Supplementary Material

1. EEG data preprocessing

EEG raw signals were down-sampled from 5 kHz to 1 kHz with an anti-aliasing filter with cutoff 0.9 π rad/sample and transition bandwidth 0.2 π rad/sample. Slow fluctuations in the data were removed via Laplacian-based slow trend detection. Next, highly contaminated channels were excluded from the data. Uncorrelated noise in each channel was estimated with the Sensor Noise Suppression (SNS) method [1], and the channel-wise noise level was defined as the standard deviation of this estimated noise in the respective channel. Channels were excluded if they exhibited noise level at least 10 times the median across all channels in more than 10% of the trials. Also, time periods with high-amplitude noise across channels were excluded from the data. For detecting the contaminated periods, the continuous signals were divided into consecutive 2-second-long epochs and the ranges of estimated noise signals were computed for each epoch and channel. An epoch was marked for exclusion if its maximum range over the channels exceeded the median of the maxima across all epochs by 2-5 times (the exact threshold was determined individually). The marked epochs were concatenated to longer time periods based on their temporal proximity to each other. A maximum of four time periods of unconstrained length were marked and excluded from the data to ensure signal continuity. The remaining data were re-referenced to an average reference montage. As a final preprocessing step, Independent Component Analysis based on FastICA algorithm was applied in the symmetric mode and with the "tanh" contrast function. Resulting independent components were visually inspected based on their topography, power spectrum and single-trial time course. The components that were identified as eye-blinks and eye-movements were removed (two components were removed for each subject). The length of the preprocessed data was ensured to be within a 8.5-9.5 min range, truncating the signals from one of the ends, if necessary.

2. Dwell time calculation

X_t, Y_t are two analytic signals at a time instant t, obtained with Hilbert transformation of bandpass-filtered EEG waveforms. S_t is a product of multiplication between the two analytic signals at time t, calculated as:

$$S_t = X_t Y_t^*,$$

where * denotes the complex conjugate. The angle of the complex number S_t quantifies the phase difference between the two signals at time t. Z is a difference between phase differences taken at two time instants, calculated as:

$$Z_{t,\, t+k} = \angle(S_t S_{t+k}^*),$$

where $k = \pm 1, \pm 2, \pm 3, \ldots$ is the distance in samples forward or backward from the target sample, and $\angle$ denotes the angle of a complex number. Phase-coupling was estimated iteratively, increasing the distance between compared samples by 1 sample until $|Z_{t,t+k}|$ exceeded the $\pi/4$ threshold. The iterative process was repeated both forward and backward from the sample at time t. Dwell time was calculated as a total duration of the phase-coupling period:

$$\text{Dwell time} = \max(k_{\text{forward}}) + |\min(k_{\text{backward}})| + 1,$$

where k_{forward} and k_{backward} are the positive and negative values of k satisfying the threshold condition, respectively. Dwell time estimation was repeated for all times t of the signals, with each t sequentially taken as a target sample. In principle, a single phase-coupling period was repeatedly estimated as many times as the number of samples it spanned. The distribution of all dwell time estimates represents the distribution of probabilities with which any one data sample could belong to any of the phase-coupling periods.

References

[1] de Cheveigné A, Simon JZ. Sensor noise suppression. Journal of neuroscience methods 2008;168(1):195-202.