, sound onsets for frequent and infrequent tones were not differentiated.*