Ear-EEG for Detecting Inter-brain Synchronisation in Continuous Cooperative Multi-person Scenarios

Apit Hemakom, Valentin Goverdovsky and Danilo P. Mandic
{apit.hemakom12, d.mandic}@imperial.ac.uk

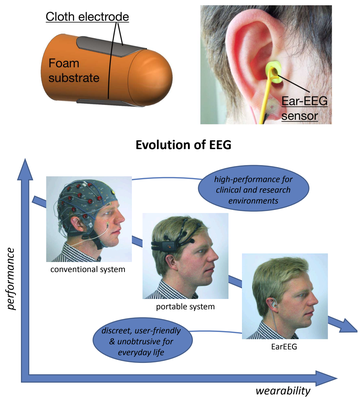
Imperial College London

1. Hyperscanning Method

- Simultaneous acquisition of cerebral data from multiple brains.
- Theta (3–7 Hz) and alpha (7–13 Hz) bands of electroencephalography (EEG) signals have been shown to synchronise between the brains most during social interaction, and they can be recorded over the right hemispheres of participants, dominating in the right centroparietal regions.
- Suppression in power (power desynchronisation) in the lower theta and alpha bands is believed to be associated with attention.
- Increased coherence in the theta band, particularly the upper portion, between hippocampal and rhinal cortices is correlated with successful encoding of new information into episodic (working) memory.

2. Ear-EEG Recording Concept

- The acquisition of EEG signals from inside the ear canal.
- Enables the recordings of: (i) alpha activity of EEG (alpha attenuation) [1], (ii) auditory steady-state response (ASSR) [2], (iii) steady-state visual evoked potential (SSVEP) [2], and (iv) P300 response [3].
- Its capability as an alternative, practical data acquisition approach to the hyperscanning technique has not been explored.



3. Intrinsic Synchrosqueezing Coherence (ISC)

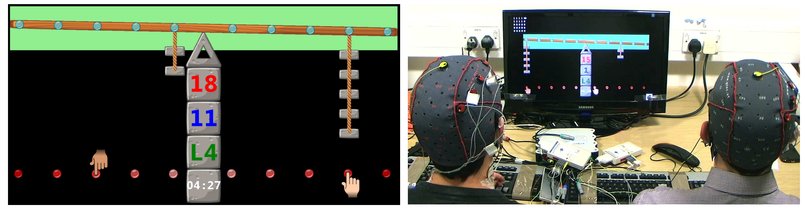
- A highly localised time-frequency data association measure [4].
- The combination of noise-assisted multivariate empirical mode decomposition (**NA-MEMD**) & short-time Fourier transform (STFT)-based synchrosqueezing transform (**FSST**) and multivariate synchrosqueezing transform (**F-MSST**).

4. Aim of the Study

To employ the enhanced discrimination capability of the ISC data association metric, in order *to evaluate the performance of ear-EEG against on-scalp EEG* as an alternative for practical data acquisition approach for the hyperscanning method in the task of identifying the most robust EEG subbands *for inter-individual neuronal synchrony detection* for cooperative multi-player gaming.

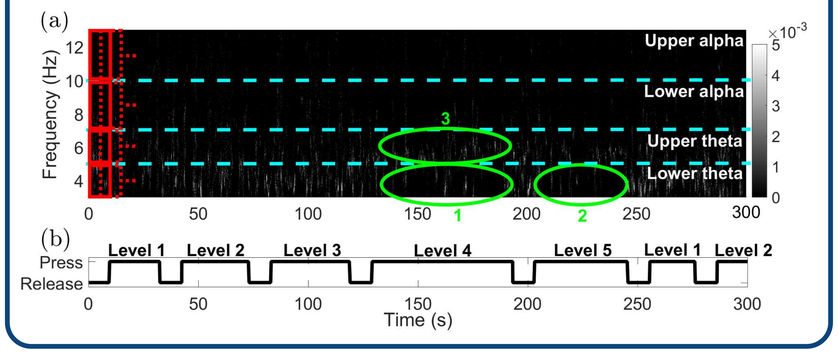
For a full control over the experiment, we have developed our own cooperative multi-player game – Bar Balancing – which was designed to encourage the participants to highly collaborate.

