

Spanning the rich spectrum of the human brain: slow waves to gamma and beyond.

Sarang Dalal, Juan Vidal, Carlos Hamamé, Tomás Ossandón, Olivier Bertrand, Jean-Philippe Lachaux, Karim Jerbi

► **To cite this version:**

Sarang Dalal, Juan Vidal, Carlos Hamamé, Tomás Ossandón, Olivier Bertrand, et al.. Spanning the rich spectrum of the human brain: slow waves to gamma and beyond.: Slow waves to gamma and beyond. Brain Structure and Function, Springer Verlag, 2011, 216 (2), pp.77-84. <10.1007/s00429-011-0307-z>. <inserm-00594852>

HAL Id: inserm-00594852

<http://www.hal.inserm.fr/inserm-00594852>

Submitted on 21 May 2011

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Spanning the rich spectrum of the human brain

Slow waves to gamma and beyond

Sarang S. Dalal · Juan R. Vidal · Carlos M. Hamamé · Tomás Ossandón ·
Olivier Bertrand · Jean-Philippe Lachaux · Karim Jerbi

Received: date / Accepted: date

Comment on:

Nunez PL, Srinivasan R. (2010) Scale and frequency chauvinism in brain dynamics: too much emphasis on gamma band oscillations. *Brain Struct Funct*, 215:67-71.

Keywords gamma · alpha · beta · oscillations · electroencephalography · magnetoencephalography · intracranial recordings

In their recent editorial, Nunez and Srinivasan (2010) assert that gamma band activity and intracranial recordings have been receiving an inordinate amount of attention in recent years. We agree that brain dynamics must be examined at all possible scales and across several frequency bands, and that it would be foolish to restrict our understanding of brain dynamics exclusively to intracranial recordings or higher frequency content. However, a number of points raised by the authors require further consideration.

How much emphasis is “too much”? A PubMed search of publications since 2007 reveals that the distri-

bution of citations across frequency bands roughly follow their corresponding power distribution in the resting scalp EEG (see Figure 1), with 1,356 papers citing alpha or mu rhythms, while 790 cite gamma band activity and only 60 mention high gamma activity. Meanwhile, since 2007, 14,992 publications have cited EEG or MEG, while only 337 mention intracranial EEG¹.

1 Historical Emphasis on Low Frequencies

Clearly, reports of alpha rhythms and scalp EEG/MEG still dominate the literature. As Nunez and Srinivasan (2010) point out, there is an extremely large body of literature describing the association of low-frequency (<20 Hz) activity with a variety of brain states, clinical conditions, and cognitive responses. Perhaps this should provide even stronger motivation to scrutinize higher frequencies, to explore the relatively uncharted territory at the frontier of neuroscience, to complement what is already known about evoked responses and lower frequency oscillations. In fact, one major reason that higher frequencies had been virtually ignored for decades is simply because this activity was either assumed to be entirely noise and therefore systematically filtered out, or deemed incompatible with the traditional phase-locked evoked response model, even in intracranial recordings. Additionally, advances in both computer technology as well as analytical techniques were necessary to bring the analysis of higher frequency brain activity to the mainstream.

This work was supported by grants to CMH from the Fondation Fyssen and to KJ from the Fondation pour la Recherche Médicale.

S.S. Dalal
Department of Psychology, Zukunftskolleg, University of Konstanz, Germany
MEG Department, CERMEP, Lyon, France
E-mail: sarang.dalal@uni-konstanz.de

S.S. Dalal, J.R. Vidal, C.M. Hamamé, T. Ossandón, O. Bertrand, J.-P. Lachaux, and K. Jerbi
INSERM U1028, CNRS UMR5292, Lyon Neuroscience Research Center, Brain Dynamics and Cognition Team, Lyon, France
Université Claude Bernard, Lyon 1, Lyon, France

¹ search included: intracranial electroencephalography, electrocorticography, stereoelectroencephalography, depth electroencephalography, and subdural recordings. See supplementary material for precise PubMed search queries.

The assertion of Nunez and Srinivasan (2010) that beta and gamma frequencies are “largely absent at the scalp” is somewhat puzzling. Hans Berger himself carefully documented and named the beta rhythm of scalp EEG in his earliest works (Berger 1929, 1930), which were soon replicated by Tönnies (1934), Jasper and Carmichael (1935), and Jasper and Andrews (1938). In the decades since, an enormous volume of literature has proliferated with numerous diverse experiments describing robust beta modulations recorded with scalp EEG (to cite only a few, Tallon-Baudry et al. 2001; Pfurtscheller et al. 2001, 2005; Muthukumaraswamy and Johnson 2004; Parkes et al. 2006) and MEG (Salmelin et al. 1995; Gross et al. 2001; Cheyne et al. 2003; Jurkiewicz et al. 2006; Dalal et al. 2008; Engel and Fries 2010).

As for gamma band activity, Nunez and Srinivasan (2010) remind us of the technical challenges facing its reliable detection in scalp recordings. Certainly, gamma band activity may suffer some additional attenuation at the scalp due to summation of neighboring sources with incoherent phases (Pfurtscheller and Cooper 1975), but the skull and scalp do not inherently form a lowpass filter as the electrical properties of the various head tissues do not vary appreciably across the 0-100,000 Hz range (Oostendorp et al. 2000). Furthermore, we must emphasize that both experimental designs and analysis strategies have evolved to overcome poor signal-to-noise ratios (SNRs) – even when noise power is a thousand-fold greater than signal power in raw data – dramatically extending the usable bandwidth of electrophysiological recordings. Indeed, simple averaging across trials using raw data or band-limited power time courses decreases noise power in proportion to the number of trials acquired (Turetsky et al. 1988).

2 Dissociating Cortical Gamma and Muscle Contamination

Electromyographic (EMG) interference contains significant power in the gamma band and thereby poses a challenge for resolving cortical gamma rhythms. Granted, this challenge may prove too formidable to allow noninvasive recordings to reliably detect gamma events in single trials. It may likewise hinder detection of transient pathological oscillations that may arise from relatively small generators, as might arise in epilepsy (Bragin et al. 2002; Tao et al. 2007; Wu et al. 2008). However, event-related paradigms benefit from repeated responses that can then be statistically analyzed across trials.

