# The 5th Annual Meeting of Korean Society for Computational Neuroscience

## Main Theme: Emotion

# Program and Abstracts

**August 28, 2013**

Seoul National University Hospital

Biomedical Research Institute

Auditorium

**Korean Society for Computational Neuroscience**

**Sponsored by Asia Pacific Center for Theoretical Physics (APCTP)**

# [Program]

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| **Opening** | |
| 09:00 – 10:00 | Registration |
| 10:00 – 10:10 | Opening Remarks |
| **Focused Session on Emotion I** | Chair: Sung-Phil Kim (Korea Univ.) |
| 10:10 - 11:00 | June-Seek Choi (Korea Univ)<br>Computational approaches to fear-induced defensive response selection |
| 11:00 - 11:10 | Coffee Break |
| **Focused Session on Emotion II** | Chair: Jee Hyun Choi (KIST) |
| 11:10 - 11:40 | Sang Hee Kim (Korea Univ.)<br>Cognitive control of emotion |
| 11:40 - 12:10 | Minho Lee (Kyungpook Natl. Univ.)<br>Incremental emotion understanding in a movie clip |
| **Lunch / Poster Session (12:10 - 14:30)** | |
| **General Session I** | Chair: Hyungtae Kook (Gachon Univ.) |
| 14:30 - 15:20 | Se-Bum Paik (KAIST)<br>On the Origin of Functional Maps in Visual Cortex |
| 15:20 - 15:35 | Woochang Lim (Daegu Natl. Univ. of Education)<br>Effect of Small-World Connectivity on Sparsely Synchronized Cortical Rhythms |
| 15:35 - 15:50 | Won Sup Kim (Chungbuk Natl. Univ.)<br>Resting state dynamics of human brain from the resting state EEG |
| 15:50 - 16:10 | Coffee Break |
| **General Session II** | Chair: Kiwoon Kwon (Dongguk Univ.) |
| 16:10 - 17:00 | Moo K. Chung (Univ. of Wisconsin)<br>Large scale multimodal brain network construction in abused children |
| 17:00 - 17:30 | Jeehyun Kwag (Korea Univ.)<br>Inhibitory neural network-dependent modulation of neural codes |
| 17:30 - 17:45 | Dongmyeong Lee (KIST)<br>Noise-induced anti-correlated slow fluctuations in networks of neural populations |
| 17:45 - 18:00 | Kiwoon Kwon (Dongkuk Univ.)<br>Numerical Methods for Diffuse Optical Tomography |
| **Society Meeting (18:00 - 18:30)** | |

[A1]

# Computational approaches to fear-induced defensive response selection

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How an intelligent agent finds optimal behavior in an aversive situation is of great importance both for clinical and theoretical purposes. Patients with psychiatric disorders such as depression tend to be stuck with sub-optimal behavior choices despite the self-harming nature. On the other hand, healthy individuals gradually shift their response choices toward minimizing negative consequences, a form of instrumental learning (negative reinforcement). Emerging series of studies suggest that prevalence of conditioned responses that are innately coupled with the associations formed by Pavlovian conditioning might be strongly related to the maladaptive behavior. Therefore, a productive and informative strategy is to test dynamic regulation of the response selection under Pavlovian-instrumental competition. In the current study, we developed a mildly complex decision making paradigm, called discriminatory avoidance learning (DIAL) to study neurobiological interactions among brain structures involved in response selection in an aversive situation. In the behavioral study, rats were placed in a shuttle box and presented with one of the two auditory cues (Cue1 and Cue2). Cue1 signals a Go response and Cue2 signals a No-go response. Choosing the correct response (Cue1-Go; Cue2-No-go) will stop the tone and subsequent foot shock, while failure to do so would result in foot shock delivered through grid floor for up to 10 s. We also built a computational model which employed a modified reward-based Q-learning algorithm to simulate the acquisition of DIAL with two distinctive cues. We compared the behavioral data with simulation results obtained from conventional associative learning models such as Rescorla-Wagner model as well as the modified Q-learning with a "viscosity" element that regulates dominance of the Pavlovian conditioning over instrumental learning. Performance of the model was evaluated in the following three aspects: 1) acquisition of the avoidance response indexed by d′ which represents the difference between the rate of hit over false alarm, 2) the rate of correct response following an incorrect response (E+1) 3) changes in d′ and E+1 as a function of viscosity. We found that changing the viscosity element modulates the acquisition of the appropriate avoidance response in a way that closely resembles behavioral data following a damage in certain brain areas.

[A2]

# Emotion and Emotion Regulation

Sang Hee Kim

*Department of Brain and Cognitive Engineering, Korea University*

People regulate their emotional responses to a variety of situations. This ability to alter one's emotion in line with cognitive goals is referred to as emotion regulation. Various methods have been proposed to be effective in altering emotions. Most research to date, however, has focused on conscious forms of emotion regulation. Recently there has been increasing attention to unconscious forms of emotion regulation. Unconscious emotion regulation can be broadly defined as any process that alters the quality, intensity and duration of emotions without conscious intention or intervention. Because emotions are fast processes, unconscious and automatic forms of emotion regulation would be more efficient than conscious and effortful forms of regulation. The first part of this talk will present a brief overview of the construct of emotion and emotion regulation, followed by neural and cognitive mechanisms that are associated with these processes. Next I will present a set of recent work from my laboratory designed to examine neural and behavioral consequences of unconscious forms of emotion regulation. Finally discussion will be made on the dual-process model of emotion regulation.

