Imperial College London

Ear-EEG

Continuous and Wearable Brain Monitoring

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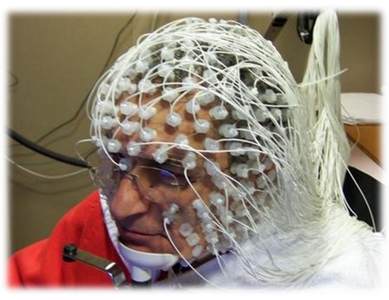
SUMMARY | We present a radically new solution for recording EEG where electrodes are embedded on a customized earpiece, as typically used in hearing aids (Ear-EEG). This provides a noninvasive, minimally intrusive and user friendly way of recording EEG over long time periods (days) and in natural environments. The operation of Ear-EEG is illustrated for alpha-attenuation and responses to auditory stimuli, and its potential in brain computer interface and fatigue-detection demonstrated. Ear-EEG signal quality is comparable with that of on-scalp electrodes, thus promising a quantum step forward for continuous and wearable brain monitoring.

(1) Existing (on-scalp) EEG Systems

Electroencephalogram (EEG) technology is widely used as a **low cost** means of recording brain activity. However, more ***widespread use of EEG is limited by conventional recording systems which are bulky and cumbersome*** and which primarily operate in the laboratory setting

This highlights the ***need for wearable systems which allow long-term recordings in natural environments*** [1]. Such systems are particularly useful in applications for which a trade-off in performance is acceptable in order to enhance user comfort



Conventional 'stationary' system

EEG system with dry electrodes

Despite advances (battery size, dry electrodes), on-scalp systems require a means for stable attachment (cap and/or adhesive), making the recording process uncomfortable and stigmatising

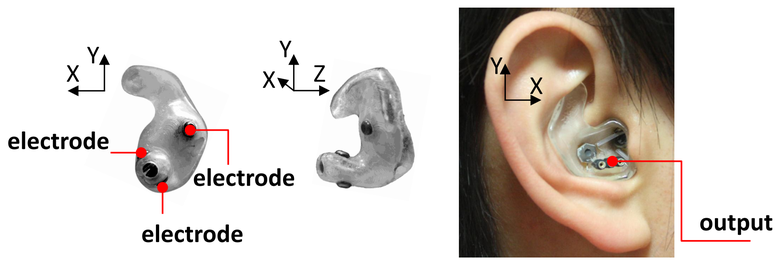
(2) Ear-EEG

In order for EEG to be adopted more widely and in natural environments, the recording technology should be [2, 3]:

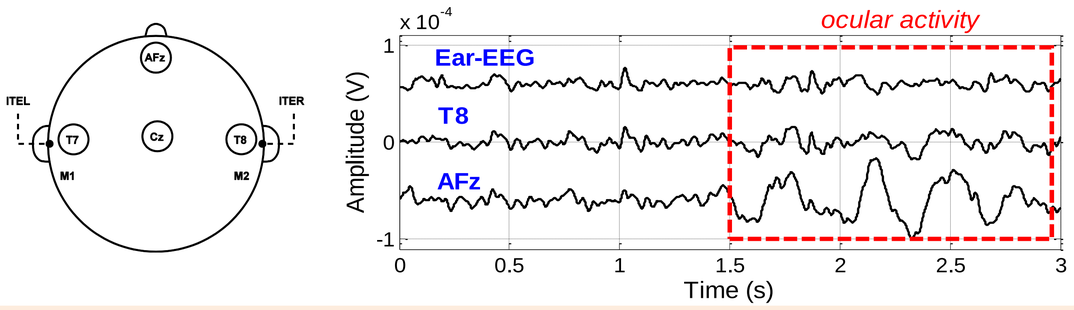
- **Discreet** - not clearly visible or stigmatising,
- **Unobtrusive** - comfortable to wear and impeding the user as little as possible,
- **User-friendly** - users should be able to attach and operate the devices themselves.

