Alpha Oscillation Tuning is Spatially Specific in Human Visual Cortex

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The alpha oscillation (8–13 Hz) is a pronounced neuronal signal measured from the human occipital lobe. Alpha oscillations are thought to reflect cognitive functions including attention and alertness, and to be synchronized across a large cortical extent. However, there is some evidence that suppression of alpha oscillations in visual cortex can be spatially specific [1-3]. Here, we used intracranial electrodes (ECoG) to measure alpha oscillations in visual cortex of nine human subjects. Subjects viewed contrast patterns masked by an aperture at different visual field locations. To quantify the alpha oscillation, we used a model to separate an oscillatory component from a non-oscillatory component (broadband) that overlap in the alpha range. This model-based estimation was essential because power in the alpha band reflects both signals, and the two signals tend to oppose one another. A simple measure of alpha power that does not remove the broadband signal would incorrectly quantify the alpha rhythm.

We find that for a given electrode, alpha oscillations were suppressed only when stimuli appeared in specific regions of the visual field. We fit a 2D Gaussian population receptive field (pRF) model [4,5] to the alpha response amplitudes as a function of stimulus position, and compared the solutions to pRF models fit to broadband responses measured from the same electrodes at higher frequencies (70-180 Hz). We find that the pRF centers are highly similar between the two measures, but that the alpha pRFs are several times larger. The results demonstrate that alpha suppression in human visual cortex is spatially tuned and is in agreement with the underlying retinotopic map.

Our findings support the possibility that the alpha suppression reflects part of the computations in generating neural responses to visual stimulation. We speculate that suppression of alpha oscillations to stimuli within or near the receptive field of a patch of cortex increases the responsivity of that cortical location, consistent with psychophysically measured benefits of attentional cueing.

References

[1] Samaha, J., et al. (2016). "Decoding and Reconstructing the Focus of Spatial Attention from the Topography of Alpha-band Oscillations." J Cogn Neurosci 28(8): 1090-1097.
[2] Foster, J. J., et al. (2017). "Alpha-Band Oscillations Enable Spatially and Temporally Resolved Tracking of Covert Spatial Attention." Psychol Sci 28(7): 929-941.
[3] Popov, T., et al. (2019). "Spatial specificity of alpha oscillations in the human visual system." Human Brain Mapping 40(15): 4432-4440.
[4] Dumoulin, S. O. and B. A. Wandell (2008). "Population receptive field estimates in human visual cortex." Neuroimage 39(2): 647-660.
[5] Winawer, J., et al. (2013). "Asynchronous broadband signals are the principal source of the BOLD response in human visual cortex." Curr Biol 23(13): 1145-1153.

Somatotopic reorganization of the sensorimotor cortex in Japanese macaques after accidental arm amputation

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The primary motor (M1) and primary somatosensory (S1) cortices show a somatotopic representation, which is a one-to-one correspondence of each body part to a small region of these cortices. The M1 is located in the pre-central gyrus including the anterior bank of the central sulcus (CS), while the S1 is located in the post-central gyrus. The hindlimb, body trunk, forelimb, and orofacial regions are represented in the M1 and S1 mediolaterally along the CS. The supplementary motor area (SMA), which is located in the medial wall of the hemisphere, is also somatotopically organized with the orofacial, forelimb, and hindlimb representations in the rostro-caudal direction. The aim of this study is to investigate how such somatotopy is affected when the subjects lose their body parts.

There are several reports on reorganization of the M1 of monkeys after accidental amputation of their upper limbs[2),3)]. However, anesthesia was used in these experiments. Anesthesia obscures somatosensory responses and increases the thresholds of ICMS[1)]. No reports on the reorganization of the SMA. Therefore, I decided to perform physiological mappings of M1, S1 and SMA using chronic set-ups in the awake state

The precise ICMS electrophysiological mapping revealed that there was shrinkage of the distal forelimb region in the M1 on the affected side where less than 10 μA ICMS could evoke movements. In the SMA, the stump region was lost or shrunk on the affected side. The mean threshold to evoke distal forelimb movements on the healthy side and that to evoke stump movements on the affected side were comparable in the M1 and SMA. On the other hand, only a little shrinkage of the S1 distal forelimb region was detected. General arrangement of somatotopy, such as hindlimb, trunk, forelimb and orofacial representations, was preserved in the M1, S1, and SMA.

In this study, chronic recording in the awake monkeys enabled us to obtain precise somatotopic mappings with lower thresholds than previous studies. The stump regions previously representing the distal forelimb shrank in the M1 and SMA, while that in the S1 was rather preserved. The reorganization of the M1 and SMA may occur when the monkeys lost their body parts to control, while the S1 may remain to be reorganized because somatosensory inputs from stumps still exist.