Whitham et al. (2007), who are cited as evidence casting doubt on the cortical origin of event-related

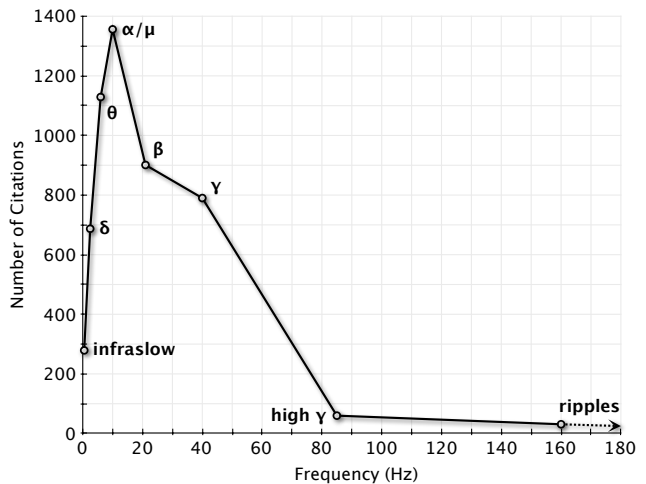


Fig. 1 EEG/MEG citations in PubMed since 2007, visualized as a spectrum across frequencies. Number of citations were plotted as a function of frequency band centers, using the following definitions. Infraslow: 0.01-1 Hz, δ : 1-4 Hz, θ : 4-8 Hz, α/μ : 8-12 Hz, β : 12-30 Hz, γ : 30-50 Hz, high- γ : 50-120 Hz, and ripples: 120-200 Hz.

gamma rhythms, in fact report a false *negative* rather than a false positive in their attempt to resolve scalp gamma modulations in the presence of ordinary background EMG. That is to say, muscular activity did not seem to produce significant *stimulus-locked* artifacts, but rather generated more continuous background noise that obscured task-induced gamma modulations. However, by subsequently inducing scalp muscle paralysis and thereby significantly reducing background noise levels, they found quite robust gamma modulations, confirmed in a follow-up study (Pope et al. 2009). These studies and others (Goncharova et al. 2003; Whitham et al. 2008) furthermore demonstrate that scalp EMG does in fact manifest most strongly close to scalp muscles, resulting in enhanced noise power along the periphery of an EEG cap but less intense centrally.

A more in-depth examination of the topography of task-related gamma modulations can provide clues as to whether they originate from cortex or artifactual sources such as the scalp muscles or eyes (Reva and Afanas 2004; Trujillo et al. 2005; Yuval-Greenberg et al. 2008; Jerbi et al. 2009a). Principal component analysis (Mäki and Ilmoniemi 2011), independent component analysis (Keren et al. 2010), and some source localization algorithms based on spatial filters analytically formalize such spatial distinctions. Spatial filters, in particular, reconstruct source activity with what is essentially a weighted average across EEG/MEG sensors in addition to averaging across trials. This allows us to not only examine the spatially distinct sources of cortical activity versus artifact, but to boost effective

SNR as well (Sekihara et al. 2004; Ward et al. 1999; Väisänen and Malmivuo 2009). For even further sensitivity and generalizability, usually a large number of trials are acquired and statistics are computed across subjects. Indeed, these strategies seem to have the greatest success in resolving gamma activity at the scalp level (Dalal et al. 2008; Muthukumaraswamy 2010; Dockstader et al. 2010; Diwakar et al. 2011). Further confirmation on the possibilities and limitations of scalp recordings can be obtained from occasional opportunities to record them simultaneously with intracranial EEG (Dalal et al. 2008; Ball et al. 2009; Litvak et al. 2010; Rampp et al. 2010).

Given these considerations, our position is that there should be even *more* emphasis on gamma and beta, and researchers should take care not to filter this activity out upon acquisition, as any desired filtering for traditional analyses can now be easily done in post-processing software. Intracranial EEG, likewise, remains an underutilized technique to study human cognition, given the number of epilepsy surgery clinics around the world.

3 Intracranial EEG and Cortical Rhythms

Intracranial EEG (iEEG) in humans provides high-fidelity recordings of great clinical and research value. While intracranial recordings may occasionally be contaminated by eye muscle activity (Ball et al. 2009; Jerbi et al. 2009a; Kovach et al. 2011), these effects are predominantly restricted to recordings sites in the vicinity of the temporal pole and are efficiently reduced by using bipolar re-referencing strategies (Jerbi et al. 2009a). Certainly, these recordings are performed in patients with brain pathologies, so individual results are best interpreted in the context of converging evidence from other techniques; nevertheless, each patient's pathology tends to be different, therefore findings that remain consistent across patients can be regarded with reasonable confidence (Jerbi et al. 2009b).

The spatial coverage of iEEG is inherently limited, and the contribution of brain regions distant from the implanted zone cannot be reliably assessed. Nevertheless, a specific region of the brain is usually targeted for implantation based on a clinical hypothesis from scalp EEG/MEG, other neuroimaging techniques, and neurological or neuropsychological symptoms; any cognitive experiment tends to be targeted based on this coverage as well. Moreover, a sufficiently large volume of cortex must be activated to produce a recordable signal at the scalp (Cooper et al. 1965; Nunez and Srinivasan 2006), further raising the likelihood of detection

by at least one intracranial electrode that would provide a partial validation of analyses from scalp recordings. Furthermore, source localization techniques similar to those applied to scalp EEG/MEG are under development for increasing the effective spatial sampling of iEEG (Dümpelmann et al. 2009; Axmacher et al. 2010). These techniques may be able to extend spatial coverage somewhat beyond the limits of the targeted brain volume. Finally, depth electrodes can access deeper brain structures such as the hippocampus (Ekstrom et al. 2005; Axmacher et al. 2010), thalamus (Sarnthein et al. 2003; Hanajima et al. 2004), and subthalamic nucleus (Litvak et al. 2010; Hirschmann et al. 2010), all of which play critical roles in brain function but are currently difficult or impossible to resolve with scalp recordings.

The earliest reports of subdural recordings in humans have shown activity across a range of frequencies, including the alpha band (Scarff and Rahm 1941; Jasper and Penfield 1949; Cooper et al. 1965). Numerous experiments in recent years have also shown task-related alpha modulations in subdural surface grids (Arroyo et al. 1993; Toro et al. 1994; Towle et al. 1995; Crone et al. 1998; Ohara et al. 2000; Crone et al. 2001; Brunner et al. 2005; Dalal et al. 2008; Blakely et al. 2009; Edwards et al. 2009; Swann et al. 2009; Fukuda et al. 2010), including centimeter-scale coherence (Shen et al. 1999; Aoki et al. 2001; Brunner et al. 2005). Tremblay et al. (2004) reported decreases of alpha band power over frontal and motor cortex not only with finger movements but with *observations* of finger movements. Furthermore, alpha modulations have been observed in depth EEG recordings as well (Dalal et al. 2009; Vidal et al. 2010). A procedure called hemispherectomy, in which a portion of skull is removed while leaving the scalp and dura, can be considered similar to dural recordings; Voytek et al. (2010) found that the procedure intensifies modulations across a broad range of frequencies – including the alpha band – relative to intact scalp EEG. However, bipolar montages, often used in intracranial recording, may inherently obscure diffuse alpha activity. Clearly, large-scale phenomena, by definition, cannot be observed with the small spatial coverage available in many human iEEG studies, but most of the experiments cited here typically recorded over wide regions of cortex and consequently revealed widespread alpha modulations; many of these studies simultaneously analyzed gamma band modulations also, finding effects that were more task-specific as well as more focal spatially and temporally. (Jerbi et al. 2009b).

