EEG correlates of sensorimotor processing: independent components involved in sensory and motor processing

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Abstract

Sensorimotor processing is one of the key functionalities of the human brain and we know of cortical areas which are specialized for sensory recognition or motor execution. But unlike early afferent and late efferent brain activities, the coupling between these steps remain concealed. In our experimental paradigm, we used stimulus presentation in complex speeded categorization-response tasks (variations of a Stroop task), which require recognition, decision, and motor response, to test the hypothesis that some functional modules are participating in both sensory as well as motor processing. We operationalize functional modules as independent components (ICs) yielded by an independent component analysis (ICA) of EEG data. We measured event-related responses by means of inter-trial coherence (ITC). We consistently found across subjects ICs with event-related ITC responses related to both sensory stimulation and motor response onsets, on average 5.8 such ICs per session. We calculated their equivalent dipoles and carried out k-means clustering. Thus, the current study reveals some EEG correlates of tightly coupled sensorimotor processing in the human brain. Our results are compatible with such frameworks, like embodied cognition, common coding, and sensorimotor contingency.

Methods

21 volunteers participated in the study. The stimuli were a combination of a coloured text presented centrally on a computer screen (visual angle: 2x1°) and a simultaneously occurring auditory word through a headset. Four different colours were used: red, green, blue, and yellow, yielding 64 possible combinations. Participants categorized each stimulus in accordance with a given rule by pressing on a keyboard Arrow Left with the index finger of the right hand or Arrow Right with the ring finger of the right hand.

Fig. 1. Experimental setup.
A demo of the experimental paradigm is available for Android (≥4.4):
https://play.google.com/store/apps/details?id=com.gmail.ndrwmlnk.IMSI

Conclusions

- We hypothesised that the Sensorimotor ICs, which we found in the study, represent functional modules in the brain, which draw the whole arch from sensory stimulation to motor response. Our findings are compatible with such frameworks as embodied cognition, sensorimotor contingency, and common coding.
- The number of Sensorimotor ICs does not correlate with the number of channels in an EEG system. It supports our expectation that these are genuine Sensorimotor ICs.