[A3]

# Incremental Emotion Understanding in a Movie Clip

Minho Lee

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In this talk, I introduce a novel emotion recognition system, which can derive human-like emotions by autonomously utilizing tightly-linked action-perception loops that enable powerful possibilities for incremental learning at many system levels. To understand human emotions in a more natural situation, we use dynamic stimuli such as movies for the analysis. Since the fuzzy GIST can successfully extract low-level visual features to represent the primitive emotional gist of a natural scene, we incorporated the 3D fuzzy GIST to effectively describe the dynamic visual and audio features related to the emotional characteristics in a movie clip. Additionally, I considered electroencephalography (EEG) signals which were stimulated while watching a movie clip to form semantic emotional features. Emotions can be regarded as the complex programs of internal actions triggered by the perception of visual stimuli. Integrated analysis of EEG and visual/acoustic information using the 3D fuzzy GIST provided us with primitive dynamic features for understanding human emotions. To interpret human emotions in an interactive and continuous learning situation, the proposed system uses an incremental adaptive neuro-fuzzy inference system (ANFIS) based on fuzzy if–then rules to model human expertise and reasoning. The system further analyzes the gradually available 3D fuzzy GIST. To benefit from humans integrated ways of perceiving internal actions from external visual stimuli, we modeled the link between visual perception and physiological emotion with in an action-perception cycle to form a constrained optimization problem. The proposed system uses an evolutionary algorithm to solve the optimization problem and automatically adjust or increase the rules for clustering the features in a fuzzy domain to obtain an improved 3D fuzzy GIST. After updating the cluster centers of individual sub-systems from the tightly linked action-perception loops, the emotional descriptors from both channels are concatenated to be used as inputs in the incremental ANFIS in the next stage in order to classify a movie clip into a positive or negative emotion. Utilizing the developmental process, the system can autonomously develop the mental ability to recognize complex human emotions through interactions with the environment. The mean opinion score (MOS) is used to evaluate the performance of the proposed emotion recognition system. Experimental results support biological evidence that emotion and visual/acoustic perception are highly interactive and integrated analysis using incremental concepts improves the understanding of complex human emotions.

[A4]

# On the Origin of Functional Maps in Visual Cortex

Se-Bum Paik

*Department of Bio and Brain Engineering, KAIST*

The cortex of higher mammals is organized into various functional maps, and understanding these maps is an extremely important problem in brain studies. One of the most studied examples is orientation maps in the primary visual cortex (V1) that are responsible for processing visual information. Despite extensive studies for years, even the most fundamental features of them –such as how they are created initially –are not understood completely.

In this talk, I will show an interesting mechanism by which the functional maps in visual cortex are created –a similar way that some visual artists paint their works – and explain why the map has a structural feature such as a hexagonal lattice pattern that is often found in nature. This serves as a good example of how models from mathematics and physics can be applicable to solving the problems in complex biological systems.

**References**

Paik & Ringach, Retinal origin of orientation maps in visual cortex, Nature Neuroscience 14, 919-925 (2011) (Cover Article)

Paik & Ringach, Link between the orientation and retinotopic maps in primary visual cortex, Proceedings of the National Academy of Sciences, 109, 7091-7096 (2012)

[A5]

# Large scale multimodal brain network construction in abused children

Moo K. Chung

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We explore various computational issues of constructing large-scale whole structural brain network with more than 1000 nodes using MRI and DTI. Existing brain network models exhibit serious defects in applying to the whole brain regions due to the small-n large-p problem. Specifically, the number of nodes p is substantially larger than the number of subjects n so the often used sample covariance and correlation matrices show the rank deficiency and they are no longer positive definite. We propose to remedy the shortcomings of the small-n large-p problem by the graphical-LASSO (GLASSO), which regularizes the estimated rank deficient covariance matrix with a sparse penalty. By exploiting the hidden topological structures in GLASSO, we can substantially reduce the computation from 56 hours to mere 10 seconds. The method is applied to multimodal MRI and DTI studies in abused children. We show that the abused children exhibit consistent white matter abnormality across different imaging modalities. The talk is based on the recent study from our group
(Chung *et al.* 2013 http://www.stat.wisc.edu/~mchung/papers/chung.2013.MICCAI.pdf).
The complete MATLAB codes used in the study will be demonstrated in the talk (http://brainimaging.waisman.wisc.edu/~chung/barcodes).

[A6]

# Inhibitory Neural Network-Dependent Modulation of Neural Codes

Jeehyun Kwag

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Rate and phase codes are believed to be important in neural information processing. However, how the interneuronal network supports the generation of the two distinctive types of neural codes is yet unclear. Here, we investigated how the feedforward (FF) and feedback (FB) inhibitory network differentially modulate the spike output patterns of hippocampal CA1 pyramidal cell (PC) by studying the input-output relation in a hippocampal neural network model.

In both excitatory neural network and FB neural network, input-output relation linearly increases, while in FF network, the output frequency remained constant in the theta-frequency range (4-10 Hz) regardless of the input frequency. Temporal dynamics of spike output was further quantified by analyzing the inter-spike interval (ISI) and its coefficient of variation (CV). ISI of excitatory network and FB network showed small variation, suggesting that these two network types promote synchronization of spike output patterns. However, FF inhibitory network showed comparably variable ISI with the greatest CV among the three network conditions.

These results show that FF and FB inhibitory network differentially control spike output patterns of hippocampal CA1 PC. FB inhibitory network may support synchronization of spike outputs promoting rate coding whereas FF inhibitory network may contribute to temporal coding in the theta-frequency range, suggesting that different inhibitory connections may have different functions in hippocampal information processing.

[O1]

# Effect of Small-World Connectivity on Sparsely Synchronized Cortical Rhythms

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Fast cortical rhythms with stochastic and intermittent neural discharges have been observed in electric recordings of brain activity. For these sparsely synchronized oscillations, individual neurons fire spikings irregularly and sparsely as Geiger counters, in contrast to fully synchronized oscillations where individual neurons exhibit regular firings like clocks. We first consider random networks of fast spiking Izhikevich interneurons, and study emergence of the fully and the sparsely synchronized states in the parameter plane of the synaptic inhibition strength and the noise intensity. Fast sparsely synchronized states of relatively high degree are found to appear when both inhibition and noise are sufficiently strong. However, random networks are non-economic ones because appearance of short-range and long-range connections are equally probable. To solve the network economy problem, we investigate the effect of small-world synaptic connectivity on emergence of sparsely synchronized cortical rhythms by varying the probability $p$ of rewiring from short-range to long-range connection in the Watts-Strogatz small-world network which interpolates the regular lattice ($p$=0) and the random graph ($p$=1). When passing a small threshold $p_{th}$, sparsely synchronized population rhythms are found to emerge in small world networks with predominantly local connections and rare long-range connections. With further increase in $p$, the degree of population synchrony becomes higher, while the axon ``wire length'' of the network increases. At an optimal value $p_{op}$, there is a trade-off between the population synchronization and the wiring economy, and hence an optimal cortical rhythms showing sparse synchronization is found to occur at a minimal wiring cost in an economic small world network.