Let us not forget one of the primary goals of brain mapping, and the decisive motivation to record hu-

man intracranial EEG – to provide important diagnostic information for patient treatment. Here, too, analysis of intracranial gamma band activity has proven critical. Functional gamma mapping appears to correlate favorably with results of electrocortical stimulation mapping of eloquent cortex (Towle et al. 2008; Wu et al. 2010; Roland et al. 2010), and can be performed far more quickly and with less stress for the patient. While lower-frequency modulations may be seen along with gamma band enhancements, their spatial extent is often larger, reducing their usefulness for planning of resective surgery. Certain kinds of pathology (tumors, epileptogenic zones) also manifest themselves with abnormally high gamma-band power (Jacobs et al. 2010b) and coherence (Le Van Quyen et al. 1997). Finally, intracranial gamma band modulations frequently show higher spatial and functional specificity than other metrics, properties that are essential for real-time and brain-computer interface applications (Leuthardt et al. 2004; Lachaux et al. 2007b; Miller et al. 2009).

4 Plausible Role for Faster Rhythms in Binding, Neuronal Communication, and Inhibition

Slow oscillations may not provide a plausible mechanism for inherently fast integration processes, considering that neuronal interactions occur at a millisecond timescale. Singer (1993) specifically hypothesized that, “oscillations in the α - and β -frequency range would be too slow to serve as carrier signal for binding at this level of processing,” especially if a few cycles of an oscillation are necessary, and proposed that the gamma range “appears as a good compromise between the opposing constraints to establish synchrony rapidly and with high temporal resolution on the one hand and over long distances on the other.” However, the role of gamma rhythms in long-distance binding remains controversial (Kopell et al. 2000), especially with respect to visual processing, as recent studies have provided evidence against gamma-mediated binding in V1 (Ray and Maunsell 2010; Lima et al. 2010).

In parallel, the theoretical interpretations and foundations of gamma-band activity in cerebral networks have diversified beyond the binding hypothesis. Recent reviews have stressed the important mechanistic role of gamma activity regarding selective neural communication, neural plasticity, and neural activation and inhibition (Fries 2009). GABAergic interneurons form one of the largest cell populations in cortex and are known to operate largely in the gamma band, appearing to provide a key role in sensory gating (Cardin et al. 2009);

a recent MEG study found that resting GABA concentration in the visual cortex of individual subjects predicts the gamma oscillation frequency induced by visual stimuli (Muthukumaraswamy et al. 2009). All of these potential implications compel further investigation of the gamma band alongside other frequencies, to explore aspects of perception and cognition that may not be accessible to other techniques.

Nunez and Srinivasan (2010) contend that studies of conscious perception during binocular rivalry using steady-state visual evoked potentials (SSVEPs) constitute the consciousness studies that are most closely related to perceptual binding. However, the hypothesis of binding by synchrony was conceived as a computational solution that could explain how a limited number of neurons, by means of their temporal coordination, may represent the enormous variability of the environment. In contrast, exogenously driving the cortical response through steady-state visual stimulation is highly useful for studying conscious perception (Srinivasan et al. 1999; Cosmelli et al. 2004). This frequency-tagging of active neural networks constitutes a powerful tool to investigate consciousness but does not necessarily explain the underlying mechanism by which consciousness arises.

5 Link between Gamma & BOLD

Accumulating evidence over the last decade suggests that investigations of gamma-band neuronal activity might be key to bridging the gap between fMRI and electrophysiological research. Numerous studies have established a tight relationship between increases in the blood-oxygenation level-dependent (BOLD) signal and task-related increases in broadband gamma (\sim 30-150 Hz) of the LFP in humans (Mukamel et al. 2005; Nir et al. 2007; Lachaux et al. 2007a) and in animals (Logothetis et al. 2001; Niessing et al. 2005). By contrast, alpha-band modulations often seem to be negatively correlated with simultaneously recorded BOLD responses (e.g., Laufs et al. 2003; Moosmann et al. 2003) but more spatially distributed.

A further indicator for the specificity of the coupling between gamma-band power and BOLD comes from recent reports indicating that positive and negative BOLD responses are associated respectively with increases and decreases of broadband gamma power in the primary visual cortex of monkeys (Shmuel et al. 2006). More recently, the coupling between negative BOLD responses and suppression of gamma power has also been suggested by direct electrophysiological recordings in the so-called *default-mode network* known to display BOLD deactivations during attention-demanding tasks.

Several studies by our group and others show that execution of externally oriented attention-demanding tasks leads to suppressions of broad-band gamma power in specific default-mode network structures (Hayden et al. 2009; Lachaux et al. 2008; Ossandón et al. 2009; Jerbi et al. 2010). Therefore future studies of broadband gamma should improve our understanding of the neurophysiological basis of the BOLD signal and advance our understanding of the functional role of large-scale intrinsic networks such as the default-mode network.

6 Final Words

The term “gamma band” as currently used represents a very broad range of frequencies that likely encompasses a few different neural mechanisms, and we support Nunez and Srinivasan (2010) in cautioning against the temptation to rely on it as a “catch-all category.” The literature describing epilepsy-related high frequency oscillations has recognized some differences across this range, using the term *ripples* to describe activity between about 80-200 Hz but distinguishing them from “fast ripples” that appear to represent a distinct phenomenon between 250-500 Hz (Bragin et al. 1999). In the cognitive domain, more differentiation needs to be made between, for example, 40 Hz narrowband oscillations and broader 70-120 Hz power enhancements (Vidal et al. 2006; Hoogenboom et al. 2006; Wyart and Tallon-Baudry 2008; Crone et al. 2010), or even higher frequency phenomena of about 130-250 Hz (often also referred to as ripples) in the hippocampus and entorhinal cortex (Axmacher et al. 2008; Le Van Quyen et al. 2010) and 600 Hz somatosensory evoked potentials (Curio et al. 1994). A more nuanced view of these high frequencies should be considered, particularly in light of a recent study demonstrating the specificity of different subbands across the 60-500 Hz range to various cognitive tasks (Gaona et al. 2011). As suggested by Curio (2000) and Jacobs et al. (2010a), perhaps the EEG/MEG community should agree on more specific, consistent terminology to better differentiate the various high-frequency phenomena in the literature. In fact, if such distinctions were made, one could argue that alpha actually attracts a rather disproportionate amount of attention for encompassing only 4 Hz of the spectrum!

