

ULTRA-SLOW FREQUENCY BANDS REFLECTING POTENTIAL COHERENCE BETWEEN NEOCORTICAL BRAIN REGIONS

X. ZHANG,^{a,b} Y.-T. WANG,^{b,c} Y. WANG,^c T. P. JUNG,^{c,d}
M. HUANG,^e C. K. CHENG^{b,*} AND A. J. MANDELL^{f,g}

^a Institute of Electronic Science and Engineering, Nanjing University of Posts and Telecommunications, Nanjing, Jiangsu 210003, PR China

^b Department of Computer Science and Engineering, University of California at San Diego, La Jolla, CA 92093, USA

^c Swartz Center for Computational Neuroscience, Institute of Engineering in Medicine, University of California at San Diego, La Jolla, CA, USA

^d Center for Advanced Neurological Engineering, Institute of Engineering in Medicine, University of California at San Diego, La Jolla, CA 92093, USA

^e Department of Radiology, University of California at San Diego, La Jolla, CA 92093, USA

^f Fetzer Memorial Trust, Kalamazoo, MI, USA

^g Department of Psychiatry, University of California at San Diego, La Jolla, CA 92093, USA

Abstract—Recent studies of electromagnetic ultra-slow waves (≤ 0.1 Hz) have suggested that they play a role in the integration of otherwise disassociated brain regions supporting vital functions (Ackermann and Borbely, 1997; Picchioni et al., 2010; Knyazev, 2012; Le Bon et al., 2012). We emphasize this spectral domain in probing sensor coherence issues raised by these studies using Hilbert phase coherences in the human MEG. In addition, we ask: will temporal–spatial phase coherence in regional brain oscillations obtained from the ultraslow spectral bands of multi-channel magnetoencephalograms (MEG) differentiate resting, “task-free” MEG records of normal control and schizophrenic subjects? The goal of the study is a comparison of the relative persistence of intra-regional *phase locking values* (PLVs), among 10, region-defined, sensors in examined in the resting multichannel, MEG records as a function of spectral frequency bands and diagnostic category. The following comparison of Hilbert-transform-generated relative phases of each designated spectral band was made using their pair-wise PLVs. This indicated the proportion of shared cycle time in which the phase relations between the index location and reference leads were maintained. Leave one out, bootstrapping of the PLVs via a support vector machine (SVM), classified clinical status with 97.3% accuracy. It was generally the case that spectral

bands ≤ 1.0 Hz generated the highest values of the PLVs and discriminated best between control and patient populations. We conclude that PLV analysis of the oscillatory patterns of MEG recordings in the ultraslow frequency bands suggest their functional significance in intra-regional signal coherence and provide a higher rate of classification of patients and normal subjects than the other spectral domains examined. © 2015 IBRO. Published by Elsevier Ltd. All rights reserved.

Key words: schizophrenia, Ultra Low Frequency, classification, MEG, PLV, SVM.

BACKGROUND

Indicators of brain regional signal coherence

Issues of neocortical connectivity came into prominence in the 19th Century in the studies of aphasia by Wernicke (1994; 1874). Growing out of studies of the role of cortical association areas in higher mental processes, these regions were regarded as linking sensory and motor mechanisms (Meynert, 1890/2005). Studies of the process of cortical sensory cell myelination revealed that neocortical sensory-motor connections required the intercalation of association cortices (“Flechsig’s rule”) (Flechsig, 1901). Geschwind’s classical papers, “*Disconnection syndromes in animals and man, I, II*” suggested that deficits in higher functions occurred as the result of disruption of the axonal pathways involving the signal relay functions of the association cortices (Geschwind, 1965). He observed that direct connections between primary sensory and motor systems were more characteristic of lower mammals (Geschwind, 1970). Neocortical networks in higher mammals manifest intrinsic patterns of spontaneous activity and therefore sensory information arrives as a perturbation of on-going network dynamics (Paulus et al., 1989). Whether by synaptic neurochemistry, electrotonic gap junctions, biogenic amine fields, impressed, recurrent and leakage currents or magnetic fields, multiple distributed networks of specialized cortical function connected by parallel, bidirectional pathways continue to be prominent in cognitive neurophysiology (Geschwind, 1975, 1985).

Magnetic resonance diffusion tensor imaging, DTI, and tractography have demonstrated discontinuities in white matter as anatomical evidence for cortical network disconnections (Mori et al., 1999; Chanrand et al., 2010; Perez-Iglesias et al., 2010). Evidence for developmental

*Corresponding author. Tel: +1-858-534-6184; fax: +1-858-534-7029.

E-mail address: ckcheng@ucsd.edu (C. K. Cheng).

Abbreviations: HT, Hilbert Transformation; ICA, independent component analysis; MEG, magnetoencephalography; PCA, principal component analysis; PLV, phase locking value; SVM, support vector machine.

over-growth and subsequent disuse atrophy promoting pruning (Chechik et al., 1999; Low and Cheng, 2006; Abitz, 2007), has suggested a developmental mechanism that may be involved in supporting connections that result in signal coherence. Pathophysiology involving regional brain connectivity via frequency and/or phase coherence continues to be seen by many as a significant contributor to psychiatric diagnoses such as autism (Firth, 2001) and schizophrenia (Bullmore et al., 1997) as well more clearly neurological signs such as the agnosias and apraxias (Silver et al., 2005). More intuitively, the latter syndromes involve an impairment of functional associations between seeing, recognizing, naming and using an object.

