PROCEEDINGS of the
23rd International Congress on Acoustics
9 to 13 September 2019 in Aachen, Germany

Studying individual noise disturbance using long term ear-EEG (electroencephalography) recordings in everyday life

Martin G. BLEICHNER[(1)]

[(1)]Neurophysiology of everyday life group, Department of Psychology, University Of Oldenburg, Germany,
martin.bleichner@uol.de

Abstract
Understanding how people are affected by noise on an individual level can improve our understanding off the non-auditory effects of noise on public health. In my research I work towards a perception based noise dosimetry using mobile ear centered electroencephalography (EEG). We have shown in the past that we can study auditory perception and auditory attention using wireless ear-EEG. For this we combine small, lightweight, wireless EEG amplifiers, with ear-EEG electrodes and use a smartphone for signal acquisition and signal processing. This setup allows us to do long term EEG recordings beyond the lab, either at work, at school or at home. Over extended periods of time we can monitor the perception of sounds/noise on an individual level at those location the person is exposed to noise. We then relate the EEG to the environmental sounds and to the subjective level of noise disturbance/annoyance. In a step by step procedure we will move from well-controlled auditory perception experiments in the lab to the study of environmental noise in everyday situations. This work will advance the field of mobile ear-centered EEG for long term EEG recordings in everyday life and will provide new insights on dealing with individual noise exposure.
Keywords: Environmental noise, mobile EEG, ear EEG, noise annoyance

1 INTRODUCTION

Sounds are a rich and important source of information regarding our environment. We are highly sensitive to auditory signals, we react quicker to auditory than visual information, and we show strong physiological responses (orienting response, startle reflex, defensive response) to sounds that indicate threats or immediate danger [1]. In our modern society, we are continuously exposed to sounds that originate from human activities including transportation, construction, industry, community, social and leisure sources.

Apart from blocking our ears we cannot help but perceive the sounds that surround us, even during sleep. Unwanted sound, generally referred to as noise, is considered an environmental pollutant with negative auditory and non-auditory effects on health [2] and hence noise pollution puts human health at risk [3]. The adverse effects of noise are often discussed in relation to noise-related hearing loss. However, there are non-auditory health effects that include noise annoyance, cognitive impairment, sleep disturbance and cardiovascular problems. In these cases, sound acts as an unspecific stressor to the individual with negative effects on biological and psychological processes. Sounds also interfere directly with various cognitive and motor tasks (for a review see [4]).

The negative consequences of extensive noise exposure at the workplace are generally acknowledged regarding noise-related hearing loss. Noise dosimeters monitor noise exposure to comply with regulatory thresholds. Yet, these measures are not sufficient in the context of non-auditory effects and so it has been difficult to determine, for example, how cardiovascular problems relate to daily noise exposure. The problem here is that the acoustic properties of a sound (e.g., the sound pressure level) cannot easily be used to deduce whether a sound is perceived as disturbing or stressful by an individual. There are large intra- and inter-individual differences in what is considered as noise and in what is experienced as annoying. What is more important than the SPL of a sound is the individuals' interpretation of a sound. In principle, every annoying, unpleasant, unwanted or disturbing sound independent of its SPL or other features can be experienced as stressful and thereby can have negative consequences on the individual well-being. How a sound is perceived therefore depends on individual listening preferences, cognitive capacity, the activity at hand, and time of exposure: the negative and disturbing properties of sound become apparent only when accumulated over time. Noise dosimetry that only regards the sound pressure level is hence not sufficient to understand and measure the non-auditory health effects of noise. To gain a better understanding of the relation between noise and non-auditory health effects one needs to consider the underlying perceptual and cognitive processes.

1.1 Perception based noise monitoring

Perception based noise monitoring could help to relate the acoustic environment a person is exposed to, to the individually perceived noise disturbance. Electroencephalography (EEG) provides an interesting tool to study the perception of noise at an individual level. Due to its high temporal resolution, EEG has been widely used to assess the fast neurophysiological processes involved in auditory perception. EEG provides insights into the conscious and non-conscious perception of sound, into auditory attention and higher cognitive processes related to sound processing [5]. Instead of relying on the acoustic properties of the sound, we may use EEG to study how environmental noise is perceived by an individual.