**Key words:** Sparsely-Synchronized Cortical Rhythm, Small-World Connectivity

[O2]

# Resting state dynamics of human brain from the resting state EEG

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Spontaneous human EEG during the resting state is modulating with long lasting high amplitude synchronization and very brief low amplitude de-synchronization states [1]. For the dynamic characterization of modulating alpha rhythm in the resting state EEG, we introduce a method of spontaneous-event related potential (SERP) analysis. Our method consists of three steps: At first, ensemble phase patterns of alpha rhythm at the moment of alpha de-synchronization state are classified using the K-mean clustering algorithm; Secondly, short time evolution of the phase pattern around each de-synchronization event is analyzed using the symbolic sequence dynamics; Finally, a global map of dynamic organization is constructed by integrating the temporal motifs representing the recurrent phase patterns around de-synchronization state.

Using the EEG data from seven subjects, very large number of de-synchronization event is collected from spike-like events in the time plot of inverse of alpha amplitude. The classification of the phase patterns of the de-synchronization state produces four different kinds of traveling waves, two propagating from posterior to anterior ($PA_L$ and $PA_R$) and two in reverse directions ($AP_L$ and $AP_R$) for C=8 classification. The presence of two spiral waves, one rotating in clockwise (CS) and the other in count clockwise (CCS), are also observed in addition to two standing waves ($ST_A$ and $ST_P$).

For the symbolic sequence analysis, we construct a triad symbol for each de-synchronization event. It is composed of a present pattern and its previous and next patterns, as a sequence of pre-present-post patterns. Then the occurrence rates of all possible triad symbols are compared with those of surrogate data where the sequence of all phase patterns is completely randomized. The triad symbols with very large normalized Z-score could be identified as dominant temporal motifs [2], which include the triad symbols, $ST_P$-CCS-$ST_A$, $ST_P$-CS-$ST_A$, CCS-$ST_A$-$AP_L$, and so on. We could also identify temporal anti-motifs as the triad symbols with very large negative Z-score. The anti-motifs include the triad symbols where strongly inhibited transitions like the transitions between CS and CCS, between $ST_P$ and two PA patterns, and between $SP_A$ and two AP patterns are included.

Integrating the information on the temporal motifs and anti-motifs, we could construct a global map of recurrent transition dynamic during the resting state. The global map contains the information on how the transitions among four traveling waves $PA_L$, $PA_R$, $AP_L$ and $AP_R$ occur. It is very interesting to notice the role played by the two spiral waves CS and CCS. As the motion of a spiral wave is recorded by tracing the phase singular point of a spiral wave, we observed that a traveling wave could switch its propagation as the spiral wave crosses the traveling wave in a transverse direction. This result indicates that the role of two spiral waves is to switch the propagation of traveling waves systematically.

In conclusion, using the SERP analysis of the spontaneous human EEG, we identified the recurrent phase patterns that involve the switching of traveling waves. Very interestingly, it is shown that the propagation of a traveling wave is systematically controlled by a spiral wave which drifts across the traveling wave. It is to be investigated on the function roles of the traveling waves and spiral waves, and also on the neural mechanisms of switching the propagation of the traveling waves [3] and the formation of spiral waves [4].

**Key words: s**pontaneous EEG, resting state, traveling wave, standing wave, spiral wave

## References:

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[O3]

# Noise-induced anti-correlated slow fluctuations in networks of neural populations

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Coherent spontaneous fluctuations (< 0.1Hz) in fMRI blood-oxygen-level-dependent (BOLD) signal have been observed for a resting state of the human brain [1- 4]. Functional connectivity analysis has identified clusters of brain areas exhibiting correlated fluctuations [1-4] and anti-correlation relationship between task-positive and task-negative areas [2-4]. In this study, we propose a model explaining the generation of slow fluctuations and the organization of the clusters. Based on the slowness and the anti-correlation relationship, we describe the brain as a network of neural populations which act as brain areas and prefer one of the two states, UP (active) state and DOWN (quiescent) state [5], and consider excitation-inducing or inhibition-inducing connections between brain areas. Without noise, this system can have multiple stable states in which each area can be in UP, DOWN, or intermediate state. Presence of noise can make the system slowly move from one stable state to other and this is manifested as organized slow fluctuations. We implement this mechanism using a Wilson-Cowan model [6, 7] with excitatory and inhibitory neurons constituting the neural populations. The neural activity is translated into BOLD signal through the Balloon-Windkessel hemodynamic model [8, 9]. With various networks with 2, 3, and 4 nodes, we show that the system without noise can have multiple stable states which are fixed points, and observe slow fluctuations and various organization including anti-correlated clusters. Similar behaviors are observed in the cases with random networks and modular networks. We analyze the functional connectivity in connection with the underlying networks.

**Key words: Wilson-cowan model, Resting state network, BOLD signals**

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[O4]

# Numerical Methods for Diffuse Optical Tomography

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Diffuse optical tomography(DOT) is to find optical coefficients such as the absorption and scattering coefficients from many pairs of light measurements due to a singular sources. One of application areas could be functional neuroimaging modality. Compared to fMRI and PET, DOT is cheap, portable, and has a better time resolution. Compared to EEG, the analysis is rather simpler. The numerical methods for DOT have two approaches: one is finite element method based nonlinear minimization method and the other is analytical solution based linearized DOT. These two numerical methods are surveyed. In these methods, the derivative of the operator mapping the optical coefficients function space to the photon density distribution. The derivatives (or n-th derivative) are reported to be closely related with first order (or n-th order) term in Born expansion [1]. The numerical method for the second-order Born approximation is suggested [2]. Another neurological and medical examples of DOT and nearinfrared spectroscopy can be found in [3].

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[P01]

# Neurovascular coupling via interactions of NO, EET, and 20-HETE

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In many experiments, it has been discovered that neuron and astrocyte regulates the brain blood flow via the generated vasoactive agents from them [1]. Usually, vasoactive agents are directly generated from neuron and astrocyte. Those vasoactive agents dilate or contract the blood vessel via action on its smooth muscle cells, and there are several kinds of them: NO, EET, prostaglandin, 20-HETE, and so on. But vasoactive agents have no additive effect. For example, although NO inhibitor is added to the blood with EET inhibitor, the inhibition effect shows no increase. In addition, NO sometimes inhibits the effects of EET or 20-HETE.

