ESMRMB 2013
European Society for Magnetic Resonance in Medicine and Biology
30th Annual Scientific Meeting, October 3–5, Toulouse/FR

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Fundação para a Ciência e a Tecnologia
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Complexity analysis of resting-state networks

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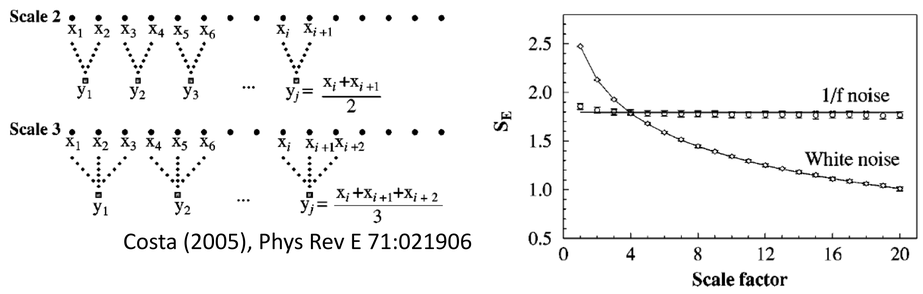
1 Purpose/Introduction

Brain is a highly complex organ and brain activity shows a nonlinear behavior. Nevertheless, little is known about the complexity behaviour of resting-state blood oxygen level dependent (BOLD) signals. Recent works have shown that Multiscale Entropy (MSE) analysis [1] can be used to assess the complexity of BOLD signals [2] and that the complexity of the BOLD activity correlates with aging and cognitive performance, when comparing healthy young and elderly groups [3]. In this work, we tested the hypothesis that different brain regions and resting-state networks (RSNs) show different complexity behaviours.

1 Multiscale Entropy (MSE)

Coarse-Graining: time-series are down-sampled at different times scales



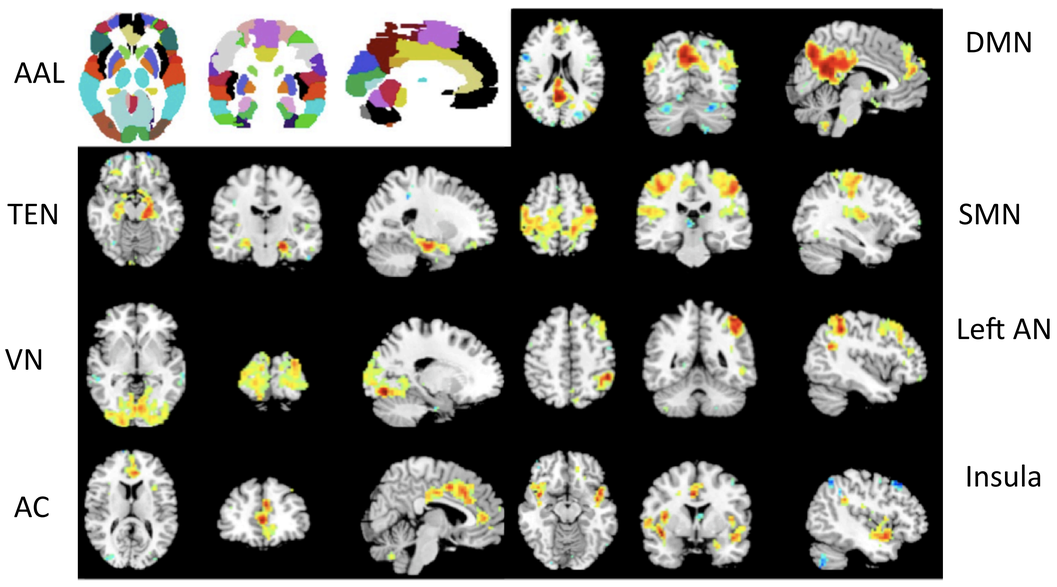
Costa (2005), Phys Rev E 71:021906

Sample Entropy calculation: measure of complexity

2 Subjects and Methods

Resting-state data were obtained from 17 healthy subjects using a 1.5T scanner and a BOLD sequence with TR/TE=2000/50ms and a scanning time of 5 min. Data were slice timing corrected, realigned, normalized into MNI template, resampled, smoothed, detrended, filtered (0.01-0.08Hz), and covariates (head motion, global mean, white-matter and cerebrospinal fluid signals) were regressed out using DPARSF/SPM8 software. Subsequently, mean BOLD signals were obtained for 90 Anatomic Automatic Labeling (AAL) regions and 8 RSNs (default-mode network, DMN; temporal epileptic network, TEN; sensorymotor network, SMN; visual network, VN; right and left attention networks, ANs; anterior cingulate, AC, and insula) plus the posterior cingulate/precuneus (PC) region, as DMN node [4]. MSE algorithm (http://www.physionet.org) was then applied to the time series: sample entropy (SE) values were calculated for each region/network and averaged among subjects. A complexity index (CI) was then obtained by summing mean SE values for scales 2 to 4. Mean SE values in function of scale were compared using the unilateral Mann-Whitney in order to identify significant differences ($p<0.05$) between regions/networks. Finally, masks for specific regions were applied to RSN functional connectivity (FC) maps [4] to calculate region-associated mean z-scores.

