The Dynamics of Interactions at Rest

Organizer: Stefania Della Penna

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The Complex Scenario of Dynamic Large Scale Interactions at Rest

In recent years, fMRI analysis of interactions in the absence of any external stimulus (resting state) subdivided the cortex into a moderate number of functional parcels consisting of regions showing correlated activity over long periods of time (resting state networks, RSN [1]). The function of such interactions at rest and their link with the multifaceted aspects of behavior can only be explained by including the temporal dimension. As a matter of fact MEG studies on resting state interactions in spontaneous rhythmic activity of the brain suggest more complex structures of communication, involving frequency-specific interactions determining dynamic patterns of local and global integration [2-4] and spectrally-selective dynamic changes following task [5]. In this framework, the recent technical advances and the related interpretations in the dynamics of MEG resting state interactions are here reported. Results on the investigation of different aspects of architecture dynamics through linear and non linear analyses in time-frequency domain and at multiple spatio-temporal scales and the related functional role are discussed.

[1] Power JD et al., (2014) Neuron
[2] De Pasquale F et al., (2012) Neuron
[3] Brookes M et al., (2011) PNAS
[4] Hipp JF et al., (2012) Nature Neuroscience
[5] Betti V et al., (2013) Neuron

Speakers:

- **Robert Oostenveld** (Radboud Univ., The Netherlands / NatMEG; Karolinska Inst., Sweden)
  "On the large scale of studying dynamics with MEG: lessons from the HCP"

  As part of the Human Connectome Project (HCP), which includes high-quality fMRI, anatomical MRI, DTi and genetic data from 1200 subjects, we have scanned and investigated a subset of 100 subjects (mostly comprised of pairs of twins) using MEG. The raw data acquired in the HCP has been analyzed using standard pipelines [ref1] and both raw and results at various levels of processing have been shared though the ConnectomeDB [ref2].

  Throughout the process of the HCP we have not only analyzed (resting state) MEG data, but also have developed the data analysis protocols, the software and the strategies to achieve reproducible MEG connectivity results. The MEG data analysis software is based on FieldTrip, an open source toolbox [ref3], and is shared alongside the data to allow the analyses to be repeated on independent data.

  In this presentation will outline what the HCP MEG team has learned along the way and I will provide recommendations on what to do and what to avoid in making MEG studies on (resting state) connectivity reproducible.

1. Larson-Prior LJ, et al., Neuroimage, 2013
2. Hodge MR, et al., Neuroimage, 2016
3. Oostenveld R, et al., Comput Intell Neurosci. 2011

- **Markus Siegel** (Univ. of Tübingen, Germany)
  "BOLD fMRI Correlation Reflects Frequency-Specific Neuronal Correlation"

  The brain-wide correlation of hemodynamic signals as measured with BOLD fMRI is widely studied as a proxy for integrative brain processes. However, the relationship between hemodynamic correlation structure and neuronal correlation structure remains elusive. We investigated this relation using BOLD fMRI and spatially co-registered, source-localized MEG in resting humans. We found that across the entire cortex BOLD correlation reflected the co-variation of frequency-specific neuronal activity. Resolving the relation between electrophysiological and hemodynamic correlation structures locally in cortico-cortical connection space, we found that this relation was subject specific and even persisted on the centimeter scale. At first sight, this relation was strongest in the alpha to beta frequency range (8-32 Hz). However, correcting for differences in signal-to-noise ratios across electrophysiological frequencies, we found that the relation extended over a broad frequency range from 2 to 128 Hz. Moreover, we found that the frequency with the tightest link to BOLD correlation varied across cortico-cortical space. Our work provides direct evidence for the neuronal origin of BOLD correlation structure. Moreover, our work suggests that, across the brain, BOLD correlation reflects correlation of different types of neuronal network processes and that frequency-specific electrophysiological correlation provides information about large-scale neuronal interactions complementary to BOLD fMRI