Recent developments in mobile EEG technology even allow brain activity recordings beyond the lab (BTL) in everyday life. Especially new electrode placement approaches such as ear EEG provide new possibilities to study brain activity in public without drawing attention of other people towards the participant (as it would be the case for an EEG cap).

Hence, ear-centered mobile EEG provides the means to study noise perception in everyday situations. This approach can be instrumental to improve our understanding of the relation of the environmental soundscape – sound perception – and sound annoyance.

In this concept paper I introduce my approach to study noise perception in everyday life using long term mobile ear EEG.

2 STUDY NOISE PERCEPTION IN EVERY DAY LIFE USING MOBILE EAR EEG

For a perception based noise dosimetry we have to record brain activity in every day situations. EEG provides information about how people perceive sounds.

Traditionally EEG is recorded under well controlled laboratory conditions. A person sits motionless in a dimly lit, quite room and is exposed repeatedly to specific stimuli. The person is equipped with an electrode cap. Setting up an EEG cap can take up to one hour before the person can start with the experiment. Both, the used stimuli as well as the entire situation in which the brain activity is recorded are very different from those situations in which a person is normally exposed to noise. It is conceivable that this experimental situation also influences the way a person reacts to sounds, It is hence not necessarily representative of how people perceive sound in their familiar environments or during stressful situations.

Mobile EEG provides the possibility to record brain activity beyond the lab. This opens up new possibilities to study the relationship between brain activity and individual noise perception.

There are three recent key developments in mobile EEG technology that are essential for extended BTL recordings: small and lightweight wireless amplifiers, smartphone-based experimentation, including signal processing and analysis [6], and ear-centered EEG [7, 8].

2.1 Mobile EEG

We have repeatedly demonstrated the feasibility of using wireless EEG hardware for recording EEG during walking [9], during music performance [10], during language processing [11], and during outdoor memory formation [12] to name just a few examples. In these studies a small wireless amplifier is attached to the back of the head. The mobile amplifier can either be used in combination with a classical EEG cap or with dedicated ear electrodes (see below). The data is transmitted via Bluetooth either to a PC or smartphone (see below). Besides EEG, mobile amplifiers generally also record information about the movement of the amplifier

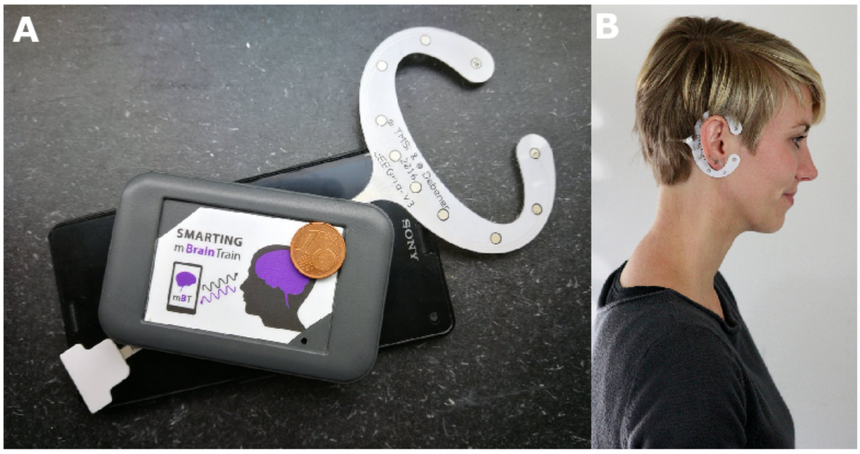

Figure 1. A) Our transparent EEG setup for long term mobile ear EEG recordings. The wireless EEG amplifier, is connected to electrodes that are positioned around the ear(cEEGrid). The data is transmitted via Bluetooth to an off the shelf android smartphone. Stimulus presentation is done on the smartphone itself. (B) cEEGrid electrodes are positioned around the ears, and allow to record brain activity conspicuously in public.