References

1) Tokuno, H., & Tanji, J. (1993). Input organization of distal and proximal forelimb areas in the monkey primary motor cortex: a retrograde double labeling study. Journal of Comparative Neurology, 333(2), 199–209. https://doi.org/10.1002/cne.903330206

2) Qi, H. X., Stepniewska, I., & Kaas, J. H. (2000). Reorganization of primary motor cortex in adult macaque monkeys with long-standing amputations. Journal of Neurophysiology, 84(4), 2133–2147. https://doi.org/10.1152/jn.2000.84.4.2133

3) Wu, C. W., & Kaas, J. H. (1999). Reorganization in primary motor cortex of primates with longstanding therapeutic amputations. Journal of Neuroscience, 19(17), 7679–7697.https://doi.org/10.1523/JNEUROSCI.19-17-07679.1999

Individual differences of natural perceptual content in the human brain can be estimated via brain response prediction using deep neural networks

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Abstract Body

Recently, various methods have been developed to decode perceptual experiences, induced by natural stimuli, from brain response measured with functional magnetic resonance imaging (fMRI) (e.g., 1–2). Social application of such brain decoding methods is promising, but has been prevented by the physical constraints and high measurement cost of fMRI. To solve this problem, we have previously proposed a novel framework for decoding perceptual content from brain response predicted based on deep neural networks (DNNs) instead of one measured with fMRI (3). In this framework, fMRI measurements are taken for several hours only during the construction of DNN-based models predicting fMRI response of individuals to natural stimuli, and afterwards are not needed to decode perceptual content induced by any natural stimuli. Thus, this framework can dramatically reduce the physical constraints and measurement cost of fMRI decoding. The previous study also observed that perceptual content decoded from predicted fMRI response varied across individuals. However, it remains unclear whether this variability captures individual differences of perceptual content decoded from actually measured fMRI responses. This is an important question to be answered for facilitating real-world applications of our framework. To address this question, we measured fMRI responses to natural video scenes from 68 experimental subjects and collected 86 types of perceptual labels associated with the scenes (e.g. semantic content, impressions, etc.). For each subject, the time series of each perceptual label were decoded separately from predicted and measured fMRI responses. Then, the patterns of individual differences for each label were evaluated using the dissimilarity of the decoded time series between all possible pairs of subjects. Finally, Spearman correlations of the patterns were tested between predicted- and measured-response decoding. We found significant correlations for 80 of the 86 perceptual labels. Among them, the highest correlation coefficient was 0.74. This result suggests that predicted-response decoding successfully captures the individual differences in perceptual content estimated with measured-response decoding. Thus, our framework can decode individual differences of natural perceptual content in the brain with almost no fMRI measurement, which greatly expands the applicability of brain decoding in real-world situations.

References

1. Nishida S, Nishimoto S. Decoding naturalistic experiences from human brain activity via distributed representations of words. NeuroImage. 2018;180(A):232–242.
2. Seeliger K, Güçlü U, Ambrogioni L, et al. Generative adversarial networks for reconstructing natural images from brain activity. NeuroImage. 2018;181:775–785.
3. Nishida S, Nakano Y, Blanc, A, et al. Brain-mediated Transfer Learning of Convolutional Neural Networks. Proceedings of the Thirty-Fourth AAAI Conference on Artificial Intelligence. 2020;34(4):5281–5288.

Why is Visual Information Conveyed by the Subcortical Pathway Coarse?

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Abstract Body (10 pt)

Facial expression plays an important role in social life of primates including humans. This information is processed along two visual pathways which meet at the amygdala [1, 2]. One pathway is the ventral cortical pathway, and the other is the subcortical pathway. The ventral cortical pathway consists of a series of cortical regions – one part of the most developed regions in the primate brain. The subcortical pathway consists of a fewer number of stages of phylogenetically ancient regions – superior colliculus, pulvinar, and amygdala. The ventral cortical pathway processes information slowly but accurately, whereas the subcortical pathway rapidly but coarsely [3]. The subcortical fast processing most likely arises from the smaller number of processing stages. However, it remains unclear what features of processing in this pathway renders the transmitted information coarse. To address this question, we developed a convolutional neural network model (SNN) incorporating three key features of the subcortical pathway; shallow architecture, differenece-of-Gaussian (DoG)-type receptive fields similar to those in the first stage of the subcortical pathway, and a greater degree of spatial pooling. Here, we show that the SNN is a good model for the subcortical facial expression processing and the shallowness is not the only one feature crucial for the coarse processing. SNN successfully learned to discriminate facial expressions with moderate accuracy (mean, 46.5%; chance level, 14%), indicating a coarse nature of processing. Units in the final stage represented spatial frequency in the retina-based, not object-based, reference frame, in a way similar to the representation in the amygdala [4]. The coarse processing and the retina-based spatial frequency representation indicate that the SNN reasonably captures the subcortical facial expression processing. We further compared performances of the SNN and three modified models in which the three features of the SNN were replaced one by one with the corresponding features in the cortical pathway. All modified models showed higher accuracies and were less influenced by retina-based spatial frequency than the SNN. These results suggest that all three features of processing (processing shallowness, receptive field organization, and degree of spatial pooling) underlie the coarse representation of facial expression in the subcortical pathway.

