2018 Annual report

"Understanding brain plasticity on body representations to promote their adaptive functions"

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Grant-in-Aid for Scientific Research on Innovative Areas
(Research in a proposed research area), Interdisciplinary Area,
supported by Japan Society for the Promotion Science (JSPS), and
The Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan

Area No. 4603
Fiscal Year: 2014 – 2018
http://embodied-brain.prg

Contents

Project overview and Activities of Steering Committee

Jun OTA
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I. OBJECTIVE OF THIS PROGRAM

With coming of a super-aged society in Japan, many disorder accompanying aging, such as motor paralysis due to stroke / cerebral degeneration disease, are rapidly increasing. Establishment of an effective rehabilitation method to overcome these motor disabilities is an urgent task. In order to deal with this problem, it is indispensable to elucidate the mechanism of brain adaptation to changes in body function. For example, an increase in fall due to age suggests that brain adaptation is not associated with a decrease in motor function. Conversely, even in a disease state without any dysfunction in the locomotorium, abnormality may occur in the body perception. These facts indicate that an internal model of the body (we call this “body representation in the brain”) is constructed and maintained in our brain, and when abnormality occurs in the body representation in the brain, it means serious dysfunctions to the sensory system and motor system occur. In the embodied-brain systems science area, we aim to clarify the neural mechanism of the body representation in the brain and its long-term change mechanism and apply it to rehabilitation intervention. For this reason, we try to integrate brain science and rehabilitation medicine with the intermediation of system engineering which can consistently describe the behavior of human as a mathematical model. By doing this, we aim to create a new academic area of "Embodied-brain Systems Science" that comprehensively understands body cognition and motion control, and establishes a truly effective rehabilitation method.

II. ACTIVITIES OF THE PROGRAM

During three years from the start of the program until 19 January 2019, the program has over 513 journal papers (including 353 international journals), over 371 international conference presentations, and over 726 domestic oral presentations. From the fourth year onwards, we publish transdisciplinary research papers steadily and especially we published two textbooks from University of Tokyo Press (in Japanese) in the end of 2018.

Specific research results include the research that identifies activity dynamics with multiple time frequencies in the brain by using machine learning technique from fMRI measurement data (Brain science group), the research that obtains muscle synergy in walking / upper limb movement with a novel statistical data analysis method (Systems engineering group), development of rehabilitation system that activates physical Illusion with Immersive VR and analysis of degree of intervention to the body representation in the brain (Rehabilitation medicine group).

In addition to these, top-level researchers also participated in subscribed research groups. Several research projects could get excellent research results than expected when this project started. The outcomes of this area are widely outreached to more than 14,000 people. Young researchers association is also organized, and the training to the next generation researchers is carried out to undertake excellent studies on interdisciplinary research field.

III. ACTIVITIES OF THE PROJECT

Here we will describe from two categories: activities as the project, activities in academic societies.

A. Activities as the project

- 2nd international conference on embodied-brain systems science (EmboSS 2018)
Date: Dec 5-6, 2018
Place: Osaka, Senri life science center
Contents: 2 days conference with 6 invited talks by Prof. Paolo Dario (Scuola Superiore Sant’Anna), Prof. Etienne Burdet (Imperial College London, Prof. Sten Grillner (Karolinska Institutet), Prof. Peter Strick (University of Pittsburgh), Prof. Trevor Drew, (Université de Montréal, and Prof. Mark Hallett (National Institute of Neurological Disorders and Stroke). Presentation by the area organizer and principal investigators. Poster session by researchers.

- 2nd evaluation meeting
Date: Dec. 7, 2018
Plase: CiNet, Osaka
Contents: Meeting with Advisory board members (Prof. Paolo Dario, Prof. Yoshikazu Shinoda, and Prof. Koji Ito).

- 7-th project meeting
Date：Feb 28 - March 2, 2019
Place: Iwate Prefecture
Contents: Invited talk. Oral and poster presentations by area members. Discussion.

B. Actuvities in academic societies

- The 2018 IEEE EMBC2018
Date: July 17, 2018
Place: Hawaii, USA.
Contents: Workshop, 8 oral presentations including two international invited talks.
Attendees: 30

- The 36th Annual Conference of the RSJ (RSJ2018)
Date: September 6, 2018
Place: Chubu University, Kasugai, Aichi

Contents: Organized session: 10 presentations

- IEEE MHS 2018 (Micro-NanoMechatronics and Human Science)

Date: December 11, 2018
Place: Nagoya University, Nagoya, Aichi
Contents: Plenary Talk (Dr. Y.Hayashi, Univ. of Reading), Organized session（5 Oral Presentations, 3 Poster Presentations), Keynote speech (Dr. Izawa)

- 31th SICE distributed autonomous system symposium

Date: January 24-25, 2019
Place: National Museum of Ethnology, Osaka
Contents: Organized Session (3 Oral Presentations)

IV. Collaboration among groups

In this area, we have promoted trans-group studies from the start of the area. At this moment, we can see many collaborations among area members, including those in the first and the second periods subscribed research group members. The topics in collaboration are shown in Fig. 1. Here, meaning of the numbers in Fig. 1 is shown as follows: (1) sense of agency, (2) posture control, (3) muscle synergies, (4) sense of ownership, (5) upper-body movement, (6) dystonia, (7) brain imaging, (8) locomotion, (9) grasping, (10) artificial thumb, (11) soft touch, (12) crawling, (13) body schema, (14) neural plasticity, and (15) soft actuator

V. Activities of young researchers

We run the Associates of Young Researchers of Embodied Brain Systems Science to develop interdisciplinary research methods and young members. Currently we have 49 members. In this year, we hosted organized sessions three times in academic conferences, provided two invited talks for an academic symposium, held and two research symposiums.

We hosted organized sessions and provided 11 talks at the IEEE 40th EMB Conference (Annual International Conference of the IEEE Engineering in Medicine and Biology Society). We hosted organized session and provided 10 talks at The 36th annual conference of the Robotics Society of Japan (RSJ 2019), and 8 talks at SICE Symposium on Systems and Information (SSI 2019).

We provided two invited talks (Ryosuke Chiba, Asahikawa Medical University; Shiro Yano, Tokyo University of Agriculture and Technology) at The 1st Korea-China-Japan international symposium on disability overcome (KIST, Korea).

We held a research symposium on the embodied cognition and EMG signal processing (Talks: Wen Wen, The university of Tokyo; Shohei Shirafuji, The university of Tokyo).

We held another symposium on a spinal cord activity under the voluntary actions and adaptive control mechanisms on musculoskeletal model (Talks: Tomomichi Oya, National Institute of Neuroscience NCNP; Ryusuke Chiba, Asahikawa Medical University).

VI. Future plan

The plan in 2019 fiscal year is shown as follows:

- Sep 17, 2019: 3rd Public Symposium at The University of Tokyo.

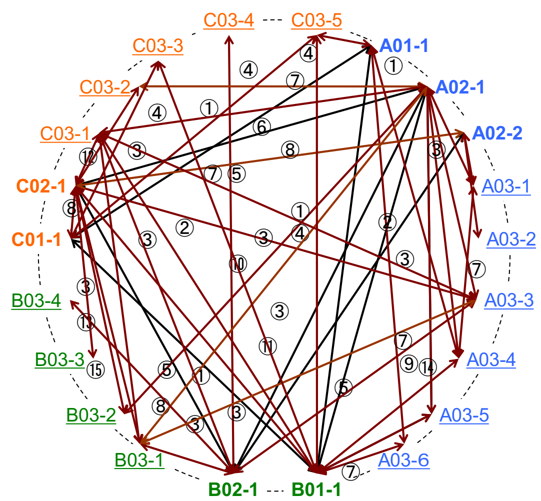

Fig. 1 Trans-area collaboration

Annual report of international activity support group

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I. Aim of the Group

The international activity support group is a planned research to support the international activities within the scientific research on innovative areas. The research program on embodied-brain systems science aims to realize model-based rehabilitation based on the concept of biomarkers and models of body representation in the brain. For this aim, the group sets up core-projects that integrate Group A (brain science), Group B (system engineering), and Group C (rehabilitation medicine), and promotes their fusion research as the international collaboration.