(using accelerometers or gyroscopes). I.e. from this data we get information about the movements of the participants, which can help in interpreting the EEG data, or in dealing with artifacts.

2.2 Ear-centered EEG

Ear-centered EEG allows registration of brain activity using a small number of EEG sensors located in or around the ear in a socially more acceptable manner [13]. There is ample evidence that ear-centered EEG allows to record meaningful neural signals [13, 8, 14, 15, 16, 17]. We have developed the so called cEEGrid (www.cEEGrid.com), a sensor array with ten electrodes that is positioned around the ear [8] (1B). The electrodes are positioned with a double sided sticker around the ears. The contact between electrode and skin is provided by a small amount of conductive gel.
With these electrodes we can record for example neural processes related to auditory processing or auditory attention [8, 14, 18]. Studies using simultaneous recording from cEEGrid (with a wireless EEG amplifier) and a traditional high-density EEG (using a classical lab amplifier) have confirmed that the signals recorded around the ear originate from neural sources rather than other physiological processes [7]. We have also shown that other neural processes such as changes in alpha power [8], sleep stages [7], and epileptic activity [7] can be captured with the cEEGrid. Finally, we have shown that EEG can be recorded reliably over several hours [7].

2.3 Smartphone based EEG acquisition

Smartphones have been used for data acquisition and stimulus presentation in several projects [8, 12]. We have developed a closed-loop smartphone-based brain-computer interface prototype, demonstrating that EEG signal acquisition, stimulus presentation, signal processing, signal classification and classification-dependent feedback can all be realized together on a single, off-the-shelf smartphone [6]. Other have demonstrated smartphone-based privacy-aware stereo audio recordings [22]. The combination of this technology can be used to record EEG and audio simultaneously on a single mobile system, and therefore allows to relate the ongoing EEG with the current soundscape.

We call the combination of wireless EEG, ear electrodes and smartphones 'transparent EEG' [7]. Unlike classical EEG caps, transparent EEG allows unobtrusive and convenient EEG acquisition of naturally behaving individuals in everyday situations without drawing attention of other people. Figure 1 shows the components of our recording setup.

2.4 Methodological Consideration - Leaving the lab: step by step

The study of EEG in everyday situations poses considerable challenges compared to traditional lab based experimentation. In traditional EEG experiments the goal is to have maximal experimental control over the experiment and to manipulate only one specific variable to exclusively study the effects of this manipulation. EEG signals are analyzed in respect to some event (a visual or auditory stimulus). This event is presented multiple times to the participant. By averaging over multiple repetitions, the brain response that is specific to the processing of the event emerges from the underlying background noise. In beyond lab recordings this level of control is not possible any more. We have considerable less control over the participant (i.e. to ensure task compliance) and we have little to no control over the environment. This makes beyond the lab studies considerably more complex.

In order to bridge this gap we take a step by step procedure. There is a considerable literature on EEG/ERP results for a wide variety of cognitive tasks. This knowledge also allows to generate specific hypothesis regarding effects of auditory processing and auditory attention. In order to understand the relation of sound exposure and sound experience in everyday situations we carefully have to built upon the existing literature to be able to interpret of mobile ear EEG results. I see five stages:

1. Replicate established paradigms with the limited electrode coverage of ear EEG under lab conditions.
2. Replicate established paradigms beyond the lab.
3. Adapt existing paradigms so that they can be integrated into a workday.
4. Adapt existing paradigms so that they make use of the natural soundscape.
5. Study the relationship of sound experience and sound exposure in everyday situations.

Figure 2 shows the ERP results of an auditory oddball paradigm recorded while the participant was sitting quietly at an office desk in front of his computer will doing the task.

This approach allows us to start with clear expectations on the resulting ERPs and to relate our BTL findings to the lab EEG literature.

2.5 Mobile EEG vs. EEG during motion

EEG is notorious for its susceptibility to artifacts. These artifacts can originate from physiological and non-physiological sources. Physiological artifacts originate for example from shoulder, eye, or mouth movements. Non-physiological artifacts originate for example from cable or electrode movement, or interference from other technical devices.