More dynamical approaches to characterizing functional relations among brain regions have included an assessment of mutual similarity in frequency, wave length and/or phase properties of the (assumed to be) linear oscillating brain regional electromagnetic (EEG, MEG) fields (Singer, 1999; Srinivassen et al., 1999; Sowards and Sowards, 2001; Uhlhaas and Singer, 2006). Synchronization, coherence and phase locking are some of the relational dynamical states that have been seen as indicators of dynamical relations between sensory and sensory associative systems, exchanges of information and the coordination of related sensory and motor activities (Chen et al., 1998; Engel et al., 1999; Boonstra et al., 2006). Particularly prominent in the elucidation of the relationship between frequency and phase correspondence and cooperative sensory and conscious experience is the pioneering work of Wolf Singer. Temporal “binding” (integration of distributed neurons into functional cell assemblies) via transient neural synchrony in the millisecond range is hypothesized to be involved in perceptual integration, attentional selection and working memory as well as states of consciousness. Perceived compound functions of sensory disparate qualities can be reflected in transient long distance synchronization of gamma oscillations across widely separated regions of the brain in both animals and man (Singer, 1998; Engel et al., 1999; Melloni et al., 2007). Neuropharmacological effects on EEG phase correspondence have also been reported (Ehlers et al., 2012). It is in the context of these and similar studies of the functional significance of frequency and phase coherence across disjoint brain regions (Kitzbichler et al., 2009) that encouraged us to use regional relative phase correspondences to explore the *function-related* coherences of inter-regional signals as reflected in the human resting (taskless) MEG (Liang et al., 2002; Melloni et al., 2007; Murias et al., 2007).

Slow wave phase locking as dynamical variables

With respect to the electromagnetic properties of the brain, *phase* can be seen as a manifestation of the actions of synchronized assemblies of near-periodically firing neurons. A set of unsynchronized individual neuronal cyclic patterns of firing and recovery can be imagined to be functionally distributed around a topological circle, S^1 , in a distribution of phases. These temporal locations can be marked numerically from 0.0 to 1.0, i.e. phase is *modulo one*. Each phase can be represented by a fraction of real number, 1.0 as its

position along the imagined limit cycle (Takada et al., 1997). *Phase locking* occurs when two or more neuronal activation-recovery cyclers are in juxtaposition in time (Winfree, 1987). Models and observations have suggested that one of two brain dynamical phase locking scenarios result: (1) Persistent weak coupling leading to slow changes in mutual phase; (2) Transient, intermittent strong pulsed coupling resulting in fast changes in phase-related functions (Goel and Ermentrout, 2002). In such systems, perturbation can induce a *phase resetting* event (Ashuthan and Canavier, 2009) displacing the trajectory of the phase further along the limit cycle. This is manifested by either the shortening of the current period or its lengthening as the trajectory jumps backward along the topological circle. As a construction in differential form with relative phase $\equiv \theta$, if $-f(\theta) = d\theta/dt$ is a non-linear damping force and $-g(\theta)$ is a non-linear restoring force, then under suitable conditions, $d\theta/dt = \omega$; $d\omega/dt = -g(\theta) - f(\theta)\theta$ has a unique, limit cycle (Jordon and Smith, 1987) which can serve as the imagined sine-circle manifold of the *Hilbert Transform* (HT) of the MEG data (King, 2009; Le Van Quyen et al., 2001).

Recently, evidence is emerging that functionally relevant frequencies in the delta and sub-delta range are more common than past studies seemed to indicate (Birbaumer et al., 1990; Ackermann and Borbely, 1997; Knyazev, 2012). One possible mechanism involved in slow wave phase locking was suggested when the MEG was examined across a spectral range in studies combining cortical surface electrodes, microelectrodes and depth electrodes in cats (Ball et al., 1977; Gloor et al., 1977). These studies suggested that afferentation and deafferentation of overlying neocortical layer V juxtaposed to white matter axonal pathways can be a dynamical variable within this spectral range. Regionally localized cortical slow waves in the 0.1–4.0-Hz range are observed in traumatic axonal injury consistent with a deafferentation hypothesis (Huang et al., 2012). Neocortical regions sharing, in space and time, the same bundles of axons as input may initiate cortical area phase locking as reflected in the increased stability of their phase locked, reverberating activity (Hopfield, 1982). In the context of neocortical network dynamics, if two neurons are simultaneously active as in their mode locking, that situation can be simulated with a covariance-based update rule, therefore increasing neural network synaptic efficacy (Sejnowski, 1976).

Phases in MEG's multiplicity of time scales

Issues of time scale emerge from the intrinsic, hierarchical multiplicity of times of the human MEG. Its $f^{-\alpha}$ power spectral scaling exponent of 1.5–2.5 (α computed as the slope of its power spectral *log–log plot* (Mandell et al., 2011b) is consistent with the absence of a *single* characteristic time of a magnetic field in general and in the human MEG in particular (Feynman et al., 2006; Mandell et al., 2011a; Freeman and Quiroga, 2012; Nunez and Srinivassen, 2006). Recent studies implicate information-transporting turbulent MEG waves beyond the usual Δ - Γ frequency bands (Robinson et al., 2012) into the hundreds of Hz (Robinson et al.,

Download English Version:

<https://daneshyari.com/en/article/4337524>

Download Persian Version:

<https://daneshyari.com/article/4337524>

[Daneshyari.com](https://daneshyari.com)