Specifically, two core-projects: “bodily self-consciousness core” and “synergy-based control core” are designed. The former is organized by 01 research projects group, which focuses on body consciousness and related symptom such as phantom limb/paralysis, while the latter is organized by 02 research projects group, which is investigating upper and lower limbs rehabilitation focusing on the mechanism of synergy-based control. Moreover, members of 03 research projects group (subscribed research projects) also participated in the both core-projects.

This group has three purposes; 1) to increase publication of international joint research through the activities promoting international joint research and building researcher network, 2) to feedback the outcomes of the international collaboration to the research program, and 3) to increase international visibility of the research program. Every year, the group calls for the proposal of international activities from researchers in the research program and decides the activities to be supported in the following fiscal year based on the above criteria. After the end of the international activity, the group asks the accepted proposers not only to submit their activity report but also to present their outcomes to the members of the research program at the end of the year meeting.

II. Supported International Activities in FY2017

International activities supported by the grant in FY2017 are listed below.

1	Type: Dispatch of young scientist Applicant: A02-1 K.Seki Content: The applicant dispatched young scientists in synergy-based control core to Foundation of Santa Lucia (Rome, Italy) , and asked them to discuss about muscle synergy analysis, and prepared journal paper of the international collaboration research.
2	Type: Dispatch of young scientist Applicant: A02-2 K.Takakusaki Content: The applicant dispatched a young scientist in synergy-based control core to Prof. Trevor Drew’s laboratory in University of Montreal, and asked him to conduct international collaboration about posture control.
3	Type: Invitation of outstanding researcher Applicant: A02-2 K.Nakajima Content: The applicant invited Prof. Marc A Maier (Université Paris Descartes), who is an outstanding researcher in synergy-based control core, and conducted international collaboration about adaptive posture and locomotion control.
4	Type: Invitation of outstanding researcher Applicant: B01-1 J.Izawa Content: The applicant invited Prof. Etiene Burdet (Imperial College of London) during Dec. 1st – 8th, who is an outstanding researcher in bodily self-consciousness core, and discussed with him about mathematical modeling of neuro-rehabilitation. During the stay, he joined EmboSS2018 conference and gave a Plenary Talk. After the conference, he participated lab tour.
5	Type: Invitation of outstanding researcher Applicant: B01-1 T.Kondo Content: The applicant invited Dr. Yoshikatsu Hayashi (University of Reading), who is an outstanding researcher in bodily self-consciousness core, and discussed with him about BCI neurorehabilitation. During the stay, he joined EmboSS2018 and discussed with the project members. After the symposium, he gave a Plenary Talk in IEEE MHS2018 conference.
6	Type: Invitation of outstanding researcher Applicant: C01-1 T.Inamura Content: The applicant invited Dr. Max Ortiz Catalan (Chalmers University of Technology) to an international workshop held in EMBC2018 (Hawaii, USA), who is an outstanding researcher in bodily self-consciousness core, and discussed with him about treatment methodology for phantom limb pain.
7	Type: Invitation of outstanding researcher Applicant: C02-1 T.Hanakawa Content: The applicant invited Dr. Giulia Cisotto (University of Padova), who is an outstanding researcher in synergy-based control core and discussed with her about writer’s cramp (focal hand dystonia).

III. Future Perspective

In this year, the group supported 7 international activities within the research program. Through these activities, international visibility of our research program increased. In the future we will proceed to write international collaborative papers as a result of these activities.

Activities of Group A (Brain Science) in 2018

Eiichi Naito
Center for Information and Neural Networks (CiNet), National Institute of Information and communications technology (NICT)

I. Purpose of the research projects in Group A

In the research projects of Group A, we have aimed to elucidate neural substrates of body representations in the brain and to identify biomarkers that reflect changes in the body representations. We have been focusing on three topics: (1) body cognition (sense of agency and body ownership), (2) muscle synergy control and (3) anticipatory posture adjustment, and we have been conducting manipulative (interventional) neuroscience to investigate how changes in the body representation cause changes in bodily perception and motor control vice versa. We have conducted experiments both in humans and in animals (monkeys, cats and rats). By using electrophysiological and neuroimaging techniques, we have been revealing how body representations change (1) when we manipulate participant's bodily awareness e.g. in a virtual reality environment, (2) when we manipulate physical states of musculoskeletal system and (3) when monkeys start performing bipedal walking and so on. To elucidate biomarkers that reflect changes in the body representations, we use neuronal decoding techniques. Here, we identify brain regions where the activities contain important information to predict contents of changes in bodily perception and motor control. By sharing the knowledge about causal relationship between internal body representation and bodily perception and motor control with research projects B and C, we help them to construct a model and also contribute to reveal a principle of neuro-rehabilitation. This fiscal year was the last year of the Embodied-Brain project. Many achievements have been obtained from Group A (A01, A02-1, A02-2 and six A03 projects) and from collaborations across Groups A, B and C.

II. Members

We have promoted the inter-group and inter-project collaborations based on the following research team organization.

Research project A01: Neural mechanisms inducing plasticity on body representations
Principal Investigator: Hiroshi Imamizu (Univ of Tokyo). Funded Co-Investigator: Akira Murata (Kindai Univ), Yukari Ohki (Kyorin Univ), Takaki Maeda (Keio Univ). Other 12 Co-Investigators.

Research project A02-01: Neural adaptive mechanism for physical change
Principal Investigator: Kazuhiko Seki (NCNP). Funded Co-Investigator: Eiichi Naito (NICT), Shinji Kakehi (Tokyo Metropolitan Institute). Other 16 Co-Investigators.

Research project A02-02: Adaptive embodied-brain function due to alteration of the postural-locomotor synergies
Principal Investigator: Kaoru Takakusaki (Asahikawa Med Univ). Funded Co-Investigator: Katsumi Nakajima (Kindai Univ), Other 7 Co-Investigator.

Research project A03-1: Visualization of brain functional dynamism by hybrid functional analysis with real-time feedback
Principal Investigator: Kyousuke Kamata (Asahikawa Med Univ).

Research project A03-2: Neural basis for the reference frame and the functional synergies in controlling eye-head coordination
Principal Investigator: Yuriko Sugiuchi (Tokyo Med Dent Univ). Other 1 Co-Investigator.

Research project A03-3: Development of assistive technologies for rehabilitation by visualizing neural representation of muscle synergies using electroencephalography
Principal Investigator: Natsue Yoshimura (Tokyo Tech). Other 3 Co-Investigators.

Research project A03-4: Human fronto-parietal network for embodied-brain system: A combined electrocorticographic decoding, stimulation and lesion study
Principal Investigator: Riki Matsumoto (Kyoto Univ: moved to Kobe Univ since 2019). Other 5 Co-Investigators.

Research project A03-5: Understanding the interaction between tactile and nociceptive information in the somatosensory cortex and controlling of nociception
Principal Investigator: Hironobu Osaki (Tokyo Women's Medical Univ). Other 2 Co-Investigators.

Research project A03-6: Body representation changes underlying motor recovery after internal capsular stroke in macaques
Principal Investigator: Noriyuki Higo (AIST). Other 3 Co-Investigators.

III. Activities

1. 2nd International Symposium on Embodied-Brain Systems Science: EmboSS2018
Date and Time: December 5-6, 2018
Place: Senri Life Science Center (〒 560-0082 1-4-2

Shinsenri-higashi-machi, Toyonaka, Osaka)
General and program chair: Eiichi Naito (NICT), **Co-chair:** Akira Murata (Kindai UNiv)
Contents: The 2nd International Symposium on Embodied-Brain Systems Science (EmboSS2018) included 6 invited lectures by internationally distinguished researchers and 10 oral presentations about main achievements obtained through the Embodied-Brain project. A total of 139 people including non-project members participated in this symposium. During two days, we had 4 topic sessions. In each session, following invited lectures, our selected members made their oral presentations and we had serious questions and debate after each talk. We also had poster sessions during two days, a total of 73 posters were presented and debated.