In this study, we propose the multi-compartment model, which consists of neuron, astrocyte, and vessel. It is described by the following sequence: 1) the activated presynaptic neuron triggers glutamate release, 2) the glutamate binds to the metabotropic receptor of astrocyte or NMDA receptor of postsynaptic neuron, 3) the bounded glutamate increases the calcium concentration in both astrocyte and neuron, 4) the calcium concentration increase creates arachidonic acid in astrocyte and NO in neuron, 5) the arachidonic acid is metabolized to transform EET or 20-HETE, which are inhibited partly by NO, 6) EET increase the $K^+$ channel conductance of smooth muscle cell (SMC), 7) 20-HETE decreases the $K^+$ channel conductance of SMC, 8) SMC is hyperpolarized via the outward $K^+$ influx, 9) voltage-dependent $Ca^{2+}$ channel of SMC is deactivated, and $Ca^{2+}$ concentration decreases, 10) the contraction force of SMC decreases, so that vessel dilates. From the mathematical model, we obtain the simulation results for the direct effect of neuronal derived NO, the inhibition of 20-HETE by NO, the interaction of EET, and their corresponding vessel response, as an expansion of the EET generation model in Bennet's study [2].

**Key words:** Neurovascular coupling,

**References:**

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[P02]

# Functional Brain Mapping using Neural Oscillation Synchronized by Speech

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Upon aiming to establish a normative system for brain mapping of language function and to apply this system to a later encoding interface, we investigated whether speech reflects synchrony with brain oscillation depending on intelligibility. The most recent achievement in this area was obtained using an electrocorticography (ECoG) from patients [1]. We acquired data using a Magnetoencephalography system from healthy volunteers while speech sound was presented in either intelligible or unintelligible manner. We first looked at the synchrony focused on the aspect of amplitude modulation of speech extracting the envelope of a speech sound, which is an auditory feature essential for speech understanding [2]. Synchrony was then measured using mutual information (MI). The brain oscillation that best synchronises with the intelligible speech was found in the lower frequency bands (theta and alpha). We further observed the highest MI in the left temporal sensors, especially in the early (50 msec post onset) and later (400 msec post onset) time window. Unintelligible speech did not show any meaningful synchrony with brain signal.

**Key words:** Brain oscillation, Speech intelligibility, Mutual information, Magnetoencephalography.

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[P03]

# Information Flow of Transition between REM and NREM For Sleep Disorders

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In sleep disorders such as nocturnal frontal lobe epilepsy(NFLE) or periodic limb movement disorder(PLMD), recent studies suggest that they have sleep stage disturbance compared to normal sleep. In this view, we focused especially on REM(Rapid Eye Movement) - NREM state transition and observed the functional brain network topology difference in this transition. The functional networks are constructed by phase synchronization and symbolic transfer entropy derived from electroencephalogram(EEG) signals with 5 channels and 512 Hz sampling rates. Subjects are NFLE(n=6) and PLMD(n=4) patients. 4 states are defined by pre-REM which is 5 minutes before REM, start-REM that during 5 minutes after REM starts, end-REM(during 5 minutes before REM ends) and post-REM which is during 5 minutes after REM ends. We observed that network topology and transition property differences between sleep disorder patients in all frequency bands. We suggest that different directed functional network topology and their alteration on REM-NREM transition correspond to fundamental circuitary of different sleep disorders, and could be used as one of the neural correlates.

**Key words:** REM, NREM, transition, sleep disorder, information flow

**References:**

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[P04]

# Topographical changes of theta and gamma rhythms during REM sleep in chronically sleep restricted mice

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## Background

Theta and gamma rhythms during natural REM sleep have been observed in associated with high cognitive functions. In order to investigate the modulation factors of the gamma rhythms during REM sleep, we apply chronic sleep deprivation experiment, which is reported to impair cognitive function in previous sleep research, to mouse model. Particularly, the influences of chronic sleep deprivation on gamma power during REM sleep are investigated using spectral topographical analysis.

## Methodology

Mice were sleep deprived by being caged in a rotating wheel, which rotate three seconds every seven seconds for 18 hours a day. Using recently developed 40 channel microarray, electroencephalography (EEG) was acquired during baseline (BL), five successive sleep restricted days (SR), and three successive recovery (R) days. We tracked basic sleep architectural changes: occurrence, duration and total sleep time of REM sleep. Then, we calculated the EEG power averaged by each day and each channel in theta (5–10 Hz) and gamma (30–50 Hz) band using MATLAB.

## Principal Findings

Total REM sleep time increased significantly in SR1 and SR3, but not in SR5 compared with BL, where the episode duration of REM sleep significantly increased in SR3 and SR5 ($p<0.05$, paired t-test). In chronically sleep deprived condition, the increase of gamma power was observed mostly in the frontal cortex. Interestingly, this increase of gamma power in the frontal lobe was not observed in the acutely sleep deprived brain, *i.e.*, in SR1 ($p<0.05$, paired t-test). The topographic analysis of theta showed that theta power significantly increased both in frontal and parietal cortex in SR1 ($p<0.05$, paired t-test); however the increase of theta power in the parietal cortex returned to the level of natural sleep from SR3 and theta in the frontal cortex returned to the baseline level in SR5. After cessation of sleep restriction, *i.e.*, in R1 and R3, theta and gamma powers were the same level of natural sleep.

## Conclusion

In this study, we found that EEG gamma power changed topologically along with chronic sleep deprivation condition. Although the functional roles of gamma power during REM sleep are fully understood, our observations suggest that increase of gamma power in the frontal cortex may reflect impaired cognitive consequences or restorative brain function induced by CSR.

**Key words:** REM, Gamma oscillation, Sleep deprivation

[P05]