References

[1] Pessoa, L., Adolphs, R. (2010). Emotion processing and the amygdala: from a'low road'to'many roads' of evaluating biological significance. *Nat. Rev. Neurosci.*, 11(11), 773-782.

[2] Petry, H. M., Bickford, M. E. (2019). The second visual system of the tree shrew. *J. Comp. Neurol.*, 527(3), 679–693.

[3] Inagaki, M et al. (*in revision*). Rapid processing of threatening faces in the amygdala of non-human primates: subcortical inputs and dual roles

[4] Inagaki, M., Fujita, I. (2011). Reference frames for spatial frequency in face representation differ in the temporal visual cortex and amygdala. *J. Neurosci.*, 31(28), 10371–10379.

Longitudinal recording of neurons from two fMRI-defined face patches

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Abstract Body

The visual analysis of faces plays an important role in the social life of humans and other primates. The capacity to recognize and interpret the structural details of faces is reflected in multiple specialized visual areas of the primate inferior temporal cortex. FMRI mapping experiments agree with targeted electrophysiological recordings that these regions respond more strongly to faces than to other categories of visual stimuli. Less is known, however, about the plasticity of face patch neurons as a function of visual experience. To address this question, we tracked the spiking responses of individual cells to visual stimuli that were presented experimentally over the course of several weeks. We used a 4.7T vertical scanner to first localize fMRI face patches across the temporal cortex and then surgically targeted neurons in the anterior fundus (AF) and anterior medial (AM) face patches with specialized microwire array electrodes. These microwire arrays have the capacity to maintain the stable isolation of dozens of neurons across sessions[1,2)], allowing us to track single-unit changes in visual responses over extended periods of time. Here we report longitudinal recording of over 200 single neurons over a period of 1.5-5 weeks, during which time we repeatedly presented a broad array of face and non-face visual stimuli. In the AM face patch, neurons showed a steady reduction in the late-phase responses, but not early-phase responses to certain stimuli. While the timeline varied across combinations of neurons and stimuli, this reduction generally played out over a period of 3-12 days. Analysis revealed that the rate of plasticity was dictated by individual neurons rather than by particular stimuli, since a given cell showed comparable timelines for different stimuli. Control experiments varying the presentations per session further revealed that response reduction was determined by the number of elapsed days, rather than the number of stimulus repetitions. Neurons in AF patch showed markedly less inter-session plasticity than those in AM, but a higher level of within-session adaptation, which recovered by the next day. These results demonstrate at least two distinct modes of response plasticity to faces and non-face images among neurons in fMRI-defined macaque face patches.

References

1) McMahon DB, Jones AP, Bondar IV, Leopold DA (2014) Face-selective neurons maintain consistent visual responses across months. Proc Natl Acad Sci U S A. 111(22):8251-6

2) McMahon DB, Bondar IV, Afuwape OA, Ide DC, Leopold DA. (2014) One month in the life of a neuron: longitudinal single-unit electrophysiology in the monkey visual system. J Neurophysiol. 112(7):1748-62.

Identification of cerebral cortices for arm kinematics with deep neural network and explainable AI

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Abstract Body (10 pt)

1. Introduction: Cerebral cortical representation of motor kinematics is essential for understanding human motor behavior and efficient control of brain-computer interface. Numerous studies have found the existence of a relationship between neuronal activity and the motor kinematics such as acceleration, velocity, and position [1-3]. However, regardless of the difference between characteristics of kinematic parameters, the neural representation of them is hard to be distinguished in macroscopic functional images such as fMRI, EEG, and MEG. The reason might be that the cortical signals are not sensitive enough to segregate the kinematic characteristics due to the limited spatial resolution. Considering the different role of each cortical areas for producing movement [4], there would be a specific cortical representation depending on the characteristics of acceleration, velocity, and position.

2. Methods: To find out the representation of kinematics in the brain, we introduced an approach to map the salient cortical regions responding each kinematics based on a neural network model of a causal relationship between cortical activity and hand motor kinematics. Nine right-handed participants were recruited in the experiment. The participants did 240 trials of a directional center-out reaching task in the 3D space. During the reaching movement, magnetoencephalography (MEG) signals of 306 channels were recorded. Movement signals of participants were acquired by accelerometer which attached to an index finger. From the accelerometer signals, velocity and position signals was integrated. We adopt two state-of-art techniques to find neural representation of kinematic parameters. The time-series deep neural network (DNN) models were used to measure the relationship between the cortical activity and motor kinematics during hand reaching movement. An architecture of DNN models was bidirectional long-short term memory (bLSTM) [5]. By the models, arm kinematics in a 3D space was predicted by the cortical source activity localized from magnetoencephalography (MEG) data. Then, an explainable artificial intelligence (AI) method called integrated gradients was adopted to extract the map of cortical regions, which strongly contributed to predict each kinematic parameter, from the DNN models [6].

3. Results: We found that there were unique as well as shared brain regions for decoding each kinematic attribute. The shared regions were found in bilateral supramarginal gyri within posterior parietal cortex (PPC), that is known to relate with selection of a goal of movement and integration of external sensory information. On the other hand, the unique regions were represented as mutually exclusive maps for each kinematic characteristic: the contralateral motor cortex for acceleration, parieto-frontal system for velocity, and bilateral

visuo-spatial areas with saccadic eye movement areas for position.