For EEG that is recorded during motion, the artifacts can be so large that the brain signal is not interpretable anymore (but see also [9] for a successful example). There are a number of signal processing procedures that allow to attenuate these artifacts [20, 19]. However, especially in those cases in which the motion artifact is tightly time locked to the event of interest, the data often cannot be recovered. For example, if person always turns his head towards a new sound, an artifact will always coincide with the neural event of interest. In these cases it will be very difficult to disentangle the signals.

However, mobile EEG does not necessarily imply that the EEG data is recorded while the participant is moving. Indeed, when one thinks about a normal work day at the office, there are many periods in which a person is moving very little. Figure 3 shows the amount of head movement during a lab recording and a recording that was done in an office environment. For the office recording we see periods with a lot of movements and periods in which the amount of movement is similar to a lab recording. That is despite of occasional large movements, in which the EEG data may not be usable, there will be many periods in which the quality will be comparable

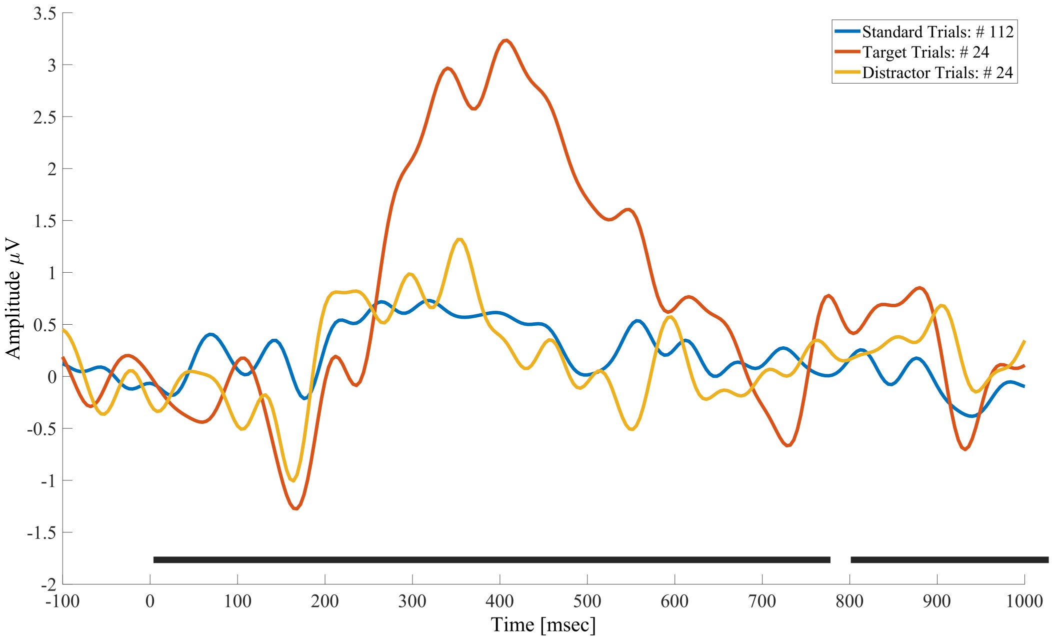

Figure 2. Single subject data of a mobile ear EEG recordings of an participant doing auditory oddball paradigm at his desk. A sequence of double tones was presented, consisting of a standard tone (blue), which was presented regularly (70% of all presented tones), a pitch deviant (red) target tone (15% of all presented tones), in response to which the participants had to tap on the screen of the smartphone, and a pitch deviant distractor tone (yellow, 15% of all presented tones), which required no response. The ERP for the distractor and target tone shows a N100. For the target tones, which required a overt response, the expected P300 ERP is clearly visible. Indicated in black are the onsets and duration of the two tones of the stimulus.

to lab recordings.
The advantage of mobile long-term ear EEG is, that evidence can be accumulated over extended periods of time. Phases in which the signal is strongly contaminated by artifacts can be removed from the analysis, and sufficient data for an analysis is available.