From the Group A, following members made their oral presentations,
Morning session on December 5
Brain networks building up sense of agency
Presenter: Hiroshi Imamizu (A01: Univ of Tokyo)
Afternoon session on December 5
EEG cortical current source estimation and synergy analysis
Presenter: Natsue Yoshimura (A03-3: Tokyo Tech)
Morning session on December 6
Neural correlates of hand muscle synergy and its plasticity (slow dynamics)
Presenter: Kazuhiko Seki (A02-1: NCNP)
Neural substrates of functional synergies-Structural basis for synergies in the head-neck motor system-
Presenter: Yuriko Sugiuchi (A03-2: Tokyo Med Dent Univ)

2. A joint meeting across A-B-C groups
Date and Time: December 7, 2018, 13:30-16:30.
Place: Center for Information and Neural Network, National Institute of Information and Communications technology (〒565-0871 1-4 Yamadaoka, Suita-city, Osaka)
Local organizer: Eiichi Naito (NICT)
Attendees: 26: Hiroshi Imamizu (A01:Univ of Tokyo), Akira Murata, Kei Mochiduki (A01:Kindai Univ), Tomomichi Oya, Kazuhiko Seki (A02-1:NCNP), Eiichi Naito, Kaoru Amemiya, Satoshi Hirose, Tsuyoshi Ikegami, Masaya Hirashima (A02-1:NICT), Kaoru Takakusaki (A02-2: Asahikawa Med Univ), Yuriko Sugiuchi (A03-2: Tokyo Med Dent Univ), Natsue Yoshimura (A03-3: Tokyo Tech), Hajime Asama, Wen Wen (B01: Univ of Tokyo), Toshiyuki Kondo, Shiro Yano (B01: Tokyo Univ of Agri and Tech), Jun Ota (B02: Univ of Tokyo), Ryusuke Chiba (B02: Asahikawa Med Univ), Shinya Aoi, Kazuo Tsuchiya (B02: Kyoto Univ), Tetsuro Funato (B03: Univ of Electro-Communications), Shinichi Izumi, Tamami Sudo (C01:Tohoku Univ), Dai Owaki (C02:Tohoku Univ), Arito Yodu (C03-1: Ibaraki Prefectural Univ of Health Sciences)
Contents: Two young researchers, Tomomichi Oya and Ryusuke Chiba, presented their data related to the issues of neural substrates of muscle synergy and computational model of postural control, which could not be covered during the EmboSS2018 meeting. The tiles of their talks are as follows:

1. Roles of multiple sensory-motor loops in motor control – Coherence between cortex, spinal cord and muscle–
   Presenter: Tomomichi Oya (A02-1: NCNP)
2. Relation between parameter and behavior in standing posture maintenance model
   Presenters: Ryusuke Chiba (B02: Asahikawa Med Univ)

IV. CONCLUDING REMARKS

This fiscal year was the last year of the Embodied-Brain project. Through this project, the Group A has indeed produced many scientific outcomes about body representations in the brain related to body cognition and motor control. As for body cognition, we have unveiled that, among various frontoparietal networks, the inferior frontoparietal network connected by the inferior branch of the superior longitudinal fasciculous (SLF III) is particularly involved in human body cognition (sense of agency and body ownership) through the processes of bodily state monitoring and error signal processing (A01, A02-1, A03-4). As for motor control, we have revealed that both cortico-spinal and rubro-spinal tracts are involved in synergy control of hand and upper limb muscles but their controlling styles are different (A02-1) and we also showed specific involvement of supplementary motor area for postural control and adjustment (A02-2). As for slow dynamics in body representations, we have successfully showed developmental dynamics of functional lateralization of body cognition to the human right hemisphere (A02-1), temporal dynamics in which motor memories are consolidated into distinct brain regions overtime after motor learning (A01), and long-term physiological adaptations to tendon transfer (body alteration; A02-1). One of the representative achievement of the Embodied-Brain project was evaluation of motor rehabilitation based on muscle synergy analysis, in the sense that this was achieved by large-scale interdisciplinary collaboration across brain science, system engineering and rehabilitative medicine (A02-B02-C02). In addition to above-mentioned outcomes, we have got new findings about plasticity of pain pathways (A03-5) and functional compensation after brain damage (A03-6), we have also beautifully demonstrated anato-functional networks of head-eye motor coordination (A03-3) and built up computational model of motor-functional recovery based on damaged-brain data (A03-6, C01). Finally, we also had tremendous progress in technical development of real-time decoding and EEG decoding (A03-1, A03-2). Personal and interdisciplinary interactions across brain science, system engineering and rehabilitative medicine have been enormously progressed through the Embodied-Brain project.
Since the Embodied-Brain Systems Science is an important academic field, which enables us to solve many serious problems in cognitive and motor functions emerging in the Japanese super-aging society, I am quite confident that the Embodied-Brain Systems Science should be further promoted with the highest priority.

Annual report of research project A01-1

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***Abstract*—Our research project mainly examines the bodily self-consciousness, which is a perceptual expression of the embodied brain system. More specifically, we aim to find neural correlates of bodily self-consciousness, and neural mechanisms in which changes in bodily self-consciousness lead to changes in body representations in the brain. Based on these findings, we develop methods to make intervention and manipulation on the bodily self-consciousness. In this fiscal year, we succeeded in intervention of the bodily self-consciousness using magnetic and direct current brain stimulations and developed a smartphone application to normalize altered bodily self-consciousness in schizophrenic patients, which are large steps forward to intervention and manipulation of the bodily self-consciousness. We published eight articles on our basic research.**

I. Introduction

Healthy humans feel the bodily self-consciousness, which includes senses of agency (SoA; "I am moving this body") and body ownership (SoO; "This is my body"). Our research project mainly examines the bodily self-consciousness, which is a perceptual expression of the embodied brain system.

II. Aim of the Project

We aim to identify neural correlates of SoA and SoO. Based on the identified correlates, we investigate neural mechanisms in which changes in bodily self-consciousness lead to long-term changes in body representations in the brain. Furthermore, we establish methods to make intervention and manipulation on the bodily self-consciousness by using the findings. Finally, we will develop effective methods for promoting adaptive changes in the body representation, to reflect body states properly.

III. Research Topics

A. Development of basic techinques for manipualtion of bodily self-conciousness

A group of the principal investigator intensively committed to experiments for intervention and manipulation of SoA.

1) **Intervation of SoA using brain stimulation**: Based on our previous study on fMRI decoding attribution of movements to self or others [1], we hypothesized that the right inferiro parietal lobe (rIPL) intermadiates sensory prediction error and subjective judgement of SoA. To test this hypothesis, we applied a transclanial magnitic and a direct current stimuli to rIPL. As a result, we found that the simuli weaken correlation between sensory prediction error and subjective rating of the attribution, which supported our hypotheis.

2) **fMRI neurofeedback training to manipulate SoA**: To enhance effect of the training, we explored training methods. We gave feedback information on the activation level of rIPL while 8 subejcts underwent a motor task but found that this method was not effective. We recently tried another method in which we made subejcts conentrate on the neurofeeback training and tansfer the training effect to the motor task in 7 subejct. We are now analysing the recnt result.

3) **Psychiatric disorders and SoA**: It is known that SoA alters in many types of psychiatric disorders. We developed a mehtod to investigate brain nework that causes common alterations in cognitive functions across multiple disorders, and published it in *eLife* [2]. It is also known that SoA is weakened in autistic spectrum disorder (ASD). We investigated synergy of finger movements in ASD and found an exessive dependence on the ring finger, to which the cerebellum was related [3]. This result suggested contribution of the altered synergy control to the weaked SoA.

4) **Voluntary control of postural sway based on visual feedback**: We found that intentional control of posture based on visual feedback enhances postural sway [4], which suggests that natural feedback of SoA is necessary for effective rehabilitation.