4. Discussion: The cortical regions imply that the acceleration is related with muscle force, the velocity coordinates the movement, and the position decides a target and plans the movement. To the best of our knowledge, it is the first study to discriminate the kinematic brain regions by the DNN models and explainable AI.

References

[1] Ashe, J. and A. P. Georgopoulos (1994). "Movement parameters and neural activity in motor cortex and area 5." Cereb Cortex 4(6): 590-600.

[2] Jerbi, K., et al. (2007). "Coherent neural representation of hand speed in humans revealed by MEG imaging." Proc Natl Acad Sci U S A 104(18): 7676-7681.

[3] Bourguignon, M., et al. (2019). "Coupling between human brain activity and body movements: Insights from non-invasive electromagnetic recordings." Neuroimage 203: 116177.

[4] Vesia, M. and J. D. Crawford (2012). "Specialization of reach function in human posterior parietal cortex." Exp Brain Res 221(1): 1-18.

[5] Schuster, M. and K. K. Paliwal (1997). "Bidirectional recurrent neural networks." Trans. Sig. Proc. 45(11): 2673–2681.

[6] Sundararajan, M., et al. (2017). Axiomatic attribution for deep networks. International Conference on Machine Learning, PMLR.

Morphological evidence for multiple distinct channels of corticogeniculate feedback originating in mid-level extrastriate visual areas of macaques and ferrets

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In the visual system, retinal information reaching the lateral geniculate nucleus (LGN) of the thalamus is mainly relayed to the primary visual cortex (V1). Geniculocortical projection neurons in the LGN include magnocellular, parvocellular, and koniocellular cells that convey distinct visual information. Sparse geniculocortical projections to extrastriate visual cortical areas are thought to originate primarily from koniocellular cells. Feedforward geniculocortical projections are complemented by reciprocal, feedback corticogeniculate projections. In macaque monkeys and ferrets, multiple morphologically distinct corticogeniculate subtypes exist in both V1 and V2. Here we investigated whether corticogeniculate neurons are also present in extrastriate visual cortex and whether these neurons are morphologically homogeneous, i.e., aligned with primarily koniocellular geniculocortical inputs, or diverse. We identified and characterized the morphology of corticogeniculate neurons in three macaque extrastriate visual cortical areas: V4, MT, and MST, and their ferret homologs: area 21a, PMLS, and PLLS respectively. We discovered morphologically diverse corticogeniculate subtypes in all three extrastriate areas across the two species. Most extrastriate corticogeniculate neurons were morphologically similar to those previously identified in V1 and V2. Whether unique corticogeniculate subtypes send stream-specific information to the LGN is not known, but prior physiological evidence based on axon conduction latencies and visual response properties suggests that distinct corticogeniculate subtypes align with the feedforward parallel processing streams. Together, our findings suggest that V1-independent connectivity between the LGN and extrastriate visual cortex, in ferrets and macaques, involves multiple diverse corticogeniculate cell types possibly relaying functionally distinct visual signals.

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Macromolecular tissue volume mapping of lateral geniculate nucleus subdivisions in in vivo human brains

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Abstract Body:

The lateral geniculate nucleus (LGN) is a key thalamic nucleus in the visual system, which has an important function in relaying retinal visual input to the visual cortex, and is also hypothesized to be involved in visual functions such as attention and reading. The human LGN is composed mainly of the magnocellular (M) and parvocellular (P) subdivisions, each of which has different visual functions. Non-invasive identification of these subdivisions is, however, difficult due to the small size of the LGN. Here we propose a method to identify these subdivisions by combining two structural MR measures: high-resolution proton-density weighted images and macromolecular tissue volume (MTV; Mezer et al., 2013) maps. We defined the M and P subdivisions based on MTV fraction data and tested its validity of the definition by (1) comparing the data with human histological data from BigBrain (Amunts et al., 2013), (2) comparing the data with functional magnetic resonance imaging measurements on stimulus selectivity, and (3) analyzing the test-retest reliability. The findings demonstrated that the spatial organization of the M and P subdivisions was consistent across all subjects and in line with LGN subdivisions observed in the human histological data. Moreover, the difference in stimulus selectivity between the subdivisions identified using MTV was consistent with previous physiology literature (Derrington and Lennie, 1984; Denison et al., 2014). The definition of the subdivisions based on MTV was shown to be robust over measurements taken on different days. These results suggest that MTV mapping is a promising approach for evaluating the tissue properties of LGN subdivisions in living humans. This method will open an avenue for direct comparisons of LGN subdivision properties with behavioral or functional data or evaluating the consequence of visual disorders on LGN tissue properties.

Reference:

Amunts K, Lepage C, Borgeat L, Mohlberg H, Dickscheid T, Rousseau M-É, Bludau S, Bazin P-L, Lewis LB, Oros-Peusquens A-M, Shah NJ, Lippert T, Zilles K, Evans AC (2013) BigBrain: an ultrahigh-resolution 3D human brain model. Science 340:1472–1475.