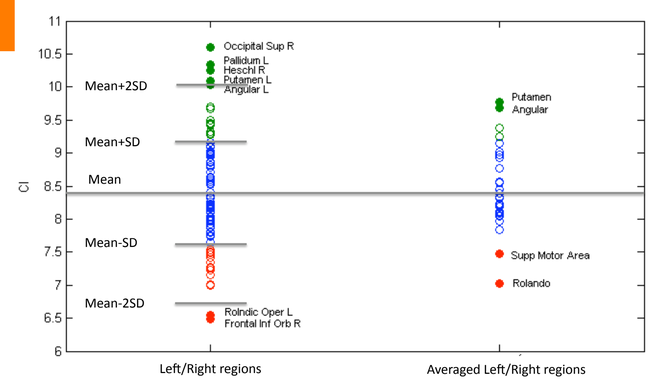
2 Regions and resting-state networks

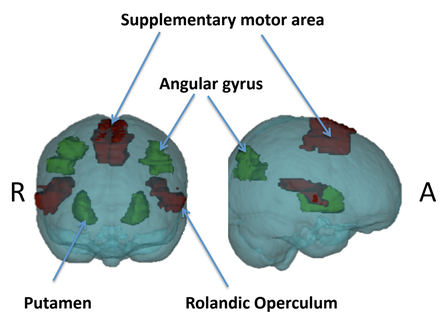


3 Results

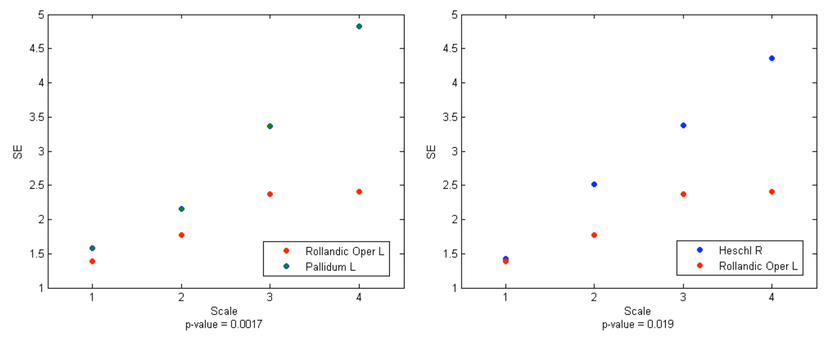
Overall, it was observed that brain regions' MSE behavior differs from both white and 1/f noises. Additionally, basal ganglia and frontal lobe regions show the highest and the lowest MSE complexities, respectively. Regarding specific regions, it was observed that the angular gyrus and the putamen showed the highest complexities whilst the Roland operculum and the supplementary motor area showed the lowest. Significant differences were observed between highest and lowest complexity regions. Regarding networks, it was observed that the insula and the SMN differed significantly in complexity from ANs. Both the insula and SMN showed the highest CIs, whilst the ANs showed the lowest CIs.

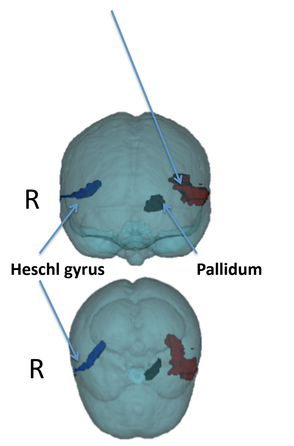
3a Complexity of AAL regions





Higher/Lower complexity regions are shown in green/red
Intermediate complexity regions are shown in blue