B. Mechanisms of body representation in the human brain and clinical applications

Yukari Ohki (funded co-investigator, Kyorin University) and her colleagues performed experiments described below.

1) They analyzed 64-channel EEG recordings, obtained in previous years. Normal human subjects (n = 18) performed a rubber hand illusion paradigm. In the last year, they performed event-related spectrum change analysis, and observed stronger activities in the left hemisphere. This year, they used cluster-based permutation test to examine if EEG changes could be detected in the right hemisphere, which was reported to be important for SoO in previous studies. For the test, all samples were selected whose t-value was larger than some threshold, and the selected samples were clustered based on temporal, spatial and spectral adjacency. They detected a cluster in the right occipito-parietal areas (P4-P6, PO4-8, O2). In the areas, the event-related potential was weaker than the midline areas (FCz-Cz). They also analyzed the event-related spectral change. When comparing trials with and without SoO, significant clusters were observed in the left occipito-parietal areas (α-γ bands). However, by comparing trials under strong and weak SoO, powers in the γ band were increased in the right occipito-temporal areas. The results suggest that EEG can be used to detect brain activities in the right hemisphere relating to SoO, which might be difficult to detect online. This study was done with Dr. Hayashi (Reading University, International Activities Supporting Group).

2) They also examined markers for SoO and SoA. They performed experiments of the active rubber hand illusion, by using VR. Normal human subjects manipulated a CG right hand presented 12 cm in front of the real one, by moving the latter.

They have to move the CG in a circle, when delays between hand and CG motions were introduced (90-480 ms). The larger the delay was, the more SoO and SoA were decreased. In addition, movements were more deviated from the circle under larger delays. They found that the agency was determined not only by the delay but also by the movement variability, whereas the body ownership was mostly determined by the delay. The findings suggest that the goal-related motor performance influences the agency judgment more strongly than the ownership [5].

C. Physiological mechanisms of body representation in the monkey brain

Akira Murata and Kei Mochizuki (funded co-investigator, Kinki University) investigated the effect of corollary discharge for neuronal activity in the parietal cortex of the monkey. For this purpose, the group tried to find neural activity related to sensory attenuation resulted by corollary discharge in the somatosensory area of monkey. The activity of single cells in the right somatosensory cortex were recorded while tactile stimulations on the monkey left hand were applied with a brush controlled by a lever manipulated with monkey's right arm. With this set up, the brush moved on somatosensory receptive field in several conditions; synchronously with pushing/pulling lever movement, with some time delay (100ms -600ms) from lever movement or automatically moved without any lever movement (passive stimulation). Of 388 neurons that has somatosensory receptive field on the left hand were recorded from the right post central cortex. The responses of these neurons were influenced by lever movement, showing less or higher activity compared with passive somatosensory stimulation, or not influenced [6]. Statistical analysis was also applied to study correlation between neuronal activity and delay length. Of 388 recorded somatosensory neurons, 73 neurons showed less activity with longer delay, while 104 neurons showed higher activity. In other words, former neurons indicate enhancement and latter ones indicate attenuation during arm movement. This is likely due to corollary discharge accompanied by motor behavior of the right arm. The remaining neurons didn't have significant correlation with length of delay. Furthermore, some neurons showed activity correspond with lever movement, but not with brush movement. This might be due to corollary discharge or proprioceptive input.

D. Methodology for studying aberrant sense of agency in schizophrenia, and its underlying pathophysiology

Takaki Maeda (funded co-investigator) and his colleagues have progressed in understanding for neural basis of SoA thorough behavioral, computational, neuroimaging and physiological studies. They developed a smartphone application (APP) to normalize distorted SoA in schizophrenia.

1) They measured resting-state fMRI in 20 healthy subjects and compared with behavioral data of the Keio method. They analyzed functional connectivity for the normal emergence of SoA and showed the agency neural network. This study will contribute to identification of target connectivity for the future neurofeedback training.

2) To study neuro-dynamical account for SoA emergence, they employ a recurrent neural network (RNN). The RNN model successfully reproduced the behavioral features of SoA task in the healthy controls. Moreover, the simulated lesion experiment illustrated that bidirectional changes of SoA (excessive and diminished SoA) could be induced by the temporal perturbations of signals in sensory-motor prediction process.

3) They have continued a post-surgical operation study on SoA for 13 participants. The influence of resection around insula or inferior parietal lobe could provide critical roles of those areas for SoA.

4) They developed rehabilitation systems on SoA in which patients could normalize their distorted SoA using the originally programmed smartphone APP. In order to evaluate effectiveness of the APP, they developed predicting system of mental state using smartphone-based passive sensing of everyday life log information [7].

5) As a neuro-physiological study on SoA, they investigated readiness potentials preceding the voluntary action reflected the reliability of action consequence [8], and associative learning of social values in patients with schizophrenia by measuring skin conductance response to interpersonal stimuli [9].

IV. Future Perspective

We found various types of neurons underlying the bodily self-consciousness, which deepened understanding neural basis of the bodily self-consciousness. We found EEG markers of the bodily self-consciousness but online monitoring of the makers was left for the future work. We succeeded in intervention of the bodily self-consciousness using brain stimulation and developed a smartphone application to normalize altered bodily self-consciousness in schizophrenic patients. These results will largely contribute to effective methods for promoting adaptive changes in the body representation.

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Annual report of research project A02-01

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Abstract*—In the FY2018, we established 1) slow dynamics in the adaptation to tendon-transfer surgery 2) *understanding of developmental adaptation in the human cerebrocerebellar loop (slow dynamics), and development of new fMRI decoding method, and 3) State prediction in the cerebro-cerebellum and fully-digitized evaluation of cerebellar ataxia.

I. Introduction

Our research group is based on three major Neuroscience hub in japan (NCNP, NICT, TMIMS) and include 18 scientists. Through frequent collaboration and discussion, we would like to find how the embodied brain control our body.

II. Aim of the Group

Aim of our collaborative study is to know the neural organization of muscle synergy generator and controller using electrophysiology and functional Brain imaging and propose the biomarker of brain plasticity on body representation. Research Topics

III. Research Topics

A. Neural adaptation in response to change in the musculoskeletal system

The musculoskeletal system can change over time (e.g. development or aging) or by injuries. After limb amputation or traumatic injury, somatosensory and motor cortical areas, as well as subcortical areas are reportedly subject to substantial reorganization, accompanied by an alternative (compensatory) motor coordination. However, so far, only little information is available about the cortical and subcortical adaptations to this physically modified body and its underlying mechanisms. By changing a primate's body using tendon cross-union of two forearm muscles, Seki's group seek to study the physiological adaptations on cortical and subcortical level as well as the time course with which those changes occur within and between cortical structures. This animal model will specifically be useful for neural description of both fast and slow dynamics of adaptation. We trained monkeys to perform a simple grasping task with two different objects (power grip and precision grip). Behavioural observations as well as chronic EMG (electromyographic) recordings from different forelimb muscles were used to evaluate the recovery and functional performance of the monkey. In this FY, First, analysis of the unidirectional muscle relocation model revealed that there are two phases in the slow dynamics of adaptation. We established a new analysis method to decompose muscle activity patterns x their changes after tendon transfer (3 months) by nonnegative matrix factorization (NNMF) (B01: Collaboration with Dr. Yano and Kondo). By using this method, we extracted two element that showing different time constant in a course of adaptation. While one element seemed to be responsible for the acute phase of recovery, other element showed dominant contribution for the later period. This suggests that different neural adaptation mechanisms worked in the acute phase and the chronic phase. Secondly, from the analysis using bi-directional rearrangement model (cross-transferred model), we found the possibility that there are 2 phases in the adaptation process of the motor control strategy mediated by "muscle synergy" (B03: collaboration with Dr. Funato). Throughout the adaptation period, we found that the spatial pattern of muscle synergy was invariant, while the time variation of each muscle synergy changed in two phases. During the adaptation acute phase, the time-varying pattern of a muscle synergy was changed as if it swapped between two muscle synergies in which the transferred muscles were belonging to. However, as the task performance increase, it again changed toward the original pattern.