# The Theory of Predictive Homeostasis May Explain the Properties of A-type Potassium Channels

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A large diversity of potassium (K+) channels maintain a homeostatic level of neural excitability by counteracting excitation. It has been proposed that their properties may be optimized to effectively predict and counteract synaptic excitation through a process of "predictive homeostasis" [1]. This would allow a neuron to accurately predict its synaptic input and to generate an output corresponding to prediction error. Prediction errors have been observed in a wide variety of neurons and are an efficient means of communication. The theory suggests that the kinetic properties of a particular type of K+ channel function to recognize and counteract a specific and statistically common temporal pattern in a neuron's synaptic excitation. The amplitude and time course of an excitatory postsynaptic potential (EPSP) may be a common pattern in many types of neurons, whether it is caused by a single powerful synapse in some neurons, or in other neurons by spatial integration over multiple synapses with nearly synchronous synaptic activity. There is experimental evidence that EPSCs are often followed at short latency (~2 ms) by IPSCs that substantially counteract synaptic excitation and can cause a subsequent decrease in excitability below its homeostatic baseline (according to theory, these IPSCs also provide a mechanism of predictive homeostasis). We have formulated the hypothesis that rapid (~0.5 ms) activation of A-type K+ channels during the rising phase of EPSPs counteracts the increase in excitability, and the rapid inactivation (~3 ms) counteracts the subsequent decrease in excitability below its homeostatic baseline. Without inactivation, the combination of A-type inhibition with inhibitory synaptic conductance would render the neuron's spike output insensitive to synaptic excitation. To test this hypothesis, we have performed NEURON simulations of a thalamocortical neuron in lateral geniculate nucleus and a pyramidal neuron in CA1 of hippocampus. We found that the experimentally measured rate of inactivation of A-type channels is nearly optimal for minimizing deviations in excitability during EPSPs consisting of naturally occurring EPSC-IPSC sequences. This supports our specific hypothesis that A-type K+ channels predict and counteract synaptic excitation, as well as a more general theory of the role of K+ channels in making predictions based upon natural temporal patterns.

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**Key words:** NEURAL CODING, COMPUTATIONAL MODEL, INFORMATION THEORY

**References:**

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[P06]

# Spiking Dynamics in Heterogeneous Clustered Neural Network

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It has been known that the anatomical network in cortex is characterized by the properties of inhomogeneous connection between nodes like small-world, scale-free network. We studied the effect of structurally inhomogeneous connection properties on the spiking dynamics of clustered network. From the neural network model with clustered scale-free network, we found that each cluster exhibit the different firing rate fluctuations and spiking time variability due to the inhomogeneous properties. We also check the firing rate fluctuations of each cluster through simplified model. Thus, the hub clusters in scale-free network exhibit more frequent transition and variability in the spiking dynamics than periphery ones. We hope that our model can help understand the relationship between the underlying structure and spontaneous brain activity.

**Key words:** Spiking variability, Inhomogeneous connection, Neural network model

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[P07]

# Revealing Connectional Plasticity of the Brain Network Enables Identification of Neuropathic Pain Animal

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## Abstract

Pain is a multidimensional experience emerging from the flow of information in the brain. It is reasonable, therefore, to understand pathological pain in terms of connectional plasticity of the brain network. Understanding altered patterns of the brain network in pathological pain would give an opportunity to evaluate subjective pain disorders in an objective manner. Here, we hypothesized that neuropathic pain alters functional connectivity pattern of the resting-state brain and this enables identification of the brain with neuropathic pain. We acquired fluorodeoxyglucose micro positron emission tomography (FDG micro PET) images in awake rats with spinal nerve ligation (SNL) (SNL group, n = 13; sham group, n = 10). Resting-state brain networks were constructed using our algorithm that defines the node set representing the whole brain. Graph theoretical analyses revealed SNL resulted in decreased small-worldness and more fragmented modular structure compared to sham group. Connectivity pattern analyses showed the regions in the brainstem, sensorimotor cortex, and some of the prefrontal cortex became highly connected following SNL, whereas the cerebellum and some prefrontal regions showed decreased connections. In addition, we found close relationships between characteristics of connectivity and metabolic changes. Based on our findings, we performed connectivity pattern-based classification of SNL (accuracy of 91.30 %). Our findings suggest that pathological pain is associated with connectional plasticity of the resting-state brain and this enables identification of the brain with pain disorders.

**Key words:** neuropathic pain, micro PET, brain network, connectivity pattern, classification

[P08]

# Analysis of spatio-temporal network dynamics in the brain: in vivo two-photon imaging study

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## Abstract

Neuronal systems are complicated dynamical systems. Neurons influence one another, forming complex patterns of the networks, and change their patterns dynamically over time. Therefore, in order to elucidate how the neuronal systems operate, the spatio-temporal network of the neurons should be understood.

In vivo two-photon calcium imaging provides an opportunity of investigating the dynamics of the spatio-temporal network at a single cell resolution by allowing measuring the activity of multiple cells simultaneously. Here, we performed two-photon calcium imaging in the primary somatosensory cortex and the cerebellum using anesthetized mice. Cells were imaged either with Oregon BAPTA-1 (OGB-1) or by inducing the expression of G-CaMP3. Preprocessed calcium signals were constructed into the spatio-temporal networks by employing sliding-window analysis. Network dynamics of the spontaneous activity were explored with regard to the physical location of the cells using network dynamics movie. In order to explore the dynamics of the neural networks in low dimensional space, we applied principle component analysis (PCA) to connectivity matrix of the spatio-temporal network, projecting the population activity onto a new state space.

**Key words:** spatio-temporal network, in vivo two-photon imaging, dynamics

[P09]

# Gamma band oscillation deficits for auditory steady state responses in mice lacking phospholipase C beta 1

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## Background:

Several studies have shown that in schizophrenia patients, the gamma band oscillations (GBO) elicited by auditory steady state stimulation (ASSS) is significantly lower compared to healthy control subjects. Recently, mice lacking phospholipase beta C 1 (PLCβ1) was suggested as a mouse model for schizophrenia, evidenced by its behavior phenotype of schizophrenia patients. Hereby, we test the GBO during ASSS in PLCβ1.

## Methods:

Bilateral electroencephalogram (EEG) and bilateral local field potential (LFP) were recorded from frontal and auditory cortex, respectively, in four PLC β1 knock-out and five wild type mice while they are exposed to auditory steady state stimulation with frequency range from 20 to 50 Hz at 10 Hz interval. Mean power at each stimulation frequency was calculated and temporal spectral analysis was performed.

## Principal Findings:

We observed that PLCβ1 knockout mice showed reduced gamma power at 40 Hz in frontal cortex compared to wild type mice, No disruption of evoked responses was observed in other stimulation frequencies.

## Conclusions:

These findings provide an insight into neural network deficits in cortical processing in PLCβ1 knockout mice and also provides a novel electrophysiological information for characterization of animal models of schizophrenia disease.