Denison RN, Vu AT, Yacoub E, Feinberg DA, Silver MA (2014) Functional mapping of the magnocellular and parvocellular subdivisions of human LGN. NeuroImage 102:358–369

Derrington AM, Lennie P (1984) Spatial and temporal contrast sensitivities of neurones in lateral geniculate nucleus of macaque. J Physiol 357:219–240.

Mezer A, Yeatman JD, Stikov N, Kay KN, Cho N-J, Dougherty RF, Perry ML, Parvizi J, Hua LH, Butts-Pauly K, Wandell BA (2013) Quantifying the local tissue volume and composition in individual brains with magnetic resonance imaging. Nat Med 19:1667–1672.

Whole brain mapping of face patch neurons during rest

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The temporal correlation of fMRI-fluctuations between brain regions is often taken as a measure of functional-connectivity. However, individual neurons within a given region exhibit diverse and sometimes uncorrelated activity-patterns from their neighboring neurons, raising the question of how to interpret area-based fMRI correlations. For example, in the cortical face patch system of the macaque, neighboring face-selective neurons can show largely independent responses during naturalistic modes of vision. This independence is manifest as unique interactions with distinct networks across the brain. Here we asked whether the profile of spontaneous activity within face patches is equally diverse. We used simultaneous fMRI and electrophysiology to investigate how the activity of neurons within a single face patch voxel relate to spontaneous fMRI-fluctuations elsewhere in the brain. We found that spontaneous spiking activity of face patches AF and AM was largely shared among neurons, in contrast to the responses observed during naturalistic stimulation. The shared time course of the spiking fluctuations was positively correlated with fMRI signals across circumscribed cortical areas, including V4, TEO and other face patches areas, and ventral premotor areas. Strikingly, we found negative correlation with the LGN and brain stem neuromodulatory ascending pathways. The specific pattern of fMRI correlations with neural spiking was not found in either the local LFP or fMRI activity.

Using radiomics as prior knowledge for optimizing transcranial magnetic stimulation

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Abstract Body (10 pt)

Background: Imaging-guided transcranial magnetic stimulation (TMS) is a fast-growing research field in neuroscience (Carpenter & Philip, 2020). Cortical morphometry, as a phenotype of human brain, plays a vital role in the development of diagnostic atlas and brain-based interventions (Lu, 2020, 2021), yet few studies are afoot to investigate the ageing effects on region-specific cortical morphometry and use it in the estimation of stimulation-induced electric field (E-field). This study was proposed to map the morphometric features of bilateral dorsolateral prefrontal cortex (DLPFC) and quantify the TMS-induced E-field during normal and pathological ageing.

Methods: Baseline, 1-year and 3-year follow-up structural magnetic resonance imaging (MRI) scans from normal ageing (NA) adults (n = 32), and mild cognitive impairment (MCI) converters (n = 22) were drawn from the Open Access Series of Imaging Studies. The quantitative measures of cortical morphometry included gray matter volume, cortical thickness and folding (Madan & Kensinger,2016; Lu, 2020). Head model was developed to simulate the impact of morphometric changes on the E-field induced by TMS.

Results: Ageing had a nonlinear effect on the changes of volume and cortical thickness in the bilateral DLPFC. A pronounced ageing-related reduction was found in the gyrification of left DLPFC in MCI converters, which could predict the decline of global cognition at the 3-year follow-up. Along with the reduced gyrification in left DLPFC, the E-field intensity and focality of TMS model was consequently decreased in MCI converters.

Conclusion: Ageing has a prominent effect on region-specific cortical morphometry that leads to decreased intensity and focality of stimulation-induced E-field in old adults with cognitive declining. Our findings have important implications for conducting the transcranial brain stimulation in individuals with brain atrophy, such as Alzheimer's Disease.

References

Carpenter, L. L., & Philip, N. S. (2020). The future is now? Rapid advances by brain stimulation innovation. American Journal of Psychiatry, 177(8), 654-656.

Lu, H. (2020). Quantifying age-associated cortical complexity of left dorsolateral prefrontal cortex with multiscale measurements. Journal of Alzheimer's Disease, 76(2), 505-516.

Lu, H., Li, J., Zhang, L., Chan, S. S. M., & Lam, L. C. W. (2021). Dynamic changes of region-specific cortical features and scalp-to-cortex distance: implications for transcranial current stimulation modeling. Journal of NeuroEngineering and Rehabilitation, 18(1), 1-12.

Madan, C. R., & Kensinger, E. A. (2016). Cortical complexity as a measure of age-related brain atrophy. NeuroImage, 134, 617-629.