Four types of ICs

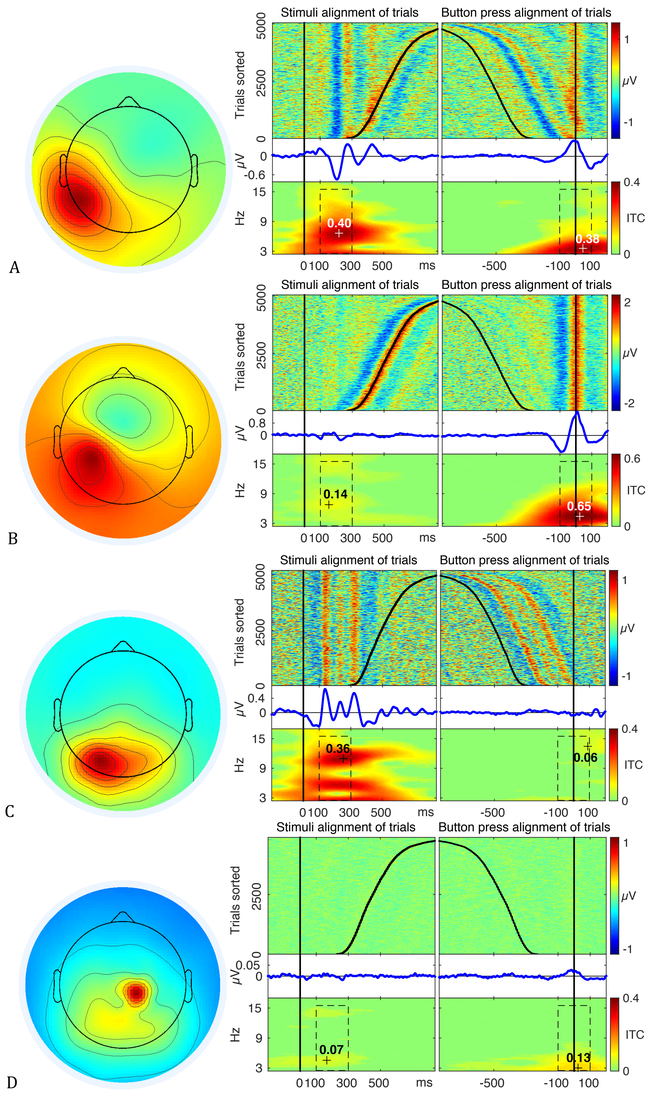

Fig. 2. Examples of (A) Sensorimotor, (B) Motor, (C) Sensory, and (D) Unspecified ICs. The round component scalp maps on the left side represent topography of ICs from 64-channel EEG recordings. Panels on the right side of each scalp map depict activity data of the IC. (1) The "**top-left**" plot in each panel shows colour-coded amplitude of the IC activity in a recording session. Trials were sorted according to latency of reaction time. The black vertical line (OX = 0 ms) shows the onsets of the stimuli and the black curve in the positive direction shows the moments of a button-press event. (2) The "**top-right**" plot in each panel depicts the same trials as the "top-left" plot, but this time trials were aligned by onset of a button-press event (OX = 0 ms). (3) The "**middle-left**" and (4) "**middle-right**" plots in each panel show ERPs (blue curves) derived from trials depicted in the plots above. (5) The "**bottom-left**" plot in each panel shows inter-trial coherence (ITC) of trials from the "top-left" plot. The maximum value of ITC in the time-frequency window of 100 ms to 300 ms by 3 Hz to 15 Hz represents Sensory ITC value of the IC. (6) The "**bottom-right**" plots in each panel show ITC of trials from the "top-right" plot. The maximum value of ITC in the time-frequency window of -100 ms to 100 ms by 3 Hz to 15 Hz represents a Motor ITC value of the IC.

We consistently found *Sensorimotor ICs*, in which event-related ITC responses are related to both sensory stimulation and motor response onsets

Artefact-related ICs rejected from data analysis

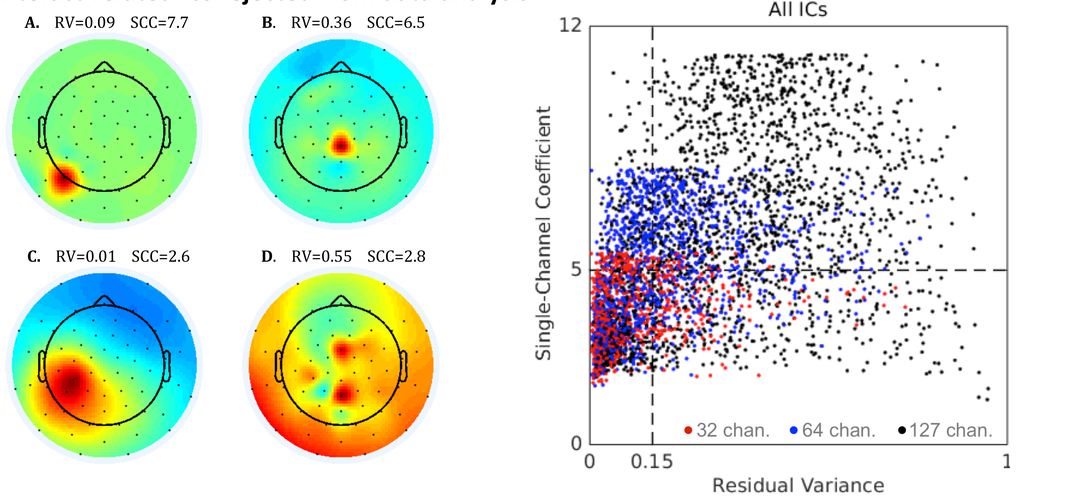

Fig. 3. Examples of artefact ICs (A, B & D) and a good IC (C) which were excluded and kept for further analysis, respectively.
RV = residual variance of an equivalent dipole of the IC. **Single-Channel Coefficient (SCC)** = (E-X)/σ. E - the highest absolute value of channel coefficients of the IC [EEG.icawinv(:,IC) in EEGLAB]; X - the mean value of channel coefficients of the IC; and σ - the standard deviation value of channel coefficients of the IC.