Figure 1 suggests that very low frequency phenomena (below 4 Hz) such as the slow cortical potential (Birbaumer et al. 1990; He et al. 2008) or infraslow fluctuations (e.g., Monto et al. 2008), as well as delta-band frequencies (e.g., Jerbi et al. 2007) may also deserve more studies and further evaluation. Ultimately, a more complete view of brain dynamics and cognition must

come from examining activity across a broad range of frequencies. As Nunez and Srinivasan (2010) point out, cross-frequency interaction may provide a mechanism for inter-network communication during cognitive processing, and already studies on cross-frequency interaction from several laboratories have been rapidly elucidating the interplay between frequency bands (Canolty et al. 2006; Jensen and Colgin 2007; Monto et al. 2008; Osipova et al. 2008; de Lange et al. 2008; Jerbi and Bertrand 2009; Le Van Quyen et al. 2010; Dalal et al. 2010; Canolty and Knight 2010). It is therefore clear that the neural correlates of cognition are not confined to a specific frequency band and that the big picture can only be achieved by putting the pieces of the puzzle back together, i.e., not only including all frequencies of the spectrum but also various measures of brain responses across multiple spatial scales.

We shall also conclude with inspiration by Jacobs (2010), who notes that so much valuable information has been gained from simply opening up filters, using faster sampling rates, and examining the full frequency spectrum in subsequent analyses; indeed, her editorial closes with optimism that ever higher frequency activity reflecting ever earlier responses will arise from technical advances, not to the exclusion of lower frequency correlates, but rather in the context of them, and we couldn't agree more.

References

- Aoki, F., Fetz, E. E., Shupe, L., Lettich, E., Ojemann, G. A., Dec 2001. Changes in power and coherence of brain activity in human sensorimotor cortex during performance of visuomotor tasks. *BioSystems* 63 (1-3), 89–99.
- Arroyo, S., Lesser, R. P., Gordon, B., Uematsu, S., Jackson, D., Webber, R., Sep 1993. Functional significance of the mu rhythm of human cortex: an electrophysiologic study with subdural electrodes. *Electroencephalogr Clin Neurophysiol* 87 (3), 76–87.
- Axmacher, N., Cohen, M. X., Fell, J., Haupt, S., Dümpelmann, M., Elger, C. E., Schlaepfer, T. E., Lenartz, D., Sturm, V., Ranganath, C., Feb 2010. Intracranial EEG correlates of expectancy and memory formation in the human hippocampus and nucleus accumbens. *Neuron* 65 (4), 541–9.
- Axmacher, N., Elger, C. E., Fell, J., Jul 2008. Ripples in the medial temporal lobe are relevant for human memory consolidation. *Brain* 131, 1806–17.
- Ball, T., Kern, M., Mutschler, I., Aertsen, A., Schulze-Bonhage, A., Jul 2009. Signal quality of simultaneously recorded invasive and non-invasive EEG. *NeuroImage* 46 (3), 708–16.
- Berger, H., 1929. Über das elektrenkephalogramm des menschen. *Arch Psychiat Nervenkr* 87, 527–570.
- Berger, H., 1930. Über das elektrenkephalogramm des menschen. Zweite mitteilung. *J Psychol Neurol* 40, 160–179.