Analysis of the two muscle relocation models revealed that there are at least two phases of slow dynamics of central nervous system adaptation to body modification. While the muscle synergy spatial pattern (muscle synergy generator: assuming spinal cord and primary motor cortex) does not change, time variation of muscle synergy (muscle synergy controller: cerebellum, premotor precursor · parietal cortex etc.) is flexible according to the adaptation phase. This prototype of adaptation may be applicable for other models.

B. State prediction in the cerebro-cerebellum and fully-digitized evaluation of cerebellar ataxia

B-1. State prediction in the cerebellum

Kakei's group, together with Tanaka's group in JAIST (B01), has demonstrated that the cerebellum provides a forward model, which predicts future inputs from the cortical motor areas. Recent computational studies hypothesize that the cerebellum performs state prediction known as a forward model. To test the cerebellar forward-model hypothesis, we analyzed relationship between activities of the three major groups of cerebellar neurons: mossy fibers (MFs) (inputs, n=94), Purkinje cells (intermediate, n=83), and dentate cells (DCs) (outputs, n=73) in the cerebro-cerebellum, all recorded from the same monkey performing step-tracking movements of the wrist. We found that activities of MFs at time $t+t_1$ were reconstructed as a linear sum of activities of DCs at time t. Namely, DC activities encode predictive information about future MF activities (i.e. output from the motor cortex). Our result further demonstrated that the cerebellum is compatible with a Kalman filter, a specific type of a forward model (Tanaka et al., The Cerebellum, *in press*).

B-2. Fully-digitized evaluation of cerebellar ataxia

Evaluation of movement disorders is hampered by a poor precision of movement examination by physicians. To overcome this problem, Kakei's group, in collaboration with Kondo's group (B02), developed a whole-body motion evaluation system [2]. This system provides ten-times higher precision of motion analysis of: 1) a body part of interest (Fig. X, *black dots*); 2) the whole body as a link of bones (Fig. X, dots with other colors). We are now developing a fully-digitized clinical scores for ataxia (SARA) in collaboration with an international consortium.

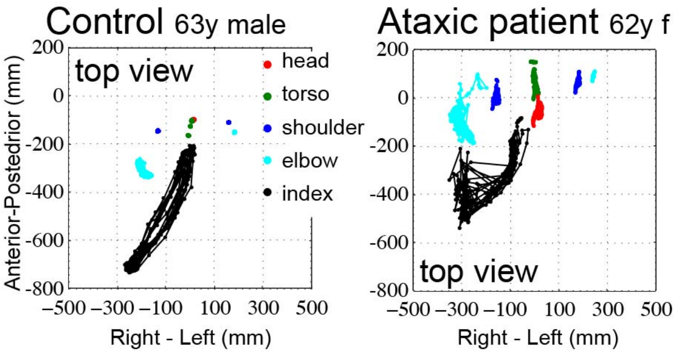

Fig. 1. Digitized SARA (nose-finger test) with Kinect v2. In contrast to low (a few cm) resolution of conventional SARA, it is possible to evaluate body movement with 1-mm resolution using our digital-SARA. It should be emphasized that most clinical evaluations focus only on movement of small body parts (e.g. index finger: black dot), while our system provides a precise description of both individual body parts and the whole body.

C. Development of human cerebrocerebellar loop (slow dynamics)

In association with Kakehi's investigations about cerebrocerebellar loop, Naito's (CiNet/NICT) group conducted MRI experiments to investigate how human cerebrocerebellar loop develops both anatomically and functionally. First, using diffusion MRI, we depicted cerebrocerebellar afferent, efferent and spinocerebellar tracts in healthy children (aged 8-11 years), adolescents (aged 12-15 years), and young adults (aged 18-23 years; n = 19 per group). When we evaluated the extent of fiber maturity (e.g. degree of myelination) in each tract of both hemispheres, we found that these fiber tracts slowly mature from childhood to adulthood [1]. Next, using functional MRI, we measured brain activity while these participants performed alternating extension-flexion movements of their right wrists in precise synchronization with 1-Hz audio tones and examined developmental change in cerebellar functional connectivity. We found that, compared with adults, children and adolescents showed relatively weaker connectivity between the ipsilateral cerebellum and the contralateral primary motor cortex (M1) and relatively stronger connectivity within the local cerebellum (hemisphere and nuclei) [1]. Along with development, local connectivity within the cerebellum became weaken, in contrast, distant connectivity between the cerebellum and M1 gradually increased (Figure). The series of results showed that cerebro(M1)-cerebellar loop, which plays important roles in motor control, is still immature during childhood both anatomically and functionally, and this loop matures slowly along with human development. This study confirmed the principle of "local-to-distant" development (slow dynamics) of functional brain networks and clearly demonstrated that such slow dynamics principle is observable in the development of human cerebrocerebellar sensorimotor network.

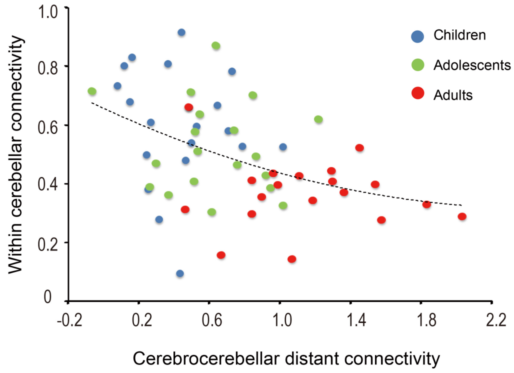

Figure 2. Local-to-distant development of the cerebrocerebellar sensorimotor network in humans. Each dot represents data obtained from each participant. Blue: Children, green: Adolescents, red: Adults. Vertical axis indicates degree of within cerebellar (local) connectivity (a.u.) and horizontal axis indicates degree of cerebro(M1)-cerebellar (distant) connectivity.

IV. Future Perspective

Through five years of collaborative research, slow dynamics in the neural adaptation to body alternation / development / adaptation to disease was investigated, and their relation to muscle synergy (generator and controller) were addressed.

It is expected that we will continue collaborative research even after the research period for elucidating underlying mechanisms.

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Annual report of embodied-brain project A02-2

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Abstract **- Voluntary movements requires a sequence of postural control that is optimized to the purposeful actions. This process is organized by the prediction of body-circumstance interaction and motor programs that produce postural synergies. The aim of our group is to understand cortical and subcortical mechanisms in these processes. In this fiscal year, we examined how postural synergies were functionally organized by descending brainstem spinal cord pathways and how they were regulated by neuro-transmitters. We found that postural synergy that was organized by integrating signals of plural descending pathways was altered by cholinergic-serotoninergic interaction operating at the pontine reticular formation (PRF). Such a subcortical mechanism may play regulate state-depending modification of postural synergy. Damages of this mechanism may underly abnormality of postural synergies accompanied by neurodegenerative disorders.**

I. Introduction

Postural control is disturbed in patients in cerebrovascular and neurodegenerative disorders. Because postural control that is optimized to the purposeful actions is required to achieve movements under the relevant circumstance, understanding neuronal mechanisms of adaptive postural control is critical so that scenario for reconstructing motor function after brain damages can be established [1].

II. Aim of the Group

The aim of our research group is to elucidate higher order mechanisms of postural control during movements. In this fiscal year, attempts have been made to understand subcortical mechanisms of controlling postural synergies in the brainstem and spinal cord in response to cholinergic and serotonergic projections to the PRF in the cat.

III. Research Topics

1. Hypothesis of generating basic postural synergy

Brainstem and spinal cord are involved in generating postural synergy by the activation of reticulospinal tract (RST), vestibulospinal tract (VST) and monoaminergic pathways (Fig.1) [2]. Activity of the RST is largely influenced by signals from the PRF that receives cholinergic efferents from the pedunculopontine tegmental nucleus (PPN) and monoamine-ergic efferents from the locus coeruleus (LC) and dorsal raphe nucleus (DR). LC and raphe nuclei constitute monoaminergic pathways to spinal cord. These pathways act on spinal moto-neurons directly and/or via spinal interneurons (INs) [2]. The brainstem receives orexinergic and GABAergic projections from the hypothalamus and basal ganglia via the substantia nigra pars reticulata (SNr), respectively [2]. Efferents from the cerebral cortex and cerebellum also converge to the brainstem. These efferents may, therefore, regulate postural synergy.