[P10]

# Frequency Dependent Transfer Functions of Optogenetically Evoked Oscillations in the Somatosensory-Motor System

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## Background

Previous tactile stimulation research has revealed that the frequencies of vibrotactile stimuli to the skin are delivered to the somatosensory cortex, coding the perceptual discrimination or integrating the tactile information. In numerous animal studies, the neural activities dependent on stimulation frequency were observed in the brain; however, how this frequency dependent information is transferred within the somatosensory-related system is not known. Hereby, we characterize the signal transfer within somatosensory-motor system by acquiring the electroencephalogram (EEG) of mice under optogenetic stimulation, and attempt to define the transfer functions of somatosensory signals in spatial, temporal, and frequency domains.

## Method

Recently developed microarray for 40-channel EEG was applied to lightly anesthetized mice. The brain regions of primary somatosensory cortex (S1), secondary somatosensory cortex (S2), primary motor cortex (M1), and sensory thalamus (VPM) of B6 Thy1-ChR2-EYFP transgenic mice were stimulated individually using 473 nm laser at five different frequencies ranging from 10 to 50 Hz at 10 Hz interval. The region of stimulation was concurrently measured by local field potential (LPF).

## Principal Findings

Both LFP at the stimulation location and cortical EEG showed their maximal responses to gamma band (30 – 40 Hz) stimulation in all the regions. The signal transfer in terms of distance from the stimulation location shows its maximal efficiency in the beta band (20 – 30 Hz). Transfer functions of optogenetically evoked oscillation were derived by quantifying the intensity distribution of LFP and EEG in spatial, temporal, and frequency domains.

## Implication

Transfer function within somatosensory-motor system will contribute to reveal the mechanism underlying how the brain decode frequency information and encode into tactile perception, eventually

integrated to higher cognition functions, such as texture recognition, tactile exploration and memory.

**Key words:** Transfer function, Somatosensory system, Optogenetics, High density EEG

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[P11]

# Coherence change in decision making point between PFC & Hippocampus

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In this study, we made the behavior experiment paradigms to predict when mouse decides the direction using the brain signals. It is well known that relation between prefrontal cortex and hippocampus has a great effect of the decision of animals. So we designed that T-maze system in order to make mouse decide the direction to go left or right. We measure the brain signals at prefrontal cortex and hippocampus of cue induced moving mouse. We observed that theta coherence between PFC (prefrontal cortex) and hippocampus change significantly at decision making point for rat studies. Also we found that gamma coherence between PFC and hippocampus increases before decision making point and sharply decrease after mouse deciding at the point. Our results indicate that the modulation of the brain signals between PFC and hippocampus can be used to predict the decision of mouse. We hope that our result could apply to brain-to-interface machine.

**Key words:** Coherence change, Decision making

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[P12]

# Pulse Shape Effect on Evoking Retinal Ganglion Cell (RGC) Responses in *rd1* Retina with Epiretinal Stimulation

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Retinal prosthesis has been developed for the patients with retinitis pigmentosa (RP) and age related macular degeneration (AMD), and is regarded as the most feasible method to restore vision. Extracting optimal electrical stimulation parameters for the retinal prosthesis is one of the most important elements. In our previous study, we compared efficiency of symmetric and asymmetric pulse and also we compared polarity effect on evoking RGC responses in retinal degenerated (*rd1*) mice. Not many studies have been performed with different pulse shapes. Therefore, here, we used rectangle, triangle, and ramp pulse and we investigated pulse shape effect on evoking RGC responses. The well-known animal model for RP, *rd1 (Pde6b$^{rd1}$)* mice at postnatal 8 ~ 9 weeks were used. From the *ex-vivo* retinal preparation (n=19), retinal patches were placed ganglion cell layer down onto 8 × 8 MEA and RGC responses were recorded while applying electrical stimuli (epiretinal stimulation configuration). All pulses were charge balanced, biphasic, cathodic phase-1$^{st}$ current pulses with 3 different shapes with same charge of rectangle pulse; 1) biphasic rectangle pulse (I: intensity, D: duration), 2) biphasic triangle pulse with double intensity (2xI, D) or double duration (I, 2xD) 3) (linear decrease or linear increase) ramp pulse (2xI). For intensity (or duration) modulation, duration (or amplitude) of the pulse was fixed to 500 μs (30 μA), changing the intensities (or duration) from 2 to 60 μA, 60 to 1000 μs. Fifty identical pulses were applied with 1 Hz frequency. The electrically-evoked RGC spikes response was defined as positive when the number of RGC spikes for 400 ms after stimulus was 30 % increase than spontaneous RGC spikes. Statistical significance was analyzed by ANOVA ($p<0.05$). RGC responses were well modulated with rectangle, triangle, and ramp pulse regardless of amplitude or duration modulation. In amplitude modulation, triangle pulse with double duration (I, 2xD) is more efficient than rectangle and triangle pulse with double intensity at I = 5 A, 10 A. In duration modulation, triangle pulse with double duration (I, 2xD) is the most efficient pulse shape on evoking RGC spikes with D = 60 μs, 100 μs pulse duration, but with 200 μs pulse duration, triangle pulse with double intensity (2xI, D) is the most efficient pulse shape, and 2$^{nd}$ efficient pulse shape is triangle

pulse with double duration (I, 2xD). In comparison with rectangle pulse and ramp pulse, linear increase ramp pulse (2xI) is the most efficient pulse shape among rectangle, linear increase ramp, and linear decrease ramp pulse at I = 5 A, 10 A amplitude while at 40 A and 50 A amplitude, rectangle pulse is the most efficient.

**Keywords**: retinal ganglion cell, *rd1* mice, biphasic current pulse, epiretinal stimulation

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[P13]

# Detrended Fluctuation Analysis and Kolmogorov-Sinai Entropy of EEG Signals

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We have measured the electroencephalogram (EEG) of young high school students in the relaxed state and in the state of the mathematical activities. We applied two methods of the nonlinear dynamics to the EEG signals; the detrended fluctuation analysis (DFA) and the Kolmogorov-Sinai entropy (KSE). We found that the EEG signals show the persistent behaviors in the two state. The Hurst exponents increased in the state of the mathematical activities. The KSEs in the relaxed state are larger than those in the state of the mathematical activities. The entropy is enhanced in the disorder state of the brain [1]

**Key words:** EEG, Brain, Detrended Fluctuation Analysis, Entropy.

**References:**

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[P14]

# Self-Organized Criticality in a Simple Neural Model

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We consider a simple integrate-and-fire neural model without synaptic plasticity. In this model, the membrane potential propagates to the nearest neighbor neurons when that potential is greater than a threshold value. When a neuron is fired, the propagating potential is leaky. Therefore, the sum of the received potential is less than the presynaptic potential. We simulated this simple model on a fully-connected network. We identified the critical membrane strength, $J_c = 4.71(1)$. At the critical membrane strength, we observed that the probability distribution function of the avalanche shows a power law, $P(s) \approx s^{-\tau}$, with the critical exponent $\tau = 1.414(5)$. The lifetime of the avalanche also showed a power law. The power law behaviors imply that this model shows self-organized criticality. We also consider the avalanche dynamics on the random network and the small-world networks.

