Supplementary material 1: Reconstructing signals in source space

EEG review traditionally uses common average-reference and bipolar montages. These are special cases of linear combinations of the scalp signals to enhance the voltage at a particular electrode or to depict the voltage gradient between neighbouring electrodes[1]. Transformation into source space is another specific type of linear combination with the goal to take the EEG back into the brain on a macroscopic level[1].

The new 25-electrode standard of the IFCN[2] fostered the idea to define a novel, standard source space by using the 25 brain regions below these electrodes. The task was to transform the scalp EEG into the compound activities of these regions using a spatial filter, i.e. a generalized linear operator that combines the 25 scalp signals in specific ways to enhance the activity from one region while reducing the volume-conducted overlap from the others[1].

The physical basis of constructing a fixed spatial filter to transform each time sample of the EEG into source space is given by the linear overlap of the brain signals at the scalp and the high accuracy in modelling the activity of a relatively large brain region by an equivalent regional source[1]. Thus, one can define the 25 EEG signals u_i (t) as the linear sum of the source activities propagated from the 25 brain regions. Each region is modelled by 3 equivalent dipoles located at an equivalent common centre point and having radial and tangential orientations to describe the local dipole currents in any direction:

(1) $u_i (t) = \sum_k l_{ik} * s_i (t)$ with k = 1…75, or in matrix annotation:

(2) $U = L S$

where U is the scalp voltage matrix, L the leadfield matrix with the propagation coefficients from source k to electrode i and S the source waveform matrix with the 75 source signals, i.e. 3 per regional source.

To obtain a stable inverse and to compensate for the unknow reference in EEG, U is first transformed into an EEG data matrix D at 81 standard electrodes using spherical splines interpolation[1] and average referenced by applying the linear operators P and A. This modifies eq. (2) as follows:

(3) $D = A\,P\,U = A\,L\,S = A\,L\,I\,S = (A\,L\,W^{-1})\,(W\,S) = L_N\,S_W$

L now contains the leadfields for the 81 standard electrodes and the identity matrix I is inserted to be replaced by the diagonal weight matrix W multiplied with its inverse (= I) in order to normalize the leadfield vectors. This is needed to avoid depth bias of the sources and to stabilize or smooth the inverse operator by regularization in source space. The diagonal in W contains the root-mean-square magnitudes of each leadfield vector, i.e. of each source topography in the 81-dimensional data space. Leadfields were calculated using regional sources at appropriate equivalent locations below the 25 electrodes in the 4-shell ellipsoid head model of the BESA software. Applying A from the left onto the leadfield vectors as on the data matrix P U, we obtain the normalized and zero-meaned leadfield matrix L_N:

(4) $L_N = A\,L\,W^{-1}$

Now, the source activities S_W, weighted by W, can be calculated by inverting eq. (3):

(5) $S_W = L_N^+\,D$ and

(6) $S = W^{-1}\,S_W$

The linear operator to estimate the source waveform matrix S_W is defined by the pseudoinverse L_N^+ of L_N:

(7) $L_N^+ = (L_N^T\,L_N + R)^{-1}\,L_N^T$

$L_N^T\,L_N$ is the correlation matrix of the normalized source topographies, thus having values 1 in the main diagonal. Hence, the coefficients in the diagonal regularization matrix R can be set specifically for each source as a percentage of 1. When the inverse L_N^+ is applied from the left onto L_N, it produces the identity matrix, i.e. each signal is rendered maximally while spread from the other sources is suppressed[1].

Two specific source montages with 25 channels, i.e. spatial filters with specific source orientations and regularizations, were defined for EEG review in this study, since it is not feasible to review all 75 signals in source space 25 at once: Source montage 25s depicts only the 25 inward radial activities of each region except for the temporal regions below F9/F10 and T9/T10, for which the first orientation of each underlying source was chosen to match the inward net orientations of the temporal polar and basal sublobar surfaces, respectively. Source montage 25r depicts the activity of each regional source after rotating the first dipole to the maximum of activity over the whole displayed source trace. Regularization was 1.2% for all sources except for the temporal sources F9/F10, T9/T10 and P9/P10 in source space 25s, where the 1st dipoles had 2% and the 2nd and 3rd dipoles 4% regularization to emphasize the typical temporal polar and basal activities of the 1st dipoles.

The channel sequence in source montages 25s and 25r was chosen as a compromise between transversal and longitudinal arrangements[2], showing the frontal and central channels from left to right at the top, followed by the left and right temporal channel groups arranged longitudinally, and the parietal and occipital channels from left to right at the bottom (figure 3). Thus, the predominant locations of EDs could be assessed at a glance. More details about sharing of the activity of an intermediate source by its neighbours, cross-talk between sources and the effects of EEG noise have been described previously[1].

References:

1. Scherg M, Ille N, Bornfleth H, Berg P. Advanced tools for digital EEG review: virtual source montages, whole-head mapping, correlation, and phase analysis. *J Clin Neurophysiol* 2002; 19: 91–112.
2. Seeck M, Koessler L, Bast T, et al. The standardized EEG electrode array of the IFCN. *Clin Neurophysiol* 2017; 128: 2070–2077.