2. Brainstem output of generating postural synergy

(1) Default or prototype of postural synergies

Electrical stimulation (40 μA, 50 Hz) was applied to various sites in the brainstem in decerebrate cats. Ia monosynaptic reflexes of quadriceps femoris (Q), posterior-biceps semitendi-nosus (PBSt), lateral gastrocnemius soleus (LG-S) and tibialis anterior (TA) was recorded in the left. Changes in knee (Fig. 2A) and ankle (Fig.2B) joints' synergies were elucidated by the changes in these reflexes. There was a topographical or-ganization in the brainstem. Specifically, stimuli applied to dorsal part of the pontomedullary reticular formation (PMRF) suppressed extensor and flexor reflexes (co-inhibition; filled circles) of both joints. However, ventral PMRF stimulation generated either extension (squares) or flexion (triangles) or co-contraction (open circles), i.e., generation of various types of synergies. While PPN stimulation evoked a synergy of co-inhibition, stimuli of the LC and raphe nuclei resulted in co-excitation, extension or flexion. Stimulation of the lateral vestibular nucleus (LVN) generated extension synergy. There-fore the VST and monoaminergic pathways mainly modulated antigravity muscle synergies. On the other hand, the RST

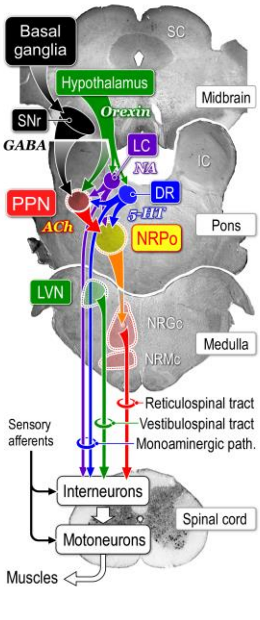

Figure 1. Hypothesis

SC & IC; superior & inferior colliculi, NRPo; nucleus reticularis pontis oralis. NRGc; nucleus reticularis gigantoce-llularis, NRMc; nucleus reti-claris magnocellularis.

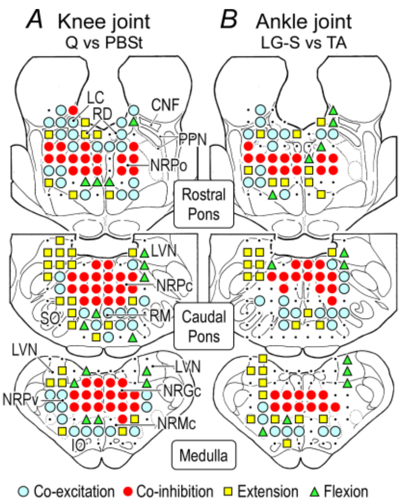

Figure 2. Postural synergies in knee (A) and ankle (B) joints by brainstem stimulation

Effects and sites of stimui on coronal planes of rostral pons (upper), caudal pons (middle) and medulla (bottom). Filled circles, open circles, squares and triangles are co-excit-ation, co-inhibition, extension and flexion, respectively. CNF; cneiform nucleus, LVN; lateral vestibular nucleus, RM; raphe magnus, SO & IO; superior and inferior olive, NRPc; nucleus reticularis pontis caudalis, NRPv; nucleus reticularis parvocellularis contributes to flexion and extension of leg joints in addition to co-excitation and co-inhibition.

(2) Neurotransmitters modulated postural synergies.

ACh and monoamine neurons exhibit state-dependent activity in relation to the alteration of muscle tone. [3] Because both groups of neurons converge to the PRF (Fig.1), changes in postural muscle tone were examined following injections of carbachol (long-acting cholinergic agonist) and 5-HT into the PRF (Fig.3A). While carbachol injection suppressed soleus muscle activities, subsequent injection of 5-HT into the same site restored muscle tone, indicating ACh-5-HT interaction at the PRF reciprocally regulates postural muscle tone. Then a critical question is how such a pontine mechanism modulates postural synergies that were shown in Fig.2?

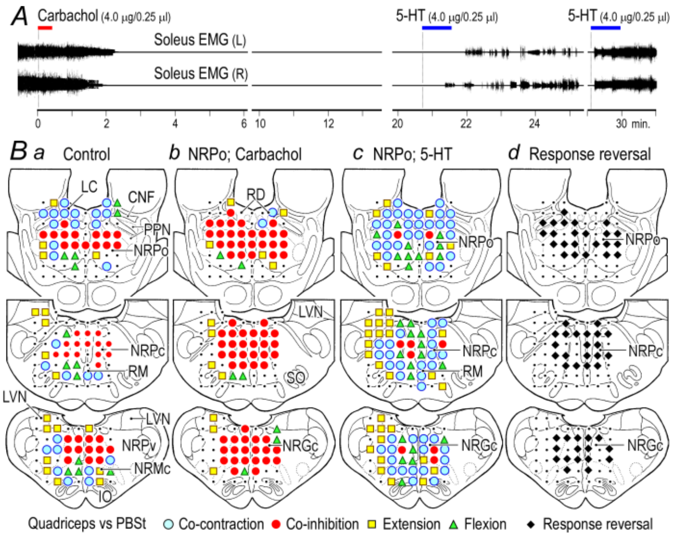

Figure 3. Alteration of postural synergy by ACh/5-HT interaction at the PRF
A. Changes in electromyographic activity (EMGs) of bilateral soleus muscles following injections of carbachol (4.0 μg/0.25 μl) and 5-HT (4.0 μg/0.25 μl) into the NRPo. B. Knee joint synergy by brainstem stimulation (a), and its alteration following pontine injections of carbachol (b) and 5-HT (c). (d) Sites which produced response reversal are indicated by filled diamonds.

In control condition, brainstem stimulation evoked postural synergies in knee joint which were resembled to those in Fig. 2A (Fig. 3Ba). Carbachol injection increased the number of co-inhibition sites instead of decreasing the number of sites of generating movement synergies (Fig. 3Bb). In contrast, 5-HT injection reduced the number sites that evoked co-inhibition while sites where stimulation generated movement synergies were increased (Fig. 3Bc). It should be noted that synergistic responses were reversed by carbachol and 5-HT injections. Because sites which produced response reversal [5] were restricted within the PMRF (Fig.3Bd), there was a need to examine how reticulospinal neurons (RSNs) contributed to the modulation of postural synergy in response to cholinergic-serotonergic interaction at the PRF.

3. Muscle tone relating RSNs and spinal INs

Because output of the RSNs are largely mediated by spinal INs (Fig.1), changes in the firing rates of the RSNs in the medullary reticular formation (MRF) and INs were examined during carbachol-induced atonia (Fig.4A) and 5-HT-induced hypertonus states. During atonia, RSNs in the dorsal to mid part of the MRF and INs in ventral horn and intermediate region had firing rates more than 10 Hz (Fig. 4A). However, RSNs in the mid to ventral part of the MRF and INs in dorsal horn and intermediate region were more active (Fig.4B) during hypertonus state. These findings revealed the presence of functional topographical organization in the RSNs and INs in relation to the generation of postural synergy. Interaction of these neurons may be the key mechanism of response reversal or alteration of postural synergy.

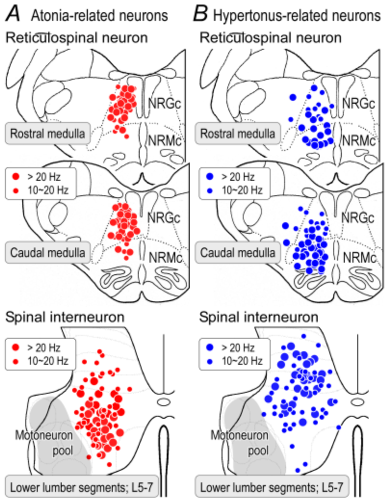

Figure 4 Muscle tone relating neurons
Locations of atonia-relating (A) and hypertonus-relating (B) RSNs and INs.