Hyper-adaptation in the Human Brain: Functional and structural changes in the foot section of the primary motor cortex in a top wheelchair racing Paralympian

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Abstract Body (10 pt)

Somatotopy is a fundamental functional structure for sensorimotor processing in the brain. Many previous neuroimaging studies have shown that congenital or acquired limb deficiencies and dysfunction cause drastic changes in somatotopic representations in the human brain (e.g., Hahamy et al. 2017). Main purpose of the present study was to examine the functional and structural changes in the foot section of the primary motor cortex (M1) in a top wheelchair racing Paralympian (participant P1), when compared to able-bodied control participants. Participant P1 had congenital paraplegia (dysfunction of bilateral lower limbs), and was an active top wheelchair racing Paralympian, who had long-term extensive wheelchair racing training using bilateral upper limbs and has won a total of 19 medals in six consecutive summer Paralympic games by now. We also examined the functional and structural changes in other three acquired paraplegic individuals (participants P2, P3, and P4), who also had long-term non-use period of lower limbs and long-term wheelchair sports training.

In all participants, we measured brain activity using functional magnetic resonance imaging (MRI) when bimanual wrist extension-flexion movement was performed, and structural MRI images were collected. Compared to 37 control participants, participant P1 showed significantly greater activity in the M1 foot section during the bimanual task, and significant local GM expansion in the M1 foot section. The significantly greater activity in the M1 foot section was also observed in participant P4, but not in P2 and P3, and the significant local GM expansion was observed in participant P2, but not in P3 and P4. Thus, the functional or structural change observed in participant P1 was observable even in an acquired paraplegic participant, but not always observable in all paraplegic participants who had long-term non-use period of lower limbs and long-term wheelchair sports training.

The functional and structural changes observed in participant P1 are likely to be the results of brain's adaptation to unusual physical environment (paraplegia), in which a brain region (M1 foot section) becomes used for a function (hand sensory-motor processing) other than its original function (foot motor control) with its organic alteration, probably through long-term physical (wheelchair racing) training. Hence, we want to propose that such functional and structural changes could be better called hyper-adaptation than normal adaption, because these are not temporary changes in function, but drastic functional changes with structural alteration, which are rarely seen in normal people (Morita et al. 2021).

References

Hahamy, A., Macdonald, S. N., van den Heiligenberg, F., Kieliba, P., Emir, U., Malach, R., et al. (2017). Representation of multiple body parts in the missing-hand territory of congenital one-handers. Curr. Biol. 27, 1350–1355. doi:10.1016/j.cub.2017.03.053.

Morita, T., Asada, M., and Naito, E. (2021). Examination of the development and aging of brain deactivation using a unimanual motor task. Adv. Robot. 35, 842–857. doi:10.1080/01691864.2021.1886168.

Promotion of cross-modal and default mode network inhibitions in young racing car drivers

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Abstract

Performing a task activates relevant brain regions, while it may deactivate task-irrelevant brain regions (e.g., cross-modal inhibition; Laurienti et al., 2002). Such task-related deactivation is believed to enable the brain to concentrate on task-relevant information processing by suppressing activities that are unnecessary for performing the task. Our previous studies have shown that deactivation patterns when performing a task change with development and aging (Morita et al., 2019; 2021), implying the possibility that the development of deactivation is influenced by the experiences we have had. In the present study, we tested our hypothesis that task-related deactivation in a sensory selection task is well developed in the brains of young racing car drivers, who are likely to have a lot of training in quickly selecting the sensory information they need and reacting to this.

We recruited 10 healthy young racing car drivers from Suzuka circuit racing school (aged 17–21 years) and 47 age-matched naïve control participants. The participants were presented with both visual and auditory stimuli. In a visual selection task, they were asked to respond to the visual stimuli by ignoring the auditory stimuli. In an auditory selection task, they were asked to respond to the auditory stimuli by ignoring the visual stimuli. We measured brain activity with functional MRI and reaction time (RT) when they performed these tasks.

Regardless of the tasks, the driver group showed a significantly faster RT than the control group. Similarly, regardless of the tasks, the sensorimotor cortex, the vestibular-related areas, and the precuneus were significantly more deactivated in the driver group than in the control group, suggesting that cross-modal inhibition in the sensorimotor and vestibular regions and default mode network (DMN) inhibition during an audiovisual selection task better developed in the former group. Of these regions, only the precuneus showed a significant correlation between the degree of deactivation and RT across all participants (participants with stronger precuneus deactivation responded faster), suggesting that the precuneus deactivation can be an indicator of faster RT.

Promotion of cross-modal inhibition in the sensorimotor and vestibular regions and of DMN inhibition in the driver group was likely due to their car racing training. Thus, the results support our view that the development of deactivation is influenced by the experiences we have had.

References

Laurienti, P. J. et al. (2002). Journal of cognitive neuroscience, 14(3), 420-429.

Morita, T., Asada, M., & Naito, E. (2019). Developmental neurobiology, 79(6), 536-558.

Morita, T., Asada, M., & Naito, E. (2021). Advanced Robotics, 1-16.

Modulation of the resting state activity in the brain by placing a strong static magnetic field over the precuneus

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Abstract:

Background: It has been discovered that placing an intense magnet over the head will change the neuromodulatory functions of the brain. However, the apparent effects on the human cerebral cortex remained controversial.