**Key words:** Self-organized criticality, Avalanche, Neural model.

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[P15]

# Classification of Various Mental Task Combinations for functional NIRS-based Brain-Computer Interface

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The goal of this study was to investigate the most suitable combinations of mental tasks for the development of practical near-infrared spectroscopy (NIRS)-based brain-computer interface (BCI) systems. To this end, we recorded concentration changes of oxygenated [oxy-Hb] and deoxygenated [deoxy-Hb] hemoglobins while seven participants were performing eight different mental tasks; left hand motor imagery, right hand motor imagery, foot motor imagery, internal singing, mental subtraction, mental multiplication, geometric figure rotation, mental character writing. Four different feature sets were extracted from the recorded NIRS signals ([oxy-Hb], [deoxy-Hb], [total-Hb], and a combination of [oxy-Hb] and [deoxy-Hb]), and classification accuracies were estimated for all possible pairs of the eight mental tasks (8C2 = 28). Linear discriminant analysis with a 10x10 cross-validation method was used for evaluating classification accuracy. As a result, three mental tasks, right hand motor imagery, mental multiplication, and geometric figure rotation, were mostly selected in mental task combinations showing accuracy high enough for practical communication (> 70 %). In particular, a combination of right hand motor imagery and geometric figure rotation task only showed high classification accuracy over 70 % on average, when using the feature set of the combination of [oxy-Hb] and [deoxy-Hb]. From the results, it was confirmed that the combination of right hand motor imagery and geometric figure rotation task can be a promising candidate task for a practical NIRS-based BCI system.

**Key words:** Near-Infrared Spectroscopy (NIRS), Brain-Computer Interface (BCI), mental tasks

[P16]

# A functional NIRS-based Brain-Computer Interface for the Classification of Covert 'Yes' and 'No' Intentions

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Functional near-infrared spectroscopy (fNIRS) has become one of the most promising neuroimaging modalities in recent brain-computer interface (BCI) research. The goal of this study was to decode fNIRS signals to classify participants' covert 'yes' and 'no' intentions for the development of a practical fNIRS-based BCI system. Eight healthy participants took part in this study. They were asked to internally answer to simple seventy 'yes/no' questions (e.g., Are you thirsty?), during which we recorded concentration changes of oxygenated [oxy-Hb] and deoxygenated [deoxy-Hb] hemoglobins using NIRS optodes attached on the participant's scalp. To extract features for classification, common spatial pattern (CSP) was applied to the raw [oxy-Hb] and [deoxy-Hb] data, and then the original data were transformed into new time series with distinct spatial patterns. The variances of the converted [oxy-Hb] and [deoxy-Hb] data were used as features, and the classification accuracy was estimated for each of the [oxy-Hb] and [deoxy-Hb] data. As a result, high classification accuracy over 80 % could be obtained even when only 5 s analysis window was used ([oxy-Hb]: 82.42 %, 84.13 % and 83.39 % for 5 s, 7.5 s and 10 s; [deoxy-Hb]: 81.74 %, 85.52 %, 84.73 % for 5 s, 7.5 s and 10 s), demonstrating that fNIRS could be used to discriminate covert 'yes/no' intentions with high accuracy. It is expected that the proposed paradigm would be used as a binary communication system for those who are in completely locked-in state (CLIS) or minimally conscious state (MCS).

**Key words:** Near-Infrared Spectroscopy (NIRS), Brain-Computer Interface (BCI), yes/no intentions

[P17]

# Localization of MEG pathologic gamma oscillations in adult epilepsy patients with focal cortical dysplasia

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Evaluate the clinical value of pathologic gamma oscillations (PGO) in noninvasive MEG for intractable neocortical epilepsy patients with cortical dysplasia by comparing PGO and interictal spike events. A retrospective analysis of MEG recordings of 30 adult neocortical epilepsy patients. PGO (30-70 Hz) and interictal spikes were separately identified, their independent or concurrent presence determined, and their source localization rates compared. Of 30 patients, PGO were detected in 28 patients and interictal spikes in 24 patients. PGO alone appeared in 5 patients, interictal spikes alone in 1 patient, and no events in 1 patient. PGO co-occurred with interictal spikes in 20.1 ± 22.1% and interictal spikes co-occurred with PGO in 15.0 ± 19.2%. Rates of event localization within the resection cavity were significantly different ($p$ = 0.029) between PGO (63.3 ± 32.6%) and interictal spike (45.6 ± 41.6%) events. In 4 of the 5 PGO-only patients the mean localization rate was 42.5%. Compared with the interictal spike localization rate, 4 of 9 seizure-free patients had higher PGO localization rates, 4 had the same rate, and 1 had a lower rate. Individual PGO events can be detected regardless of interictal spike presence. PGO can be localized to the resection cavity at least comparably to or more frequently than that from interictal spikes. Even when interictal spikes were undetected, PGO sources were localized to the resection cavity. PGO may be a useful indicator of epileptogenic focus.

**Key words:** Pathologic gamma oscillation, Magnetoencephalography, Interictal spike, Focal cortical dysplasia

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[P18]

# Frontal abnormality in patients with restless legs syndrome during a visual oddball task: a LORETA study

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Restless legs syndrome (RLS) Patients is sensorimotor neurologic disorder characterized by an irresistible urge to move one's body to stop uncomfortable or odd sensations. It has been reported that RLS patients show cognitive deficits [1], however, the mechanism is mostly unknown. To clarify this, we investigated the differences in neural activity between RLS patients and healthy controls during a visual oddball task.

17 female drug-naïve RLS patients and 13 age-matched healthy females were enrolled in this study. Multichannel event-related potentials (ERPs) were recorded during the task performance. In addition to conventional ERP analysis, the ERP sources were localized using low resolution electromagnetic tomography (LORETA).