IV. Summary and Future perspective

Findings in this fiscal year are summarized as follows. First, plural brainstem-spinal cord pathways are involved in the generation and control of postural synergy. Second, cholinergic and serotonergic reciprocity within the PRF may play crucial role in the alteration of postural synergy (response reversal) by modulating excitability of reticulospinal-interneuronal systems. Physiologically, such a transmitter-dependent response reversal can be one of the bases of state-dependent postural synergy and movement control. Because neurodegenerative disorders, such as Parkinson's disease and Alzheimer's disease, associate with severe damages in neurotransmitter systems [6], the present findings may help understanding pathophysiological mechanisms underlying abnormal posture and movements during wakefulness and sleep. In this 5 year's research term, our research group partly reveal cortical mechanisms of cognitive posture-gait control and brainstem-spinal cord mechanisms of generating postural synergy. Manner of functional connection of these systems is further required for thorough understanding normal and abnormal posture-gait control.

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Annual report of research project A03-1

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***Abstract*— For epilepsy diagnosis, it is empirically known that pathological networks render diagnosis more difficult and complex. To perform quick and clear network analysis, we applied cortico-cortical evoked potential (CCEP) recording and real-time high gamma activity (HGA) mapping. We treated eight intractable epilepsy cases with subdural grid implantation, using presurgical CCEP, HGA, and diffusion tensor imaging (DTI)-based tractography analysis. Six of eight patients had measurable pathological CCEPs. Although pathological CCEP latencies varied between 18.1 and 25.6 ms, they diminished after complete disconnection in four cases, with good postsurgical outcome (long-term postoperative seizure-free status), while the four patients with residual pathological CCEPs showed poorer seizure outcome. CCEP measurement and real-time HGA mapping enables visualization of pathological networks and may improve seizure outcome.**

I. AIM OF THE GROUP: 1) Kyousuke Kamada; Selection of Patients, Operation, recording, 2) Hiroshi Ogawa;: Recording, 3) Christoph Kapeller; Data processing, 4) Takahiro Sanada; Recording, Data procesing.

II. RESEARCH TOPICS: Intractable epilepsy may arise from multiple foci or low seizure threshold (high epileptogenicity). There is growing evidence from neuroimaging studies that intractable epilepsy involves pathological functional networks that allow rapid spread of focal seizure activity. we measured cortico-cortical evoked potential (CCEPs) to identify normal and pathological networks in intractable epilepsy patients using subdural electrode grids. Furthermore, combined CCEP, high gamma activity (HGA), and diffusion tensor imaging (DTI)-based tractography allowed us to map patient-specific networks for surgical planning 9 10. Based on these networks, we delineated a feasible surgical strategy for each patient to disconnect the functional connectome of epileptogenic foci. In addition, we used intraoperative CCEP monitoring to confirm tract disconnection.

A. First topic: Identification pathological Network in epilepsy patients. Eight patients suffering from intractable epilepsy underwent surgical treatment. CCEPs revealed pathologival network

Topic 2; Intraoperative CCEP

[Case 7] ECoG monitoring revealed two foci including in the

ECoG monitoring revealed two foci including in the right frontal lobe and the right measial temporal region,including the parahippocampal gyrus. Stimulation to the Hippocampus evoked CCEPs on in anterior fronto-temporal regions (Figure. 1). We dissected the Sylvian fissure and exposed the limen insula. The key procedure was to widely expose the upper and anterior roof of the temporal horn after

Second topic; We continuously monitored CCEPs evoked by stimulation of epileptogenic foci and language-related centers during surgical resection under general anesthesia. The surgical procedure was designed to avoid moving the grids and strips during continuous CCEP recording. Alteration of CCEP profiles and tractography-based neuronavigation enabled us to confirm successful disconnection of pathological networks in real time.

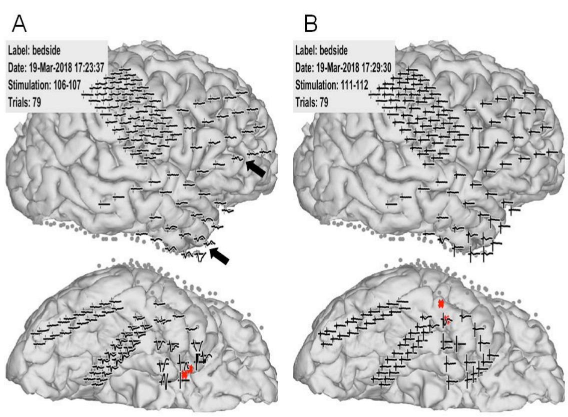
RESULTS;

Table 1. Basic clinicodemographic characteristics of individual patients

Case	Age	Foci	Pathology	Symptoms
1	29	Lt F/T	FCD I	CPS
2	28	Bil F	none	CPS/GCS
3	32	Lt T	FCD I	CPS
4	22	Rt T	FCDI/HS	CPS/GCS
5	30	Rt T	Trauma	CPS/GCS
6	31	Lt T	none	CPS
7	33	Rt T	none	CPS
8	22	Lt F	FCD II	GCS

CPS: complex partial seizure, FCD I: focal cortical dysplasia type I, FCD II: focal cortical dysplasia type II, HS: hippocampal sclerosis, GCS: generalized convulsive seizure, Lt F/T: left fronto-temporal, Bil F: bilateral frontal, Lt T: left temporal, Rt T: right temporal

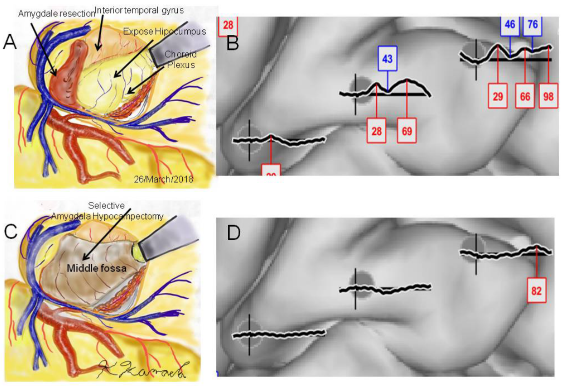
Figure 1 [Case 7]Bed-side pathological CCEP Intraoperative



removal of the anterior part of the insular cortex. We finally exposed a 25-mm section of the left ventricle roof, indicating anatomical disconnection of the uncinate fascicles. After disconnection, pathological CCEPs disappeared (Figure. 2B, D). We thus, therefore, performed selective Hippocampectomy (Figure. 2A, C). The patient was ultimately seizure-free with no neurological deficits.

Figure 2: [Case 7] Intraoperative CCEP monitoring

[Discussion] CCEP recording has become popular [1]and rapidly getting more attention to identify and monitor the subcortical confirmation of functions compared to other neuroimaging modalities [2]. Recent studies demonstrated bedside-CCEP mapping is reliable to monitor the subcortical functions and identify the new networks, which were validated ECS mapping [3]. On the other hand, few studies have applied CCEP to identify pathological



functional networks in epilepsy [4]. In this report, we described that combination of CCEP detection and tractography would contribute to identify the pathological networks in various types of epilepsy. Pathological CCEPs by electrical stimulation to foci appeared in 50% of intractable epilepsy patients, while other 50% has no pathological CCEP. There was no difference of symptoms, seizure frequency or type in both groups. In the cases with pathological CCEP, we further applied intraoperative CCEP monitoring and observed complete disappearance of pathological CCEP, which suggested us to achieve network disconnection and prevention against propagation of epileptic activity in the foci [5]. As a result, the patients had favorable prognosis of seizure control. We would like to propose that pathological CCEP would be the new biomarker for epilepsy diagnosis and intraoperative surgical decision. All patients showed rapid decreases in pathological CCEP amplitudes upon disconnection of the target fibers, which resulted in favorable seizure outcome. On the other hand, case 5 with posttraumatic epilepsy might have insufficient coverage of subdural grids and did not show any pathological CCEP, because her MRI demonstrated left hippocampus and wide lateral aspect of the left temporal lobe and occipital pole. We resected only a part of the lateral aspect only and found poor seizure control. We considered that the insufficient coverage possibly causes misleading findings and breaks precise epilepsy diagnosis. It would be better to make the coverage plan for diagnosis using non-invasive techniques such as high-density EEG or whole-head magnetoencephalography in cases with wide damaged lesion on routine imaging studies before the first surgery.