Methods: This research aimed to determine whether transcranial static magnetic stimulation (tSMS) over the precuneus (the central hub of the default mode network) could effectively suppress functional connectivity through the entire cortical network. In a sham-controlled single-blind crossover study, tSMS (or sham) on two different days was applied for 1 hour with a neodymium magnet (45 mm in diameter, 1T in the center) on the scalp of 16 healthy participants. We recorded their resting brain activity using the functional MRI before and immediately after the exposure.

Results: In contrast to the sham, tSMS suppressed the connectivity between the precuneus and the hippocampus, thalamus, and parahippocampal areas. Furthermore, we noticed that regardless of the exposure to the sham or magnet, there was an increase in the functional connectivity of the DMN on the first day compared to the second day.

Conclusion: Since the precuneus and the hippocampus, thalamus, and parahippocampal regions are involved in the formation and retrieval of memory, our result might implicate that the tSMS on the precuneus should somehow disturb the memory-related functions. Moreover, the significant difference between the first- and second-day functional connectivity could be associated with the surprise due to the novelty of the experimental setup on the first day.

Reference:

- Oliviero, A., Mordillo-Mateos, L., Arias, P., Panyavin, I., Foffani, G., & Aguilar, J. (2011). Transcranial static magnetic field stimulation of the human motor cortex. The Journal of physiology, 589(Pt 20), 4949–4958. https://doi.org/10.1113/jphysiol.2011.211953

Temporal power changes in the human ECoG induced by propofol anesthesia.

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Abstract Body

The cerebral cortical changes associated with propofol-induced unconsciousness remain unknown. To specifically pinpoint characteristics arise upon loss of consciousness, we investigated temporal changes in cortical regions during the induction into unconsciousness. We recorded electrocorticography (ECoG) data of 16 epilepsy patients and investiaged power spectrum changes in ECoG signals obtained during the induction phase from awake state to unconsciousness. For temporal changes, we assessed 1) the start point, and 2) the normalized time interval between the start and finish of power change (Δnormalized t) in the cortical areas. We found that, 1) the power increased in the range of frequencies < 46 Hz, and decreased in the range of 62–150 Hz, in global channels 2) superior parietal lobule (SPL) and dorsolateral prefrontal cortex (DLPFC) started to change early, but took a long time to complete the change whereas angular gyrus (AnG) and associative visual cortex (V3–5) started to change late, but took a short time to complete the change. The loss of consciousness induced by general anesthesia results from first, disrupted communication between self and external world, followed by disrupted communication within self, with decreased activities of SPL and DLPFC, and later, attenuated activities of AnG and V3–5.

References

1. Hanrahan SJ, Greger B, Parker RA, Ogura T, Obara S, Egan TD, et al. The effects of propofol on local field potential spectra, action potential firing rate, and their temporal relationship in humans and felines. Front Hum Neurosci. 2013;7:136.

2. Boveroux P, Vanhaudenhuyse A, Bruno M-A, Noirhomme Q, Lauwick S, Luxen A, et al. Breakdown of within- and between-network resting state functional magnetic resonance imaging connectivity during propofol-induced loss of consciousness. The Journal of the American Society of Anesthesiologists. 2010;113(5):1038-53.

3. Pujol J, Blanco-Hinojo L, Gallart L, Moltó L, Martínez-Vilavella G, Vilà E, et al. Largest scale dissociation of brain activity at propofol-induced loss of consciousness. Sleep. 2021;44(1).

4. Walsh E, Oakley DA, Halligan PW, Mehta MA, Deeley Q. Brain mechanisms for loss of awareness of thought and movement. Soc Cogn Affect Neur. 2017;12(5):793-801.

5. Davey CG, Harrison BJ. The brain's center of gravity: how the default mode network helps us to understand the self. World Psychiatry. 2018;17(3):278-9.

The microstructural modulations induced by intermittent theta burst stimulation were related to its after-effect

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Abstract Body (10 pt)

Intermittent theta burst stimulation (iTBS) is one of patterned repetitive transcranial magnetic stimulation (rTMS) protocols, which induces a long-term potentiation (LTP) like after-effect to the stimulated region (Huang et al. 2005). While several studies have reported that this LTP-like after-effect is substantially variable across participants (López-Alonso et al. 2014), the cause of its variability remains elusive. Here, we show that the LTP-like after-effect induced by iTBS is associated with the modulation of microstructural properties in the human brain. Twenty-four healthy adults participated in two sessions of experiments. In each session, iTBS was applied over either the right primary motor cortex (M1-iTBS) or Pz (Pz-iTBS; control) at 80% active motor threshold. Before and after the iTBS, we measured motor evoked potentials (MEP) to assess the modulation in corticospinal excitability. To assess the microstructural modulation induced by iTBS, diffusion magnetic resonance imaging (dMRI) data were collected. As a result, in dMRI-derived metrics of M1-iTBS, we found a significant decrease in radial diffusivity (RD) in the right precentral, postcentral, middle occipital gyrus, and left cerebellum. We also found a significant decrease in mean diffusivity (MD) in the bilateral cerebellum. By contrast, such modulation in the microstructural properties was not observed in Pz-iTBS. The regression analysis revealed that, in M1-iTBS, MEP-amplitude change was positively correlated with the degree of the decrease in MD in the left cerebellum, which was structurally and functionally connected to the right M1. We speculate that the decrease in RD and MD might be explained by the morphological changes of axons and glial cells respectively (Sampaio-Baptista and Johansen-Berg 2017). Furthermore, since the decrease in MD of the left cerebellum was positively correlated with the MEP-amplitude change, the activation of the glial cells in the left cerebellum induced by the M1-iTBS might be coupled with the iTBS after-effect on the stimulated region. Taken together, the iTBS after-effect on the stimulated region might be associated with the degree of the activation of the glial cells in the remote regions induced by iTBS.