Motivated by the above requirements, we have developed the Ear-EEG concept whereby brain activity is recorded from within the ear canal achieved by embedding electrodes on a customised earpiece (similar to a hearing aid)

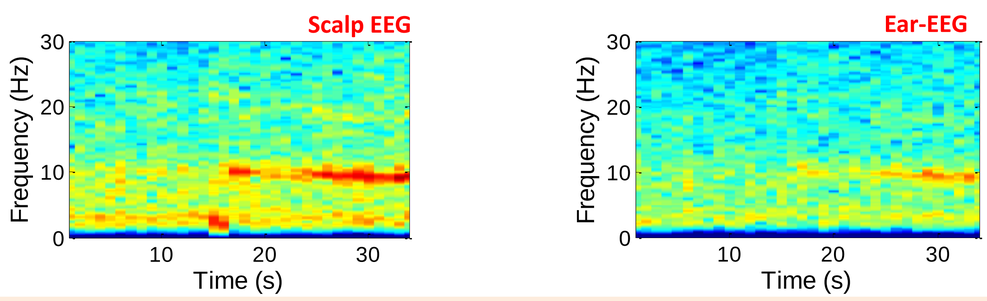
The tight fit between the earpiece and ear canal ensures that the electrodes are held firmly in place, thus overcoming some critical obstacles in scalp EEG – such as motion artifacts and experiment repeatability



Prototype Ear-EEG system: all electrodes (including reference and ground) are embedded on a customized earpiece placed within the ear canal and the outer ear



Ear-EEG exhibits a suppression of artifacts caused by ocular (eye) activity



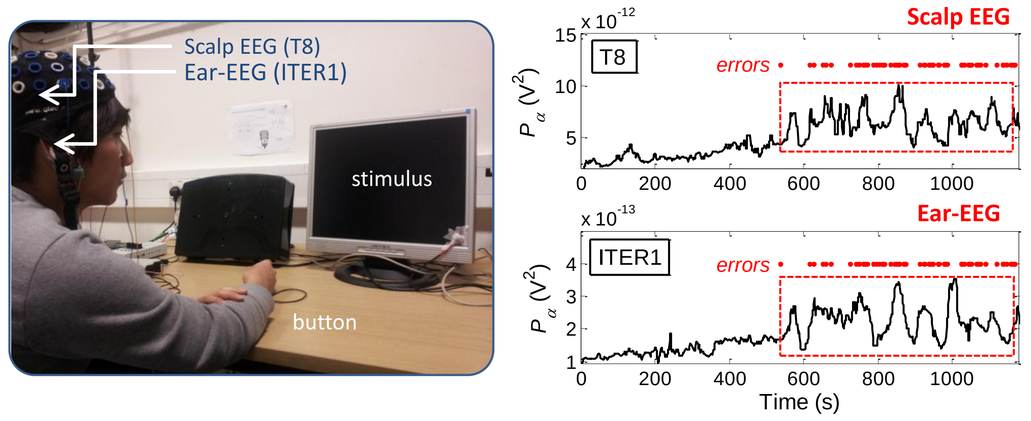
The Ear-EEG concept has been validated for a wide range of stimulus-driven and spontaneous responses

The Ear-EEG recording system is a fundamental step toward a ubiquitous fully wearable device suitable for long-term continuous use

(3) Ear-EEG: Applications

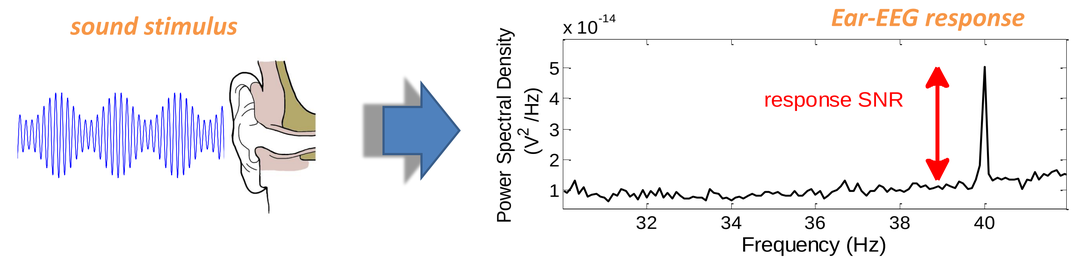
There are a wide range of EEG applications, clinical and non-clinical, for which only a *small number of recording electrodes are sufficient* but where portable, discreet, unobtrusive and user-friendly devices are paramount