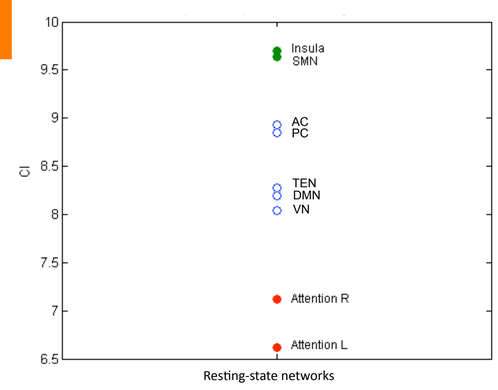


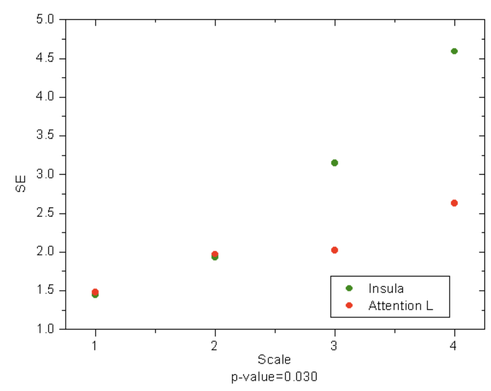


Region	CI (mean±SD)
Whole-brain	**8.39±0.85**
Frontal Lobe	8.14±0.71
Parietal Lobe	8.32±0.75
Temporal Lobe	8.39±0.75
Occipital Lobe	8.41±0.98
Limbic Lobe	8.56±0.73
Basal Ganglia	8.92±0.96

Region	Function	Complexity
Supplementary motor area	Postural stabilization; initiation of internally generated movements; bimanual coordination; planning of movement sequences	Lower
Rolandic operculum	Articulation (lips, tongue); auditory-motor integration	Lower
Putamen	Regulate movements; influence various types of learning; perception of contempt and disgust	Higher
Pallidum (left)	Regulation of voluntary movement (subconscious level)	Higher
Heschl gyrus (right)	Auditory processing (tone and semantic tasks)	Higher
Angular gyrus	Language; number processing and spatial cognition; memory retrieval; attention; and theory of mind	Higher

3b Complexity of resting-state networks

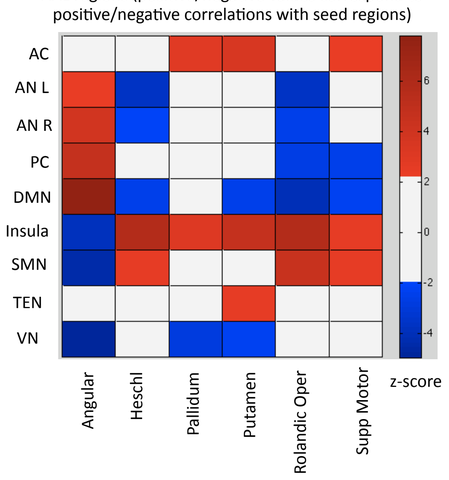




Higher/Lower complexity networks are shown in green/red
Intermediate complexity networks are shown in blue

Network	Seed Regions	Function	Complexity
Attention (AN)	BA7, BA8, BA9, BA40	Executive functions	Lower
Visual (VN)	BA17, BA18, BA19	Visual stimuli processing	Intermediate
Default-Mode (DMN)	BA23, BA31,BA8, BA11, BA23, BA39, BA40	Self-awareness	Intermediate
Temporal Epileptic (TEN)	Amygdala; Hippocampus; Parahippocampus	Memory and emotions	Intermediate
Anterior Cingulate (AC)	Cingulate gyrus (anterior)	Emotions	Intermediate
Sensorimotor (SMN)	BA1, BA2, BA3, BA4	Sensorimotor activity	Higher
Insula	Insular Cortex	Emotions, body homeostasis	Higher

RSNs functional connectivity z-scores averaged in specific AAL regions (positive/negative values correspond to positive/negative correlations with seed regions)



4 Discussion/Conclusion

We have observed that brain BOLD signals, unlike white and 1/f noises, show an increasing complexity with entropy scale. This behavior may translate the higher complexity in information transfer that occurs in brain processes. Additionally, we have shown that different brain regions and networks have different complexity behaviors. In particular, it was observed that sub-cortical regions in general have more complex BOLD signals than cortical regions. We hypothesize that either phylogenetically older and/or more highly connected regions show higher complexity. Also, we have observed that the highest and lowest complexity regions are functionally correlated with RSNs in a significant manner. In fact, the angular gyrus and the Rolandic operculum have nearly opposite correlation patterns regarding the studied RSNs, in particular with the more complex insula and SMN and the lesser complex ANs. Additionally, we observed that the insula, DMN and SMN correlate with most of the highlighted brain regions. These results suggest that connectivity and complexity are related and, consequently, further studies are needed.

References

[1] Costa (2002), Phys Rev Lett 89:0681021; [2] HA Ferreira (2012), Proceedings ESMRMB2012:106; [3]AC Yang (2013), Neurobiol Aging 34:428; [4] HA Ferreira (2012), Epilepsia 53(S5): 64

Acknowledgments

This work was financed by Fundação para a Ciência e Tecnologia (FCT) and Ministério da Ciência e Educação (MCE) Portugal (PIDDAC) under the grant PTDC/SAU-ENB/120718/2010. The authors also thank Dr. Graça Correia, Head of Radiology Department of Hospital dos Lusíadas for supporting data acquisition.