3 SUMMARY

I propose here that a perception based noise monitoring could help to better understand the relation of environmental noise and non-auditory health problems. I argue that long term mobile ear EEG can be instrumental to relate the objective sound exposure to the subjective sound experience. I have shown that the combination of wireless EEG amplification, ear-centered electrode positioning and smartphone based stimulus presentation and data recordings can be used to study auditory attention beyond the lab. The challenge in future studies will be to relate the naturally existing soundscape a person is exposed to, to the EEG signal. In a step-by-step procedure we need to translate what we know about auditory perception from lab EEG studies to the study of noise perception in everyday life.

REFERENCES

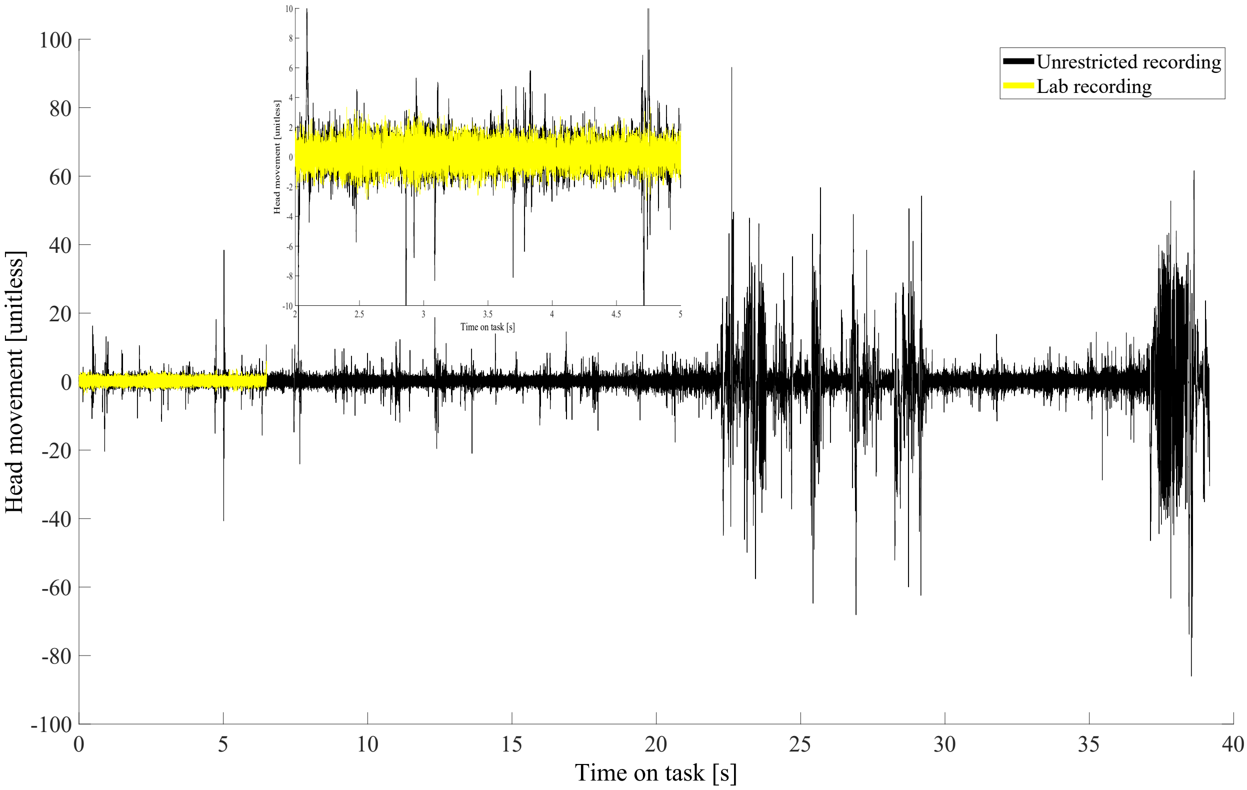

Figure 3. Comparison of head movements during an EEG recording in the lab (yellow), and an EEG recording in an office environment (black). Shown is the head movement of the participant based on the gyroscope of the mobile amplifier attached to the participants head. During the lab recording (8 minutes) the participant was asked to move as little as possible. For the office recording no specific instruction was given. One sees periods of movement (i.e. during which the participant stood up to get coffee (at around 37 minutes) and periods of relative rest (i.e. during which the participant worked silently at a computer. Apart from a rare larger movements the amount of movement was comparable to the lab recording (inset). The data quality for these periods can be expected to be similar to the data quality obtained during a lab recording.