Pilot Study: Fatigue Monitoring



As the subject became increasing fatigued their error rate in a computer-based task increased. Note a strong correlation between error rate and Ear-EEG alpha power

Pilot Study: Assessment of Hearing Threshold



Ear-EEG electrodes are located close to the primary auditory cortex and the SNR of responses to auditory stimuli match that of on-scalp electrodes [4]

Pilot Study: Brain Computer Interface

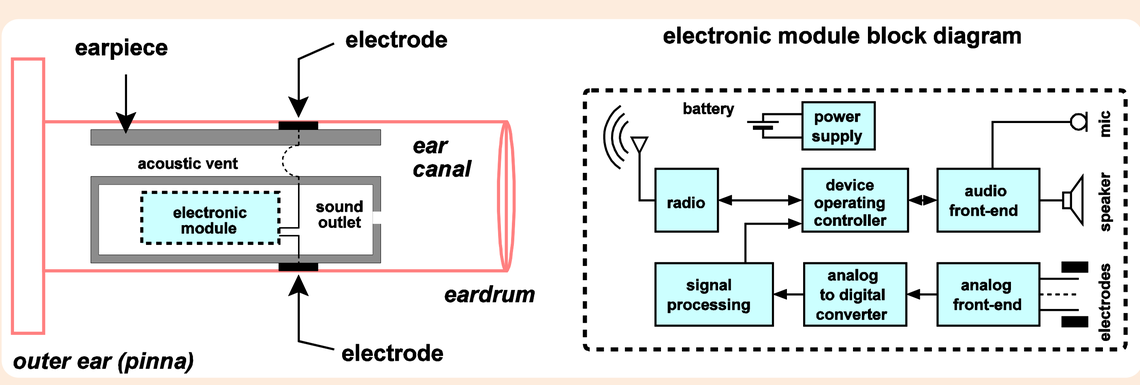
In visual stimulus-based BCI Ear-EEG exhibits a performance reduction (bits/min) of only 50% compared with on-scalp approach ***(result shortlisted for 2012 BCI award [5])***

(4) Ear-EEG: Future Opportunities

The future Ear-EEG device will be a tiny battery powered brain monitoring device with gel-free electrodes that, like a hearing aid, will perform both the recording and signal processing in situ (see below)

The functionality of the Ear-EEG platform can readily be extended beyond EEG to include other physiological signals by integrating additional non-invasive and small sensors:

- **cardiovascular function:** ear-based photoplethysmography devices available
- **respiratory function**: respiratory sounds can be recorded within ear canal
- **movement**: accelerometers are sufficiently small size and low-power



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[2] **D. Looney**, P. Kidmose, C. Park, M. Ungstrup, M. L. Rank, K. Rosenkranz, and **D. P. Mandic**, "The in-the-ear recording concept (in print)", IEEE Pulse Magazine, 2012.

[3] **D. Looney**, C. Park, P. Kidmose, M. L. Rank, M. Ungstrup, K. Rosenkranz, and **D. P. Mandic**, "An in-the-ear platform for recording electroencephalogram", *in Proceedings of the International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2011, pp. 6882-6885.

[4] P. Kidmose, **D. Looney**, and **D. P. Mandic**, "Auditory evoked responses from Ear-EEG recordings (accepted)", *in Proceedings of the International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2012.

[5] **D. Looney,** P. Kidmose and **D. P. Mandic**, "Ear-EEG: User-centered, wearable & 24/7 BCI", shortlisted for 2012 g.tec BCI award.

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