- Birbaumer, N., Elbert, T., Canavan, A. G., Rockstroh, B., Jan 1990. Slow potentials of the cerebral cortex and behavior. *Physiol Rev* 70 (1), 1–41.
- Blakely, T., Miller, K. J., Zanos, S. P., Rao, R. P. N., Ojemann, J. G., Jul 2009. Robust, long-term control of an electrocorticographic brain-computer interface with fixed parameters. *Neurosurgical focus* 27 (1), E13.
- Bragin, A., Engel, J., Wilson, C. L., Fried, I., Buzsáki, G., Jan 1999. High-frequency oscillations in human brain. *Hippocampus* 9 (2), 137–42.
- Bragin, A., Mody, I., Wilson, C. L., Engel, J., Mar 2002. Local generation of fast ripples in epileptic brain. *J Neurosci* 22 (5), 2012–21.
- Brunner, C., Graitmann, B., Huggins, J. E., Levine, S. P., Pfurtscheller, G., Feb 2005. Phase relationships between different subdural electrode recordings in man. *Neurosci Lett* 375 (2), 69–74.
- Canolty, R. T., Edwards, E., Dalal, S. S., Soltani, M., Nagarajan, S. S., Kirsch, H. E., Berger, M. S., Barbaro, N. M., Knight, R. T., 2006. High gamma power is phase-locked to theta oscillations in human neocortex. *Science* 313, 1626–1628.
- Canolty, R. T., Knight, R. T., Nov 2010. The functional role of cross-frequency coupling. *Trends Cogn Sci* 14 (11), 506–15.
- Cardin, J. A., Carlén, M., Meletis, K., Knoblich, U., Zhang, F., Deisseroth, K., Tsai, L.-H., Moore, C. I., Jun 2009. Driving fast-spiking cells induces gamma rhythm and controls sensory responses. *Nature* 459 (7247), 663–7.
- Cheyne, D., Gaetz, W., Garnero, L., Lachaux, J.-P., Ducorps, A., Schwartz, D., Varela, F. J., 2003. Neuromagnetic imaging of cortical oscillations accompanying tactile stimulation. *Cogn Brain Res* 17, 599–611.
- Cooper, R., Winter, A. L., Crow, H. J., Walter, W. G., Feb 1965. Comparison of subcortical, cortical and scalp activity using chronically indwelling electrodes in man. *Electroencephalogr Clin Neurophysiol* 18, 217–28.
- Cosmelli, D., David, O., Lachaux, J.-P., Martinerie, J., Garnero, L., Renault, B., Varela, F., Sep 2004. Waves of consciousness: ongoing cortical patterns during binocular rivalry. *NeuroImage* 23 (1), 128–40.
- Crone, N. E., Boatman, D., Gordon, B., Hao, L., 2001. Induced electrocorticographic gamma activity during auditory perception. *Clin Neurophysiol* 112, 565–582.
- Crone, N. E., Korzeniewska, A., Franaszczuk, P., Nov 2010. Cortical gamma responses: Searching high and low. *Int J Psychophysiol*.
- Crone, N. E., Miglioretti, D. L., Gordon, B., Sieracki, J. M., Wilson, M. T., Uematsu, S., Lesser, R. P., 1998. Functional mapping of human sensorimotor cortex with electrocorticographic spectral analysis. I. Alpha and beta event-related desynchronization. *Brain* 121, 2271–2299.
- Curio, G., Jul 2000. Ain't no rhythm fast enough: EEG bands beyond beta. *J Clin Neurophysiol* 17 (4), 339–40.
- Curio, G., Mackert, B. M., Burghoff, M., Koetitz, R., Abraham-Fuchs, K., Härer, W., Dec 1994. Localization of evoked neuromagnetic 600 Hz activity in the cerebral somatosensory system. *Electroencephalogr Clin Neurophysiol* 91 (6), 483–7.
- Dalal, S. S., Baillet, S., Adam, C., Ducorps, A., Schwartz, D., Jerbi, K., Bertrand, O., Garnero, L., Martinerie, J., Lachaux, J.-P., May 2009. Simultaneous MEG and intracranial EEG recordings during attentive reading. *NeuroImage* 45 (4), 1289–304.
- Dalal, S. S., Guggisberg, A. G., Edwards, E., Sekihara, K., Findlay, A. M., Canolty, R. T., Berger, M. S., Knight, R. T., Barbaro, N. M., Kirsch, H. E., Nagarajan, S. S., 2008. Five-dimensional neuroimaging: Localization of the time-frequency dynamics of cortical activity. *NeuroImage* 40, 1686–1700.
- Dalal, S. S., Hamamé, C. M., Eichenlaub, J.-B., Jerbi, K., Oct 2010. Intrinsic coupling between gamma oscillations, neuronal discharges, and slow cortical oscillations during human slow-wave sleep. *J Neurosci* 30 (43), 14285–7.
- de Lange, F. P., Jensen, O., Bauer, M., Toni, I., Jan 2008. Interactions between posterior gamma and frontal alpha/beta oscillations during imagined actions. *Frontiers in Human Neuroscience* 2, 7.
- Diwakar, M., Huang, M.-X., Srinivasan, R., Harrington, D. L., Robb, A., Angeles, A., Muzzatti, L., Pakdaman, R., Song, T., Theilmann, R. J., Lee, R. R., Jan 2011. Dual-core beamformer for obtaining highly correlated neuronal networks in MEG. *NeuroImage* 54 (1), 253–63.
- Dockstader, C., Cheyne, D., Tannock, R., Jan 2010. Cortical dynamics of selective attention to somatosensory events. *NeuroImage* 49 (2), 1777–85.
- Dümpelmann, M., Fell, J., Wellmer, J., Urbach, H., Elger, C. E., Jun 2009. 3D source localization derived from subdural strip and grid electrodes: a simulation study. *Clin Neurophysiol* 120 (6), 1061–9.
- Edwards, E., Soltani, M., Kim, W., Dalal, S. S., Nagarajan, S. S., Berger, M. S., Knight, R. T., Jul 2009. Comparison of time-frequency responses and the event-related potential to auditory speech stimuli in human cortex. *J Neurophysiol* 102 (1), 377–86.
- Ekstrom, A. D., Caplan, J. B., Ho, E., Shattuck, K., Fried, I., Kahana, M. J., 2005. Human hippocampal theta activity during virtual navigation. *Hippocampus* 15 (7), 881–9.
- Engel, A. K., Fries, P., Apr 2010. Beta-band oscillations—signalling the status quo? *Current Opinion in Neurobiology* 20 (2), 156–65.
- Fries, P., 2009. Neuronal gamma-band synchronization as a fundamental process in cortical computation. *Annu Rev Neurosci* 32, 209–224.
- Fukuda, M., Juhász, C., Hoehstetter, K., Sood, S., Asano, E., Mar 2010. Somatosensory-related gamma-, beta- and alpha-augmentation precedes alpha- and beta-attenuation in humans. *Clin Neurophysiol* 121 (3), 366–75.
- Gaona, C. M., Sharma, M., Freudenburg, Z. V., Breshears, J. D., Bundy, D. T., Roland, J., Barbour, D. L., Schalk, G., Leuthardt, E. C., Feb 2011. Nonuniform high-gamma (60–500 Hz) power changes dissociate cognitive task and anatomy in human cortex. *J Neurosci* 31 (6), 2091–2100.
- Goncharova, I. I., McFarland, D. J., Vaughan, T. M., Wolpaw, J. R., Sep 2003. EMG contamination of EEG: spectral and topographical characteristics. *Clin Neurophysiol* 114 (9), 1580–93.
- Gross, J., Kujala, J., Hämäläinen, M., Timmermann, L., Schnitzler, A., Salmelin, R., Jan 2001. Dynamic imaging of coherent sources: Studying neural interactions in the human brain. *Proc Natl Acad Sci USA* 98 (2), 694–9.
- Hanajima, R., Chen, R., Ashby, P., Lozano, A. M., Hutchison, W. D., Davis, K. D., Dostrovsky, J. O., Dec 2004. Very fast oscillations evoked by median nerve stimulation in the human thalamus and subthalamic nucleus. *J Neurophysiol* 92 (6), 3171–82.
- Hayden, B. Y., Smith, D. V., Platt, M. L., Apr 2009. Electrophysiological correlates of default-mode processing in macaque posterior cingulate cortex. *Proc Natl Acad Sci U S A* 106 (14), 5948–53.