ICs with RV>0.15 or SCC>5 were rejected from further data analysis

Distribution of ICs into the four groups: Motor, Sensory, Sensorimotor, and Unspecified

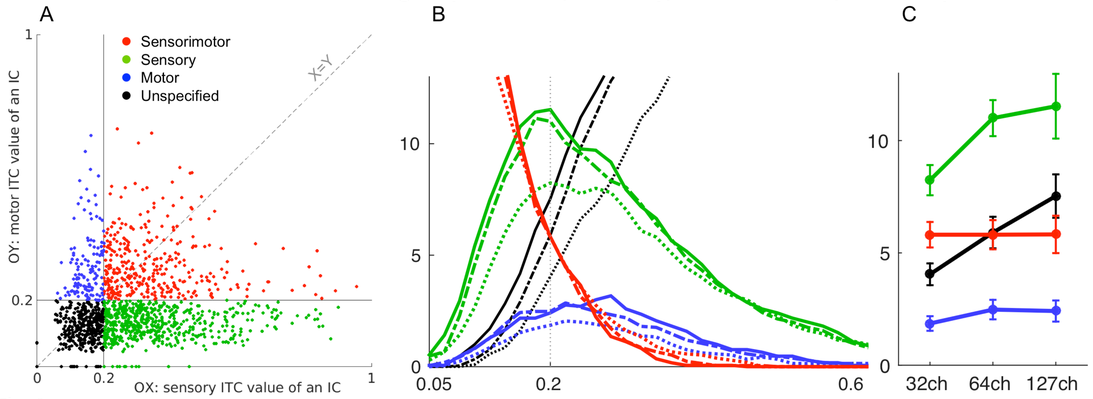

Fig. 4. Panel A depicts 1412 accepted ICs in the study from 32-, 64- and 127-channel datasets. **Panel B.** The Y-axis represents a mean number of ICs in a group per session at different points of the diagonal dashed ITC-threshold-trajectory line (X=Y) in Plot A. Dotted curves represent 32-channel datasets. Dashed curves represent 64-channel datasets. Solid curves represent 127-channel datasets. **Panel C.** The projection of the intersection points of the 12 coloured lines in Plot B with the grey dotted line at X = 0.2. Y-axis and colour coding remain the same as in Plot B. Error bars represent SEM.

The number of Sensorimotor ICs does not correlate with the number of channels in an EEG system

Three clusters of Sensorimotor EDs

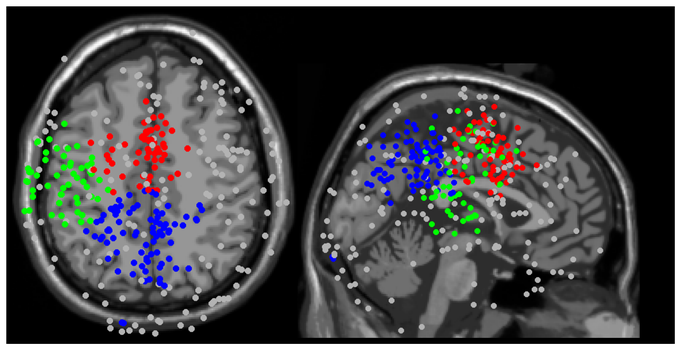

Fig. 5. Three clusters obtained by the k-means clustering algorithm from 192 Sensorimotor equivalent dipoles (EDs) reproducible across subjects from 32-, 64-, and 127-channel datasets. Sensorimotor EDs, which were not reproducible across subjects, were coloured in grey and did not participate in the k-means clustering.

In order to check whether locations are reproducible across subjects, we marked as reproducible only those Sensorimotor EDs which had neighbouring dipoles of at least 50% of subjects within the radius R=27.5 mm.

Sensorimotor ICs are possible EEG correlates of sensorimotor processing in the human brain