References

Huang YZ, Edwards MJ, Rounis E, Bhatia KP, Rothwell JC. 2005. Theta burst stimulation of the human motor cortex. Neuron. 45:201–206.

López-Alonso V, Cheeran B, Río-Rodríguez D, Fernández-Del-Olmo M. 2014. Inter-individual variability in response to non-invasive brain stimulation paradigms. Brain Stimul. 7:372–380.

Sampaio-Baptista C, Johansen-Berg H. 2017. White Matter Plasticity in the Adult Brain. Neuron. 96:1239–1251.

Structural covariance and heritability of primary visual cortex and white matter tract in neuroimaging dataset

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Abstract Body (10 pt)

Introduction. Quantifying structural covariance across brain regions is essential to understand the organization and development of the human nervous system. A previous anatomical study reported that the size of primary visual cortex (V1) varied substantially across individuals, and that the size of V1 and the optic tract (OT) covaried[1]. Here, we followed up this study using a much larger sample of *in vivo* neuroimaging dataset. Specifically, we investigated the relationship between V1 size and OT properties as well as their heritability.

Methods. We analyzed the Human Connectome Project (HCP) 7T Retinotopy Dataset, including 7T fMRI and 3T diffusion-weighted MRI (dMRI) data[2,3]. Participants of this dataset include monozygotic (MZ) and dizygotic (DZ) twins. We calculated the V1 size by applying a Bayesian retinotopy analysis method to the fMRI and structural MRI[4]. We identified the OT from dMRI data using conTrack[5]. We then quantified the size and tissue properties by calculating the cross-section area[1] and fractional anisotropy (FA). In addition, we used neurite orientation dispersion and density imaging (NODDI)[6] to estimate OT intra-cellular volume fraction (ICVF) and orientation dispersion index (ODI). We estimated the heritability based on the intraclass correlation between MZ and DZ twin pairs[7].

Results. We did not find a statistically significant correlation between V1 size and OT cross-section area (r = -0.05, p = 0.5). This may be due to measurement noise in the OT estimates: we found a low correlation between hemispheres in the estimation of the MRI-based OT cross-section area (r = 0.38). In contrast, OT FA appears to be a more stable dMRI-based measurement, exhibiting a high correlation between hemispheres (r = 0.77). Therefore, we tested correlation between V1 size and OT FA. We found a small, but statistically significant negative correlation between V1 size and OT FA (r = 0.19, p = 0.01). This result was replicated in dMRI data acquired with different parameters. In addition, we found a significantly positive correlation between V1 size and NODDI parameters (ICVF, r = 0.19, p = 0.01; ODI, r = 0.22, p = 0.003). Finally, we found a considerable degree of heritability in both V1 and OT FA (V1 size, h^2 = 0.28; OT FA, h^2 = 0.58).

Discussion. We found a small, but statistically significant correlation between V1 size and OT tissue property and this correlation was generalized across dMRI acquisition parameters. These results support the existence of structural covariance between V1 and OT in living humans. Results on NODDI analysis raise the hypothesis that subjects with larger V1 may have greater axon density with more dispersed fiber orientation. We also found that both V1 size and OT tissue properties have a considerable degree of heritability, suggesting that one of the plausible sources of the structural covariance is common genetic factors.

References

1. Andrews, T.J. (1997): Correlated size variations in human visual cortex, lateral geniculate nucleus, and optic tract. J Neurosci 17:2859–2868; 2. Van Essen DC et al. (2012) The Human Connectome Project: a data acquisition perspective. Neuroimage 62:2222–2231; 3. Benson, N.C. (2018a): The Human Connectome Project 7 Tesla retinotopy dataset: Description and population receptive field analysis. J Vis, 18(13):23; 4. Benson, N.C. (2018b): Bayesian analysis of retinotopic maps. eLife, 7: e40224; 5. Sherbondy, A.J. (2003): ConTrack: finding the most likely pathways between brain regions using diffusion tractography. J Vis, 8(9):15.; 6. Zhang H. (2012): NODDI: practical in vivo neurite orientation dispersion and density imaging of the human brain. Neuroimage, 61:1000–1016; 7. Falconer, D.S. (1996): Introduction to Quantitative Genetics, Ed. 4