Significantly reduced and delayed P300 were observed in RLS patients. At this period, RLS patients showed significantly reduced current source densities at parahippocampal gyrus and medial frontal gyrus compared to healthy controls. Our results support that cognitive dysfunction in RLS patients could be associated with the functional deficit in frontal lobe.

**Key words:** Restless legs syndrome (RLS), Cognitive dysfunction, Frontal abnormality, event-related potential (ERP), Low resolution electromagnetic tomography (LORETA)

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[P19]

# Estimation of inter-modular connectivity from inverse coherence matrix in a hierarchical modular network

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We propose a method of estimating inter-modular connectivity in a hierarchical modular network from multivariate time series of local field potentials representing modular activities. In a hierarchical modular network composed of nonlinear oscillators, the local field potentials are computed from a subset of oscillators belonging to each module. It is shown that the inverse coherence matrix element for a pair of module grows in proportion to the inter-modular connectivity defined as the number of links connecting two modules. Strong linear correlation between the inter-modular connectivity and the inverse coherence matrix elements justifies experimental efforts to estimate the inter-modular connectivity from the measurement of the local field potentials in various biological systems. It should be noted that the strong dependence is still preserved when the scope of oscillators in a module covered by a local field potential is quite limited. The length of time series for the estimation of the inter-modular connectivity is much shorter than that of individual nodes.

**Key words:** hierarchical modular network, inverse coherence matrix, nonlinear oscillator, local field potential

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# Decoding of covert yes/no intentions based on single-trial EEG analysis

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In this study, we investigated whether intentions can be identified or 'decoded' from non-invasive electroencephalogram (EEG). In particular, we tried to decode whether a subject's covert answer was 'yes' or 'no' in response to simple self-referential questions using single-trial EEG waveforms.

16 healthy subjects were required to answer covertly 'yes' or 'no' in response to the questions on their identities without any behavioral response. The questions were visually presented so that each word of a sentence appeared sequentially on computer screen one at a time. All subjects were requested to respond by judging 'yes' or 'no' in response to the critical word of each sentence, such as first name, last name, and age, when the 'respond' sign appeared. Multichannel EEGs were recorded during the task performance.

EEGs during two seconds after the critical word onset were segmented and normalized event-related spectral perturbation (ERSP) maps were constructed. The single-trial ERSP maps were divided into time-frequency (TF) windows with different sizes considering the period of each frequency band. TF windows showing significant power differences between 'yes' and 'no' were found by statistical comparison. The averaged powers within such TF windows were selected to construct feature vectors for pattern classification. Quadratic support vector machine (SVM) was used as a pattern classifier along with dimensionality reduction by non-parametric discriminant analysis (NDA).

Theta-, alpha-, beta- and gamma-band powers were significantly different between 'yes' and 'no' in many TF windows. The differences were observed commonly in 600–800 ms epochs after critical word onset, corresponding to the interval of holding the intention in memory, where stronger gamma- and weaker theta-, alpha- and beta-powers were found for 'yes' than 'no'. By cross-validation, the trained pattern classifier showed classification accuracy as high as 98%. Our findings indicate that intentions regarding binary decision in response to self-referential question can be decoded from scalp EEG.

**Key words:** Intention Decoding, Yes/no intention, Pattern classification, Electroencephalogram (EEG)

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# Functional modular organizations and morphometric alteration as a function of temperament dimensions: Novelty seeking and harm avoidance

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Novelty seeking (NS) and harm avoidance (HA) are two major dimensions of temperament in the Cloninger's neurobiological model of personality. The temperament dimensions were originally proposed to be independent of on another. However, a meta-analysis based on 16 published articles found the significant negative correlation between HA and NS (Miettunen et al., 2008). Previous neuro-functional and biological studies on temperament dimensions of HA and NS suggested that the temperament traits have significant correlations in cortical and subcortical brain regions. However, no study has investigated the functional network modular organization as a function of the temperament dimension. This study found the whole-brain connectivity modular architecture for two opposite temperament groups. The *k*-means clustering algorithm, with HA and NS of temperament traits as input, was applied to divide the 40 subjects into two temperament groups: High HA and low NS vs. low HA and high NS. Using the graph theoretical framework, we found a functional segregation of whole brain network architectures derived from resting-state functional MRI. In the 'high HA and low NS' group, the regulatory brain region, such as the prefrontal cortex (PFC), was clustered together with the limbic system. In the 'low HA and high NS' group, however, brain regions lying on the dopaminergic pathways, such as the PFC and basal ganglia, are partitioned together. These findings suggest that the neural basis of inhibited, passive, and inactive behaviors in the 'high HA and low NS' group was derived from the increased network associations between the PFC and limbic clusters. In addition, this study suggests that the existence of a relationship between the morphometry and function of the brain by correlating the volume of the limbic area and the functional connectivity density between the PFC and limbic clusters.

**Key words:** Temperament, Functional network modular organization, Voxel-based morphometry, harm avoidance, novelty seeking

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# Information transfer through decoding human affective states from EEG

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Many affective studies have investigated signatures of affects typically in peripheral nervous systems such as heart rate, skin conductance, body temperature or other associated behavioral dynamics. Yet, recent advances in the neurotechnology have provided novel approaches to finding affective states in humans from neurophysiologic features. [1] One of the major vehicles to tap neurophysiologic properties has been measuring electroencephalography (EEG) directly from the human brain providing non-invasive and efficient means to observe the dynamic patterns of brain activity. While there remain many challenges to overcome to have this EEG-based affective system reliably used outside the laboratory, a number of studies have shown a feasibility of detecting affective state changes by retrieving relevant information from EEG.[2] In this study, we performed how much information can be extracted from EEG with respect to human affective states. Specifically, we examined a heuristic hypothesis that more information of affective states would be available with more EEG electrodes (i.e. more EEG signal channels). We used an information-theoretic approach based on Hick's law to address this hypothesis by investigating a relationship between the amount of information and the number of EEG channels. To this end, we performed a simple Meta analysis by reviewing a number of previous EEG studies on decoding affective states in humans. The result showed that there was no significant correlation between the amount of extracted information and the number of EEG channels. We also observed that the amount of information transferred through the decoding process of EEG was 0.2-1.2 bits with three to sixty four channels. It indicates that it may be possible to obtain useful information about human affective states using only a small number of EEG channels, which would be beneficial to develop a commercial EEG system for affective human-computer interfaces.

**Key words:** Trend analysis, Hick's law, Information theory, Emotion classification

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