5. Cooperative Game & Experimental Setup

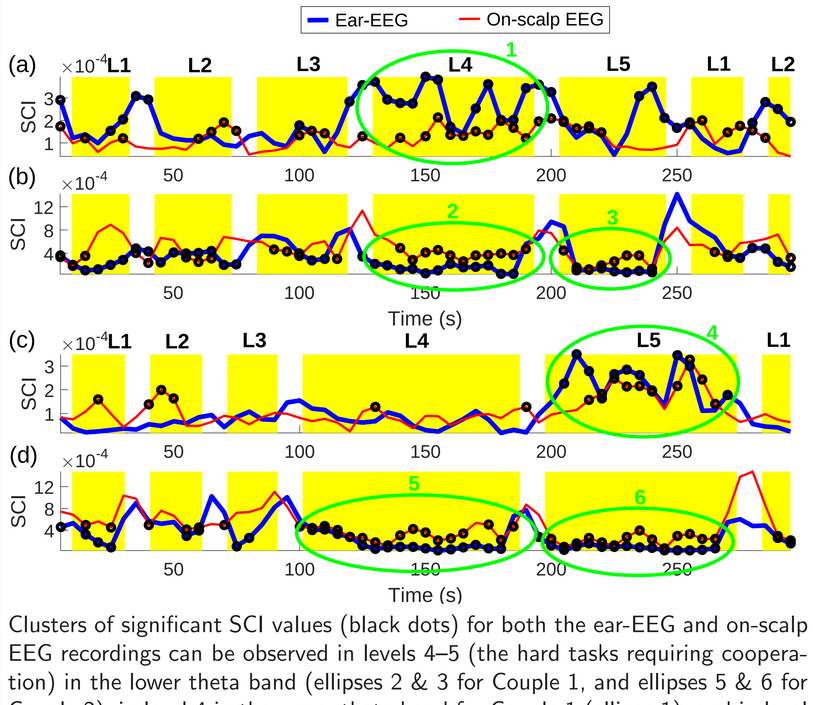


- 3 5-minute trials: 2 single trials & 1 cooperative trial.
- 5 levels of difficulty in each trial: 1 (easiest) to 5 (hardest).
- 6 couples, each couple were expected to highly cooperate during levels 4 and 5, where the wooden bar was rotating around the pivot point very fast.

6. Time-frequency Inter-brain Synchronisation between Couple 1 Estimated from Ear-EEG Recordings

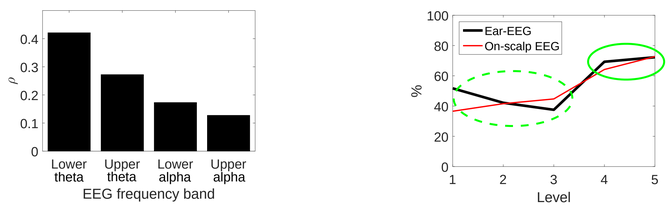


7. Time-varying Inter-brain Synchronisation in Couples 1 & 2 in the Theta Band



Clusters of significant SCI values (black dots) for both the ear-EEG and on-scalp EEG recordings can be observed in levels 4–5 (the hard tasks requiring cooperation) in the lower theta band (ellipses 2 & 3 for Couple 1, and ellipses 5 & 6 for Couple 2), in level 4 in the upper theta band for Couple 1 (ellipse 1), and in level 5 in the upper theta band for Couple 2 (ellipse 4).

8. Correlation in Inter-brain Synchronisation between the Recording Modalities, and Average Proportion of the Number of Significant SCI Values Detected in Each Level from Ear-EEG and On-scalp EEG Recordings of the 6 couples in the Lower Theta Band



9. Conclusions

- Through the estimation of neuronal synchrony produced by the ISC algorithm, both the recording modalities have effectively exhibited power de/-synchronisation in two EEG subbands (lower and upper theta bands) which associate with different cognitive tasks.
- The cooperation was mediated by synchronised attention and, to an extent, adaptive working memory of the participants, reflected respectively by the decreases and increases in significant inter-individual neuronal synchrony in the lower and upper theta bands for both the recording modalities.
- The lower theta band was the most robust neuronal marker for brain synchronisation during such a cooperative task, since: (i) it exhibited in neuronal synchrony between the modalities, and (ii) in this subband the proportions of significant neuronal synchrony detected in the easy and hard tasks yield enhanced discrimination ability by both the modalities.
- This work is a first step towards fully wearable EEG outside of a lab.

Selected works

1. D. Looney, C. Park, P. Kidmose, M. L. Rank, M. Ungstrup, K. Rosenkranz, and D. P. Mandic, "An inthe-ear platform for recording electroencephalogram," *Proc. of IEEE EMBC 2011*, pp. 6882–6885, 2011.
2. V. Goverdovsky, D. Looney, P. Kidmose, and D. P. Mandic, "In-ear EEG from viscoelastic generic earpieces: Robust and unobtrusive 24/7 monitoring," *IEEE Sensors J.*, vol. 16, no. 1, pp. 271–277, 2016.
3. M. G. Bleichner, M. Lundbeck, M. Selisky, F. Minow, M. Jäger, R. Emkes, S. Debener, and M. D. Vos, "Exploring miniaturized EEG electrodes for brain computer interfaces. An EEG you do not see?," Physiol. Rep., vol. 3, no. 4, pp. e12362-1–e12362-4, 2015.
4. A. Hemakom, K. Powezka, V. G. Goverdovsky, U. Jaffer, and D. P. Mandic, "Quantifying team cooperation through intrinsic multi-scale measures: Respiratory and cardiac synchronisation in choir singers and surgical teams," *R. Soc. Open Sci.*, vol. 4, no. 1, pp. 170853-1–170853-23, 2017.