Lateralization properties in motor brain networks

Juliana Gonzalez-Astudillo[1], and Fabrizio De Vico Fallani[1]
[1]Sorbonne Université, Institut du Cerveau - Paris Brain Institute - ICM, CNRS, Inria, Inserm, AP-HP, Hôpital de la Pitié Salpêtrière, F-75013, Paris, France

There is a direct relationship between functional specialization and the spatial organization of the human brain. This is not a random organization, on the contrary, it follows a precise order like proximity between complementary areas or functional symmetry across hemispheres [1]. A clear example is motor function, which principally involves the motor cortex, but still needs interactions with somatosensory areas for a proper preparation of the movement (see Fig. 1-A). Besides, it characterized for presenting a particular asymmetry in which each hemisphere is principally involved in controlling the contralateral side of the body [2, 3].

From this brain lateralization it emerges the qualitatively differentiation between within- and across-hemisphere interactions, that influence the strength of a region or node depending on how these contributions are conceived. By considering homotopic locations in the two hemispheres, lateralization can then be quantified using two separate metrics: segregation (σ_{ij}) and integration (ω_{ij}). The first measures the tendency for greater within-hemisphere interactions compared to between-hemisphere interactions

$$\sigma_{ij} = \frac{(LL_i + LC_i - LR_i) - (RR_j + RC_j - RL_j)}{(CL_k + CR_k + CC_k)}, \quad (1)$$

where each term represents the strength of a node in the homotopic pair of nodes i and j. In the differentiation between within- and across hemispheres edges, the capital letters respectively denotes the locations of node i and the nodes it establishes connections with (e.g. LR_i means that node i belongs to the left hemisphere and we consider the connections that link it to the right hemisphere nodes, see Fig. 1-B). Note that for the particular case of brain signals recorded with an EEG system, the electrodes placed in the midline sagittal plane (C_k) do not strictly belong to a hemisphere, so we consider them to normalize the metrics values.

Applying the same notation, integration seeks the contribution of contralateral connections, characterizing how the information flows across hemispheres. Then it is defined as the summed effect of within- and across-hemispheric interactions

$$\omega_{ij} = \frac{(LL_i + LC_i + LR_i) - (RR_j + RC_j + RL_j)}{(CL_k + CR_k + CC_k)}, \quad (2)$$

To prove the relevance of these metrics in characterizing lateralized cognitive process, we studied EEG signals from 140 subjects performing motor imagery of the right and left hand [4]. We estimated spectral coherence-based networks and we computed the previously described network lateralization metrics for each node or electrode.

We evaluated the presence of specific task-associated patterns for each metric by statistically compearing both motor conditions. We performed a t-test at the subject level and for each node, assuming a null hypothesis that the two means (σ_{ij} or ω_{ij}) were equal. We resumed the obtained results in Fig. 1, where for illustrative purposes, we show the mean t-values across subjects.

This analysis enabled us to identify the most discriminant electrodes. For both metrics engage a subset of nodes mostly located in the M1 cortex, but also the PMA, SMA and S1 areas also crucial in the planification and execution of a movement [5]. We observe that ω shows higher values, while σ also involves frontal areas, usually associated with attention and motor planning. These results show the neurophysiological plausibility of our proposed network approach. Moreover, they prove to be highly relevant features for decoding a MI mental task.

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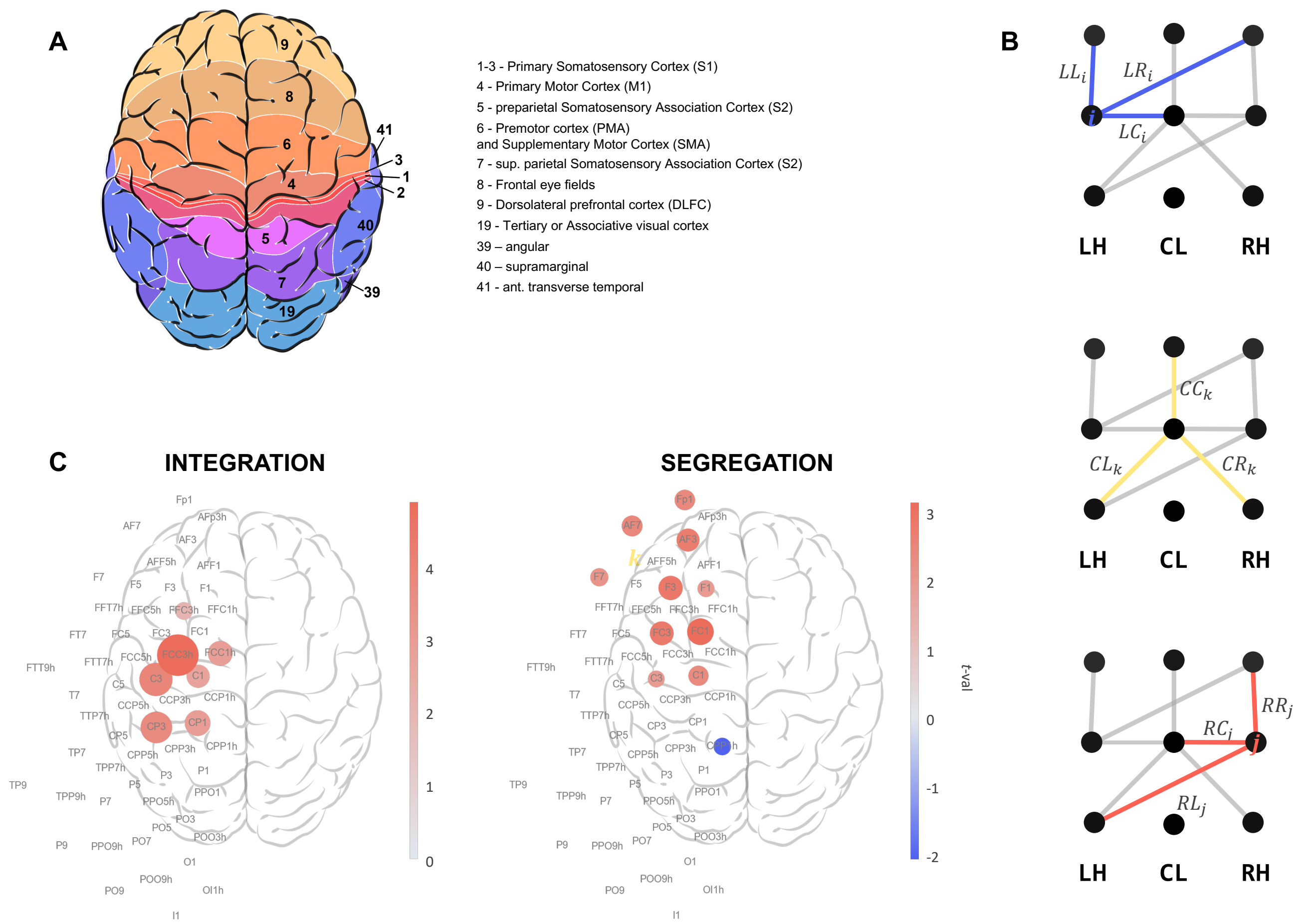

Fig. 1. A- The functional units of the cerebral hemispheres have been separated into what are called Brodmann areas. Motor cortex (M1) is area 4; the primary sensory cortex (S1) includes areas 3, 1, and 2. B- Within and inter-hemisphere connections. LH: left hemisphere, RH: right hemisphere and CL: central line. C- Group-averaged node-t-values between right and left MI mental states. By definition, lateralization metrics are anti-symmetric with respect to the hemispheres. For the sake of simplicity, only the left hemisphere is shown in here.