[1] Westman, J.C. et al., Noise and stress: a comprehensive approach. Environ. Health Perspect. 41, 291–309 (1981).

[2] Basner, M. et al., Auditory and non-auditory effects of noise on health. The Lancet 383, 1325–1332 (2014).

[3] Fritschi, L. et al., Burden of disease from environmental noise: Quantification of healthy life years lost in Europe. World Health Organization (2011). doi:10.1080/13504630.2011.629519

[4] Szalma, J.L. et al., Noise Effects on Human Performance: A Meta-Analytic Synthesis. Psychol. Bull. 137, 682–707 (2011).

[5] Lopes da Silva, F., EEG and MEG: Relevance to neuroscience. Neuron 80, 1112–1128 (2013).

[6] Blum, S. et al., EEG Recording and Online Signal Processing on Android: A Multiapp Framework for BrainComputer Interfaces on Smartphone. Biomed Res. Int. 2017, 1–12 (2017).

[7] Bleichner M.G. et al., Concealed, Unobtrusive Ear-Centered EEG Acquisition: cEEGrids for Transparent EEG. Front Hum Neurosci. 2017;11:163. Published 2017 Apr 7. doi:10.3389/fnhum.2017.00163.

[8] Debener S. et al., Unobtrusive ambulatory EEG using a smartphone and flexible printed electrodes around the ear. Sci Rep. 2015;5:16743.

[9] de Vos, M. et al., Mobile EEG: Towards brain activity monitoring during natural action and cognition. Int. J. Psychophysiol. (2013). doi:10.1016/j.ijpsycho.2013.10.008

[10] Zamm, A. et al., Synchronizing MIDI and wireless EEG measurements during natural piano performance. Brain Res. (2017). doi:10.1016/j.brainres.2017.07.001

[11] Fjaellingsdal, T.G. et al., The N400 effect during speaker-switch-towards a conversational approach of measuring neural correlates of language. Front. Psychol. 7, (2016).

[12] Piñeyro Salvidegoitia, M. et al., Out and about: Subsequent memory effect captured in a natural outdoor environment with smartphone EEG. Psychophysiology. 2019; 56:e13331. https://doi.org/10.1111/psyp.13331

[13] Bleichner, M.G. et al., Exploring miniaturized EEG electrodes for brain-computer interfaces. An EEG you do not see? Physiol. Rep. 3, e12362–e12362 (2015).

[14] Mirkovic, B. et al., Target speaker detection with concealed EEG around the ear. Front. Neurosci. 10, (2016).

[15] Mikkelsen, K. B. et al., EEG recorded from the ear: Characterizing the Ear-EEG Method. Front. Neurosci. 9, (2015).

[16] Kidmose, P. et al,. A study of evoked potentials from ear-EEG. 2013 (2013).

[17] Looney, D. et al., Auditory evoked responses from ear-EEG recordings. Eng. Med. (2012).

[18] Bleichner M.G. et al., Identifying auditory attention with ear-EEG: cEEGrid versus high-density cap-EEG comparison, J. Neural Eng. 2016; 13 066004.

[19] Mullen, T. R. et al., Real-time neuroimaging and cognitive monitoring using wearable dry EEG. IEEE Trans. Bio-Med. Eng. (2015) 62, 2553–2567. doi: 10.1109/TBME.2015.2481482

[20] Jung, T.-P. et al., Removing Electroencephalographic aretfacts by blind source seperation. Psychophysiology 37, 163–178 (2000)

[21] Debener S. et al., Using ICA for the analysis of EEG data. In book, Simultaneous EEG and fMRI: Recording, Analysis, and Application. 2010.

[22] Kissner, S., et al., A smartphone-based, privacy-aware recording system for the assessment of everyday listening situations. Proceedings of the International Symposium on Auditory and Audiological Research, 5, 445-452, (2105)