- **J. Matias Palva** (Univ. of Helsinki, Finland)
  "Functional connectivity and critical dynamics are co-localized in the human brain"

  The theory of critical brain dynamics predicts a relationship between neuronal interactions and scale-free dynamics. Experimentally, this would be evidenced by a correlation between functional connectivity, an elementary outcome of neuronal interactions, and indices of criticality such as avalanche dynamics and long-range temporal correlations (LRTCs). Such evidence has, however, remained scarce. We postulated that a coupling between criticality and connectivity would be reflected both in neuronal avalanches propagating preferentially along the pathways of functional connectivity and in co-localized modular structures in the networks of criticality and connectivity.
  We used both intra-cranial and non-invasive resting-state human electrophysiological recordings and compared connectomes of avalanche propagation and inter-areal relationships of LRTCs with connectomes functional connectivity. After establishing that the indices of criticality and connectivity can be independently assessed, we found frequency-dependent co-localization among the strongest connections of critical dynamics and connectivity. Crucially, neuronal criticality and connectivity also had co-localized modular structures and especially for power-law distributed avalanches.

  Critical dynamics is hence co-localized with functional connectivity at multiple levels of network organization, which suggests that they co-emerge in an architecture where modules characterized by internally dense connectivity, avalanche propagation, and shared dynamic states. These findings thus reveal an intimate coupling between connectivity and dynamics.

- **Matthew Brookes** (Univ. of Nottingham, UK)
  "Imaging transient networks using power envelope correlation: from methods to clinical application"

  The topic of functional connectivity in neuroimaging is expanding rapidly and many studies now focus on coupling between spatially separate brain regions. In particular, recent years have seen the introduction of a number of techniques capable of tracking the dynamics of functional networks and, with its excellent time resolution, MEG has natural advantages in this area. In this talk I will begin by outlining novel methodologies which employ MEG data, alongside power envelope correlation, to track the formation and dissolution of brain networks in real time. I will show applications in the resting state, and also how observable networks change when resting recordings are punctuated with infrequent cognitive tasks. Following this, I will introduce our recent work on in schizophrenia. I will demonstrate that the methods I describe facilitate characterisation of abnormal transient networks in the visual system in schizophrenia patients; I will explain how this fits into a broader (multimodal) picture and show that MEG offers a means predict disease symptoms, and potentially outcome. Overall my talk will show that MEG is the technique of choice for measurement of whole brain dynamic connectivity and this area has an exciting future in characterising brain function in health and disease.

- **Stefania Della Penna** (Univ. of Chieti, Italy)
  "Dynamical architecture of resting state networks reveals frequency-specific prior and idling states"

  fMRI functional connectivity over spontaneous activity subdivides cerebral cortex in a relatively small number of resting-state-networks (RSNs). According to fMRI [Spadone, PNAS 2015], RSNs represent spatiotemporal “priors” (similar connectivity patterns between rest and task) for task-networks and their modulation contributes to task-evoked responses. MEG comparisons of interactions during natural vision and rest [Betti, Neuron 2013] suggest RSNs as reflecting a state of brain “idling” (or inactivity) that must be reorganized for task-dependent interactions to emerge. Extending our previous results on the dynamical integration/segregation among RSN during rest [de Pasquale, Cerebral Cortex in press], we focus on the dynamics of betweenness centrality (BC) during natural and time-scrambled movies compared to rest. During rest, we found frequency-specific hub-clubs involving specific RSN nodes, with hubs showing joint BC fluctuations. When inspecting task-induced modulations of interaction topographies, we found that alpha and beta hub-clubs were selectively modulated by task. While in alpha the co-occurrence of hubs considerably changed during natural and scrambled movies compared to rest, in beta the dynamical co-occurrence of hubs was unaffected by movie watching but was modulated by scrambled movies. Our findings suggest that dynamics of local integration represent an idling state in alpha and a prior state in beta.