Resting state functional networks VS. Structural networks: What do their differences tell us?

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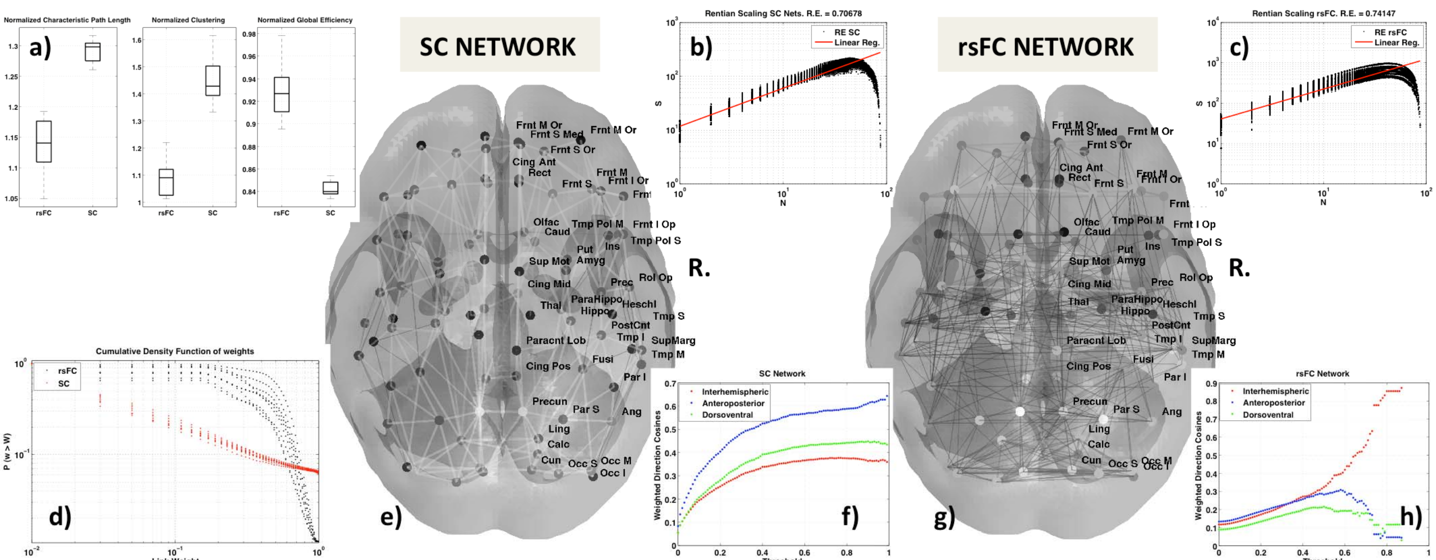
Background: Previous multimodal research on brain networks has mostly aim to find similarities between structural and resting state functional connectivity (SC-rsFC) networks [1]. There have been different approaches trying to improve these correlations by, for example, adding indirect anatomical connections, including physical distance, or performing generative models based on structural connectivity [1,2]. Additionally, we find other parallel strategies that define organization and wiring efficiency in structural networks [3]. In the current work we present a new comparative approach aiming to find differences between SC-rsFC networks, focusing in the organization and intrinsic structure. In order to find out how rsFC differs from SC network, we compare weights distribution, normalized graph metrics, links orientation and Rentian scaling.

Methods: The sample comprised ten young females (age = 18.9 ± 2.6). Two MRI acquisitions were conducted on a 3T GE Scanner, separated by a mean period of 30 days. In each of the dates were acquired: 1) high resolution T1 SPGR with voxel size $1mm^3$, 2) 120 volumes resting state (rs) GE EPI with voxel size 1,8x1,8x2,7 mm, and 3) diffusion weighted images (DWI) single shot EPI with voxel size 0.9x0.9x2.7 mm, b=0;1000 s/mm2, and 26 gradient directions evenly distributed. T1 images were coregistered to the b0 image, and segmented in 90 gray matter ROIs [4] with IBASPM. Then the DWI's were processed for motion and distortion artifacts with FSL, and computed the diffusion tensor model. Anatomical connection patterns were estimated using DW-MRI techniques and graph theory [5] between the 90 ROIs. BOLD images were preprocessed for slice timing correction and realignment with SPM8, and then coregistered to the b0 image. Time courses belonging to each ROI were averaged and then filtered with [0.01–0.09] Hz band-pass filter. ICA analysis was also carried out, and the IC with closest spectrum to the CSF time series was rejected. We performed Pearson linear correlations between all 90 time series and keep results with p<1e-03. To describe organization and complexity properties, an exhaustive network analysis was carried out over both SC and rsFC.

Results: We studied the reproducibility over the two modalities ($ICC\text{-}SC_{1,2}$ = [0,9128 0,9093], $ICC\text{-}rsFC_{1,2}$ = [0.3823 0.3694]; p<1e-100). In order to gain reproducibility for further analysis, we averaged over acquisitions (ICC-SC = 0.9372, ICC-rsFC = 0.5138; p<1e-100). Normalized graph metrics over matrices showed values closer to one for rsFC networks indicating a more random organization (figure a). We studied this effect computing the physical Rent's exponent (figures b,c) where S was the sum of all weights crossing the physical box. We obtained larger values in the rsFC networks, in concordance with the results reported in [3], where an increase of the Rentian exponent is related with a more random distribution of links and nodes in the Euclidean space. In figure d are depicted the CDFs of the weights for both networks. This figure shows that the SC network has strongly linear log-log dependence with a lower power-law exponent (i.e., a more scale-free distribution). We also attempt to find out which hubs (i.e., the twenty nodes with higher strength) were in common along the two networks and we observed that the precuneus and superior frontal lobe of both hemispheres were hubs for at least 40% subjects. In figures e and g, we depicted a thresholded version of the networks (threshold=0.7 for links and nodes in white indicating higher strengths), and we observed that in rsFC appeared more interhemispheric links than in SC networks. We quantified this effect computing the direction cosines of the links (figures f,h), which are weighted by the probability of connection, concluding that for probabilities higher than 0.5 this effect was highly relevant in rsFC networks whereas in the SC network there was a predominance of anteroposterior directions.



Discussion: We studied differences in the organization of SC-rsFC networks. Normalized graph metrics gave us an interesting view about the intrinsic organization. The results obtained with the weighted analysis of Rentian scaling and with the direction cosines give us new insights about the interdependence of both networks. We observed that rsFC networks have more random organization despite a high symmetric behaviour between hemispheres. The distribution of weights in the SC fits a lower power-law exponent than the one obtained in the rsFC, which reflects a higher probability of finding connections with high weights, as shown in Fig. 1f. Rentian scaling defines a framework for analyzing the optimal organization and cost-efficiency of the wiring network, highlighting, in our results, that the rsFC is either random or less optimal wired than the SC network.

References:

[1] Honey et al. PNAS. 2009. 106(6):2035-2040; [2] Honey et al. NeuroImage. 2010. 52(3):766-776; [3] Basset et al. PLoS Computational Biology. 2010. 6(4); [4] Tzourio-Mazoyer et al. Neuroimage. 2002. 15:273-289; [5] Iturria-Medina et al. Neuroimage. 2007. 36:645-660.