- He, B. J., Snyder, A. Z., Zempel, J. M., Smyth, M. D., Raichle, M. E., Oct 2008. Electrophysiological correlates of the brain's intrinsic large-scale functional architecture. *Proc Natl Acad Sci USA* 105 (41), 16039–44.
- Hirschmann, J., Ozkurt, T. E., Butz, M., Homburger, M., Elben, S., Hartmann, C. J., Vesper, J., Wojtecki, L., Schnitzler, A., Nov 2010. Distinct oscillatory STN-cortical loops revealed by simultaneous MEG and local field potential recordings in patients with Parkinson's disease. *NeuroImage*.
- Hoogenboom, N., Schoffelen, J.-M., Oostenveld, R., Parkes, L. M., Fries, P., 2006. Localizing human visual gamma-band activity in frequency, time and space. *NeuroImage* 29, 764–773.
- Jacobs, J., Mar 2010. Measuring cortical activity – we will only detect what we are looking for. *Clin Neurophysiol* 121 (3), 268–9.
- Jacobs, J., Manning, J. R., Kahana, M. J., 2010a. “broadband” vs. “high gamma” electrocorticographic signals. *J Neurosci* <http://www.jneurosci.org/cgi/data/30/19/6477/DC1/1>.
- Jacobs, J., Zijlmans, M., Zelman, R., Chatillon, C.-E., Hall, J., Olivier, A., Dubeau, F., Gotman, J., Feb 2010b. High-frequency electroencephalographic oscillations correlate with outcome of epilepsy surgery. *Ann Neurol* 67 (2), 209–20.
- Jasper, H., Penfield, W., Apr 1949. Electroencephalograms in man: effect of voluntary movement upon the electrical activity of the precentral gyrus. *Archive für Psychiatrie und Zeitschrift Neurologie* 183 (1), 163–174.
- Jasper, H. H., Andrews, H. L., Jan 1938. Electroencephalography: III. Normal differentiation of occipital and precentral regions in man. *Archives of Neurology & Psychiatry* 39 (1), 96.
- Jasper, H. H., Carmichael, L., Jan 1935. Electrical potentials from the intact human brain. *Science* 81 (2089), 51–3.
- Jensen, O., Colgin, L. L., Jul 2007. Cross-frequency coupling between neuronal oscillations. *Trends Cogn Sci (Regul Ed)* 11 (7), 267–9.
- Jerbi, K., Bertrand, O., May 2009. Cross-frequency coupling in parieto-frontal oscillatory networks during motor imagery revealed by magnetoencephalography. *Front Neurosci* 3 (1), 3–4.
- Jerbi, K., Freyermuth, S., Dalal, S., Kahane, P., Bertrand, O., Berthoz, A., Lachaux, J.-P., Jun 2009a. Saccade related gamma-band activity in intracerebral EEG: dissociating neural from ocular muscle activity: dissociating neural from ocular muscle activity. *Brain Topogr* 22 (1), 18–23.
- Jerbi, K., Lachaux, J.-P., N'Diaye, K., Pantazis, D., Leahy, R. M., Garnero, L., Baillet, S., May 2007. Coherent neural representation of hand speed in humans revealed by meg imaging. *Proc Natl Acad Sci USA* 104 (18), 7676–81.
- Jerbi, K., Ossandón, T., Hamamé, C. M., Senova, S., Dalal, S. S., Jung, J., Minotti, L., Bertrand, O., Berthoz, A., Kahane, P., Lachaux, J.-P., Jun 2009b. Task-related gamma-band dynamics from an intracerebral perspective: review and implications for surface EEG and MEG. *Human brain mapping* 30 (6), 1758–71.
- Jerbi, K., Vidal, J. R., Ossandón, T., Dalal, S. S., Jung, J., Hoffmann, D., Minotti, L., Bertrand, O., Kahane, P., Lachaux, J.-P., Jan 2010. Exploring the electrophysiological correlates of the default-mode network with intracerebral EEG. *Frontiers in Systems Neuroscience* 4, 27.
- Jurkiewicz, M. T., Gaetz, W. C., Bostan, A. C., Cheyne, D., 2006. Post-movement beta rebound is generated in motor cortex: Evidence from neuromagnetic recordings. *NeuroImage* 32, 1281–1289.
- Keren, A. S., Yuval-Greenberg, S., Deouell, L. Y., Feb 2010. Saccadic spike potentials in gamma-band EEG: characterization, detection and suppression. *NeuroImage* 49 (3), 2248–63.
- Kopell, N., Ermentrout, G. B., Whittington, M. A., Traub, R. D., Feb 2000. Gamma rhythms and beta rhythms have different synchronization properties. *Proc Natl Acad Sci USA* 97 (4), 1867–72.
- Kovach, C. K., Tsuchiya, N., Kawasaki, H., Oya, H., Howard, M. A., Adolphs, R., Jan 2011. Manifestation of ocular-muscle emg contamination in human intracranial recordings. *NeuroImage* 54 (1), 213–33.
- Lachaux, J.-P., Fonlupt, P., Kahane, P., Minotti, L., Hoffmann, D., Bertrand, O., Baciú, M., 2007a. Relationship between task-related gamma oscillations and BOLD signal: New insights from combined fMRI and intracranial EEG. *Hum Brain Mapp* 28, 1368–1375.
- Lachaux, J.-P., Jerbi, K., Bertrand, O., Minotti, L., Hoffmann, D., Schoendorff, B., Kahane, P., 2007b. A blueprint for real-time functional mapping via human intracranial recordings. *PLoS One* 2, e1094.
- Lachaux, J. P., Jung, J., Mainy, N., Dreher, J. C., Bertrand, O., Baciú, M., Minotti, L., Hoffmann, D., Kahane, P., 2008. Silence is golden: Transient neural deactivation in the prefrontal cortex during attentive reading. *Cereb Cortex* 18, 443–450.
- Laufs, H., Kleinschmidt, A., Beyerle, A., Eger, E., Salek-Haddadi, A., Preibisch, C., Krakow, K., Aug 2003. EEG-correlated fMRI of human alpha activity. *NeuroImage* 19 (4), 1463–76.
- Le Van Quyen, M., Adam, C., Lachaux, J. P., Martinerie, J., Baulac, M., Renault, B., Varela, F. J., May 1997. Temporal patterns in human epileptic activity are modulated by perceptual discriminations. *NeuroReport* 8 (7), 1703–10.
- Le Van Quyen, M., Staba, R., Bragin, A., Dickson, C., Valderama, M., Fried, I., Engel, J., 2010. Large-scale microelectrode recordings of high-frequency gamma oscillations in human cortex during sleep. *J Neurosci* 30, 7770–7782.
- Leuthardt, E. C., Schalk, G., Wolpaw, J. R., Ojemann, J. G., Moran, D. W., 2004. A brain-computer interface using electrocorticographic signals in humans. *J Neural Eng* 1, 63–71.
- Lima, B., Singer, W., Chen, N.-H., Neuenschwander, S., Jul 2010. Synchronization dynamics in response to plaid stimuli in monkey V1. *Cereb Cortex* 20 (7), 1556–73.
- Litvak, V., Eusebio, A., Jha, A., Oostenveld, R., Barnes, G. R., Penny, W. D., Zrinzo, L., Hariz, M. I., Limousin, P., Friston, K. J., Brown, P., May 2010. Optimized beamforming for simultaneous MEG and intracranial local field potential recordings in deep brain stimulation patients. *NeuroImage* 50 (4), 1578–88.
- Logothetis, N. K., Pauls, J., Augath, M., Trinath, T., Oeltermann, A., 2001. Neurophysiological investigation of the basis of the fMRI signal. *Nature* 412, 150–157.
- Mäki, H., Ilmoniemi, R. J., Feb 2011. Projecting out muscle artifacts from TMS-evoked EEG. *NeuroImage* 54 (4), 2706–10.
- Miller, K. J., Zanos, S., Fetz, E. E., den Nijs, M., Ojemann, J. G., Mar 2009. Decoupling the cortical power spectrum reveals real-time representation of individual finger movements in humans. *J Neurosci* 29 (10), 3132–7.
- Monto, S., Palva, S., Voipio, J., Palva, J. M., Aug 2008. Very slow EEG fluctuations predict the dynamics of stimulus detection and oscillation amplitudes in humans. *J Neu-*

- roschi 28 (33), 8268–72.
- Moosmann, M., Ritter, P., Krastel, I., Brink, A., Thees, S., Blankenburg, F., Taskin, B., Obrig, H., Villringer, A., Sep 2003. Correlates of alpha rhythm in functional magnetic resonance imaging and near infrared spectroscopy. *NeuroImage* 20 (1), 145–58.
- Mukamel, R., Gelbard, H., Arieli, A., Hasson, U., Fried, I., Malach, R., 2005. Coupling between neuronal firing, field potentials, and fMRI in human auditory cortex. *Science* 309, 951–954.
- Muthukumaraswamy, S. D., Nov 2010. Functional properties of human primary motor cortex gamma oscillations. *J Neurophysiol* 104 (5), 2873–85.
- Muthukumaraswamy, S. D., Edden, R. A. E., Jones, D. K., Swettenham, J. B., Singh, K. D., May 2009. Resting GABA concentration predicts peak gamma frequency and fMRI amplitude in response to visual stimulation in humans. *Proc Natl Acad Sci USA* 106 (20), 8356–61.
- Muthukumaraswamy, S. D., Johnson, B. W., Aug 2004. Primary motor cortex activation during action observation revealed by wavelet analysis of the EEG. *Clin Neurophysiol* 115 (8), 1760–6.
- Niessing, J., Ebisch, B., Schmidt, K. E., Niessing, M., Singer, W., Galuske, R. A. W., 2005. Hemodynamic signals correlate tightly with synchronized gamma oscillations. *Science* 309, 948–951.
- Nir, Y., Fisch, L., Mukamel, R., Gelbard-Sagiv, H., Arieli, A., Fried, I., Malach, R., Aug 2007. Coupling between neuronal firing rate, gamma LFP, and BOLD fMRI is related to interneuronal correlations. *Curr Biol* 17 (15), 1275–85.
- Nunez, P. L., Srinivasan, R., 2006. *Electric Fields of the Brain: The Neurophysics of EEG*, 2nd Edition. New York: Oxford University Press.
- Nunez, P. L., Srinivasan, R., Oct 2010. Scale and frequency chauvinism in brain dynamics: too much emphasis on gamma band oscillations. *Brain Struct Funct* 215, 67–71.
- Ohara, S., Ikeda, A., Kunieda, T., Yazawa, S., Baba, K., Nagamine, T., Taki, W., Hashimoto, N., Mihara, T., Shibasaki, H., 2000. Movement-related change of electrocorticographic activity in human supplementary motor area proper. *Brain* 123, 1203–1215.
- Oostendorp, T. F., Delbeke, J., Stegeman, D. F., Nov 2000. The conductivity of the human skull: Results of *in vivo* and *in vitro* measurements. *IEEE Trans Biomed Eng* 47 (11), 1487–92.
- Osipova, D., Hermes, D., Jensen, O., Jan 2008. Gamma power is phase-locked to posterior alpha activity. *PLoS ONE* 3 (12), e3990.
- Ossandón, T., Jerbi, K., Bayle, D., Bertrand, O., Kahane, P., Lachaux, J.-P., 2009. Task-related gamma band suppressions: a plausible electrophysiological correlate of the default-mode network? *Soc Neurosci Abstr (Program No 804.10)* SfN 2009, Chicago, IL.
- Parkes, L. M., Bastiaansen, M. C. M., Norris, D. G., Feb 2006. Combining EEG and fMRI to investigate the post-movement beta rebound. *NeuroImage* 29 (3), 685–96.
- Pfurtscheller, G., Cooper, R., 1975. Frequency dependence of the transmission of the EEG from cortex to scalp. *Electroencephalogr Clin Neurophysiol* 38, 93–96.
- Pfurtscheller, G., Krausz, G., Neuper, C., Nov 2001. Mechanical stimulation of the fingertip can induce bursts of beta oscillations in sensorimotor areas. *J Clin Neurophysiol* 18 (6), 559–64.
- Pfurtscheller, G., Neuper, C., Brunner, C., da Silva, F. L., Apr 2005. Beta rebound after different types of motor imagery in man. *Neurosci Lett* 378 (3), 156–9.
- Pope, K. J., Fitzgibbon, S. P., Lewis, T. W., Whitham, E. M., Willoughby, J. O., Jun 2009. Relation of gamma oscillations in scalp recordings to muscular activity. *Brain topography* 22 (1), 13–7.
- Rampp, S., Kaltenhäuser, M., Weigel, D., Buchfelder, M., Blümcke, I. I., Dörfler, A., Stefan, H., Aug 2010. MEG correlates of epileptic high gamma oscillations in invasive EEG. *Epilepsia* 51 (8), 1638–42.
- Ray, S., Maunsell, J. H. R., Sep 2010. Differences in gamma frequencies across visual cortex restrict their possible use in computation. *Neuron* 67 (5), 885–96.
- Reva, N. V., Aftanas, L. I., Feb 2004. The coincidence between late non-phase-locked gamma synchronization response and saccadic eye movements. *Int J Psychophysiol* 51 (3), 215–22.
- Roland, J., Brunner, P., Johnston, J., Schalk, G., Leuthardt, E. C., May 2010. Passive real-time identification of speech and motor cortex during an awake craniotomy. *Epilepsy Behav* 18 (1-2), 123–8.
- Salmelin, R., Hämeäläinen, M., Kajola, M., Hari, R., Dec 1995. Functional segregation of movement-related rhythmic activity in the human brain. *NeuroImage* 2 (4), 237–43.
- Sarnthein, J., Morel, A., Stein, A. V., Jeanmonod, D., 2003. Thalamic theta field potentials and EEG: high thalamocortical coherence in patients with neurogenic pain, epilepsy and movement disorders. *Thalamus Rel Sys* 2 (03), 231–238.
- Scarff, J., Rahm, W., 1941. The human electro-corticogram: A report of spontaneous electrical potentials obtained from the exposed human brain. *J Neurophysiol* 4 (5), 418.
- Sekihara, K., Nagarajan, S. S., Poeppel, D., Marantz, A., 2004. Asymptotic SNR of scalar and vector minimum-variance beamformers for neuromagnetic source reconstruction. *IEEE Trans Biomed Eng* 51, 1726–1734.
- Shen, B., Nadkarni, M., Zappulla, R. A., Jan 1999. Spectral modulation of cortical connections measured by EEG coherence in humans. *Clin Neurophysiol* 110 (1), 115–25.
- Shmuel, A., Augath, M., Oeltermann, A., Logothetis, N. K., Apr 2006. Negative functional MRI response correlates with decreases in neuronal activity in monkey visual area V1. *Nat Neurosci* 9 (4), 569–77.
- Singer, W., Jan 1993. Synchronization of cortical activity and its putative role in information processing and learning. *Annu Rev Physiol* 55, 349–74.
- Srinivasan, R., Russell, D. P., Edelman, G. M., Tononi, G., Jul 1999. Increased synchronization of neuromagnetic responses during conscious perception. *J Neurosci* 19 (13), 5435–48.
- Swann, N., Tandon, N., Canolty, R., Ellmore, T. M., McEvoy, L. K., Dreyer, S., Disano, M., Aron, A. R., Oct 2009. Intracranial EEG reveals a time- and frequency-specific role for the right inferior frontal gyrus and primary motor cortex in stopping initiated responses. *J Neurosci* 29 (40), 12675–85.
- Tallon-Baudry, C., Bertrand, O., Fischer, C., 2001. Oscillatory synchrony between human extrastriate areas during visual short-term memory maintenance. *J Neurosci* 21:RC177, 1–5.
- Tao, J. X., Baldwin, M., Hawes-Ebersole, S., Ebersole, J. S., Apr 2007. Cortical substrates of scalp EEG epileptiform discharges. *J Clin Neurophysiol* 24 (2), 96–100.
- Tönnies, J., 1934. Die unipolare ableitung elektrischer spannungen vom menschlichen gehirn. *Naturwissenschaften* 22, 411–414.

- Toro, C., Deuschl, G., Thatcher, R., Sato, S., Kufta, C., Hallett, M., Oct 1994. Event-related desynchronization and movement-related cortical potentials on the ECoG and EEG. *Electroencephalogr Clin Neurophysiol* 93 (5), 380–9.
- Towle, V. L., Cohen, S., Alperin, N., Hoffmann, K., Cogen, P., Milton, J., Grzesczczuk, R., Pelizzari, C., Syed, I., Spire, J. P., Apr 1995. Displaying electrocorticographic findings on gyral anatomy. *Electroencephalogr Clin Neurophysiol* 94 (4), 221–8.
- Towle, V. L., Yoon, H.-A., Castelle, M., Edgar, J. C., Biassou, N. M., Frim, D. M., Spire, J.-P., Kohrman, M. H., Aug 2008. ECoG gamma activity during a language task: differentiating expressive and receptive speech areas. *Brain* 131, 2013–27.
- Tremblay, C., Robert, M., Pascual-Leone, A., Lepore, F., Nguyen, D. K., Carmant, L., Bouthillier, A., Théoret, H., Sep 2004. Action observation and execution: intracranial recordings in a human subject. *Neurology* 63 (5), 937–8.
- Trujillo, L. T., Peterson, M. A., Kaszniak, A. W., Allen, J. J. B., Jan 2005. EEG phase synchrony differences across visual perception conditions may depend on recording and analysis methods. *Clin Neurophysiol* 116 (1), 172–89.
- Turetsky, B. I., Raz, J., Fein, G., Jan 1988. Noise and signal power and their effects on evoked potential estimation. *Electroencephalogr Clin Neurophysiol* 71 (4), 310–8.
- Väisänen, O., Malmivuo, J., Oct 2009. Improving the SNR of EEG generated by deep sources with weighted multielectrode leads. *J Physiol Paris* 103 (6), 306–14.
- Vidal, J. R., Chaumon, M., O'Regan, J. K., Tallon-Baudry, C., 2006. Visual grouping and the focusing of attention induce gamma-band oscillations at different frequencies in human magnetoencephalogram signals. *J Cogn Neurosci* 18, 1850–1862.
- Vidal, J. R., Ossandón, T., Jerbi, K., Dalal, S. S., Minotti, L., Ryvlin, P., Kahane, P., Lachaux, J.-P., Nov 2010. Category-specific visual responses: an intracranial study comparing gamma, beta, alpha, and ERP response selectivity. *Front Hum Neurosci* 4, 195.
- Voytek, B., Secundo, L., Bidet-Caulet, A., Scabini, D., Stiver, S. I., Gean, A. D., Manley, G. T., Knight, R. T., Nov 2010. Hemispherectomy: a new model for human electrophysiology with high spatio-temporal resolution. *J Cogn Neurosci* 22 (11), 2491–502.
- Ward, D. M., Jones, R. D., Bones, P. J., Carroll, G. J., Jun 1999. Enhancement of deep epileptiform activity in the EEG via 3-D adaptive spatial filtering. *IEEE Trans Biomed Eng* 46 (6), 707–16.
- Whitham, E. M., Lewis, T., Pope, K. J., Fitzgibbon, S. P., Clark, C. R., Loveless, S., Delosangeles, D., Wallace, A. K., Broberg, M., Willoughby, J. O., 2008. Thinking activates EMG in scalp electrical recordings. *Clin Neurophysiol* 119, 1166–1175.
- Whitham, E. M., Pope, K. J., Fitzgibbon, S. P., Lewis, T., Clark, C. R., Loveless, S., Broberg, M., Wallace, A., DeLosAngeles, D., Lillie, P., Hardy, A., Fronsco, R., Pulbrook, A., Willoughby, J. O., Aug 2007. Scalp electrical recording during paralysis: quantitative evidence that EEG frequencies above 20 Hz are contaminated by EMG. *Clin Neurophysiol* 118 (8), 1877–88.
- Wu, J. Y., Koh, S., Sankar, R., Mathern, G. W., Nov 2008. Paroxysmal fast activity: an interictal scalp EEG marker of epileptogenesis in children. *Epilepsy Res* 82 (1), 99–106.
- Wu, M., Wisneski, K., Schalk, G., Sharma, M., Roland, J., Breshears, J., Gaona, C., Leuthardt, E. C., Jan 2010. Electrocorticographic frequency alteration mapping for extraoperative localization of speech cortex. *Neurosurgery* 66 (2), E407–9.
- Wyart, V., Tallon-Baudry, C., Mar 2008. Neural dissociation between visual awareness and spatial attention. *J Neurosci* 28 (10), 2667–79.
- Yuval-Greenberg, S., Tomer, O., Keren, A. S., Nelken, I., Deouell, L. Y., 2008. Transient induced gamma-band response in EEG as a manifestation of miniature saccades. *Neuron* 58, 429–441.