III. Future Perspective

Intraoperative CCEP monitoring with enough coverage areas for network disconnection may reveal the underlying pathology and would be a potential intraoperative biomarker of epilepsy surgery. Further, combined CCEP monitoring with tractography may navigate neurosurgeons for disruption of epilepsy networks, enabling with greatest possible preservation of maximally preservation normal functions.

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Annual report of research project A03-2

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Abstract—**When rotational acceleration is given to the head, and the semicircular canals are activated, the head turns in the opposite direction to compensate for the head movement to maintain stable gaze [1]. Such stereotyped head movement evoked from the activated semicircular canals should be produced by activation of a proper set of neck muscles in a specific spatial and temporal pattern. Since vestibulospinal reflex is phylogenetically old, it may be the prototype of the motor control system in the central nervous system. This study was aimed at revealing the neural substrates for muscle synergies in the vestibulocollic reflex system. In the present study, we examined the innervation pattern of neck motoneurons by single vestibulospinal tract neurons that convey semicircular canal input, and discussed the functional meaning of the results in relation to the results obtained from the electrophysiological experiments in the early part this study, which showed convergent input patterns from the six semicircular canals to motoneurons of various neck muscles.**

I. Introduction

When our head turns, visual image on the retina is displaced and the vision is obscured. In order to prevent this phenomenon, head angular acceleration is detected by the semicircular canals in the inner ear, and provokes compensatory movements called vestibular reflex. In this reflex, the eyes and head rotate in the same plane as, but in the opposite direction to, the plane of head rotation. These are called vestibuloocular and vestibulocollic reflexes, respectively. Since the peripheral oculomotor system composed of six pairs of extraocular muscles is relatively simple, the pathways for vestibuloocular reflex were well analyzed both electrophysiologically and morphologically.

In the vestibulocollic reflex, the directions of canal-specific compensatory head movements are so stereotyped that signals from a particular semicircular canal must be distributed to a proper group of neck muscles in a specific spatial and temporal pattern. Since those muscles that belong to such a group have a common function to rotate the head in an exactly opposite direction in the same plane as the activated canal, they form a functional synergy. Because of anatomical and biomechanical complexity of the head-neck system, neural pathways regarding head-neck movements have not been well analyzed. Since vestibulospinal reflex is phylogenetically old, it may be the prototype of the motor control system in the central nervous system.

II. Aim of the Group

This study was aimed at analyzing the neural substrates of muscle synergies in the vestibulocollic reflex system. Our working hypothesis is that muscle synergies in the vestibulocollic reflex are basically determined at the single cell level, namely, by projection patterns of single vestibulospinal tract axons innervating neck motoneurons.

Before starting analysis of the morphology of single vestibulospinal axons to prove this hypothesis, we examined the input patterns from individual semicircular canals to various neck motoneurons in the cat. The present study revealed the following basic principles of the innervation patterns. 1) The main pathways for excitation and inhibition were disynaptic via vestibular nucleus neurons. 2) All neck motoneurons received excitation from the contralateral and inhibition from the ipsilateral horizontal canal. 3) All motoneurons receive reciprocal inputs (i.e., of different polarities) from the anterior canal on one side and the posterior canal on the opposite side. 4) Among neck motoneurons examined, four different input patterns were identified based on the differences of the vertical canal inputs. The results suggested the possibility of forming synergies among those neck muscles of different phylogenetic origins. These findings on convergent input patterns from six semicircular canals to individual neck muscles also revealed the divergent output patterns from a particular semicircular canal to multiple neck muscles.

As a next step, in order to analyze axonal projection pattern of single vestibulospinal tract axons, we stained vestibulospinal tract axons with an intracellular injection of horseradish peroxidase (HRP) and visualized the trajectories of single vestibulospinal axons to different neck motoneurons.

III. Research Topics

A. *Electrophysiological identification of single vestibulospinal tract axons*

Experiments were performed in anesthetized cats. They were mounted on a stereotaxic apparatus placed on a turntable. The middle ear cavity was opened, and fine Ag-AgCl wire electrodes, insulated except at the tips, were placed on the oval and round windows on both sides [2]. A laminectomy was performed between C1 and C4 to permit intraaxonal recording from medial vestibulospinal tract (MVST) axons.

B. Identification of semicircular canal input

Intraaxonal recording was made from axons in the ventral funiculus in the upper cervical cord between C1 and C3 with a glass micropipette filled with HRP solution with 0.2M KCl. Axons activated by electrical stimulation of the primary vestibular nerve with latencies less than 1.5 ms was regarded as monosynaptically activated [3]. They were further examined as to their responses to manual rotation of the turntable in 3D planes, and by determining the maximal response plane of rotation, the semicircular canal input to the axon was identified.

C. Intracellular staining and data analysis

After electrophysiological identification of MVST axons, HRP was injected iontophoretically through the recording electrode [4]. After the session of intracellular injection, HRP was injected into the nerves to some of neck muscles to label motoneurons retrogradely in some experiments. After a survival time of 10-36 hours, the cats were deeply anesthetized with pentobarbital sodium and were perfused and fixated transcardially. The cervical cord and the brainstem were removed and serial transverse frozen sections of 100 μm thickness were made on a sliding microtome. The sections of the spinal cord were treated for HRP by the heavy metal-intensification method of Adams [5]. Sections of the brainstem were treated with the benzidine hydrochloride method of De Olmos and Heimer [6]. Axonal trajectories and branching patterns of stained neurons were reconstructed from serial sections under a microscope equipped with a camera lucida drawing attachment.

D. Projection pattern of single MVSTaxons that reecive horizontal canal input

Injection sites of HRP were usually identified in the stem axons running in the mediodorsal part of the ventral funiculus. Stem axons were found in the medial part of the ventral funiculus throughout their course, which verified that they were MVST axons.

MVST axons that were monosynaptically activated from the contralateral horizontal semicircular canal ran in the ventral funiculus and gave rise to multiple axon collaterals to the gray matter at multiple segments in the upper cervical cord. These collaterals arose at various intervals from the stem axons. They ramified in the gray matter several times and spread in a delta-like manner. Axon terminals of these axon collaterals were distributed mainly in laminae IX (motor nuclei) [7], including the ventromedial (VM), the spinal accessory (SA) nuclei and lamina VIII dorsomedial to the VM nucleus. The latter area corresponds to the commissural nucleus described by Rexed [7]. However, our previous study showed that it contains motoneurons innervating neck muscles [8]. In well-stained axons, distribution of terminal branches in lamina IX covered most of the area in the VM nucleus. Our previous analysis on intraspinal locations of motoneurons of each neck muscle indicated that motoneurons for individual dorsal neck muscles occupied characteristic positions in the transverse plane of the ventral horn corresponding to the VM, and the overlapping between adjacent motor nuclei was rather small [8]. These findings indicated that single MVST axons that receive contralateral horizontal canal input project to motoneurons of most of the upper neck muscles. Therefore, this characteristic morphological feature of single MVST axons is considered to contribute to form a functional synergy in the vestibulocollic reflex in the horizontal canal system.

IV. FUTURE PERSPECTIVE

Our electrophysiological results indicated that excitatory outputs from the horizontal semicircular canal should be distributed to all neck muscles. The results of the present morphological study showed that in the horizontal canal system, excitatory MVST axons project to the most part of the VM in lamina IX and lamina VIII dorsomedial to the VM nucleus in the upper cervical cord, which strongly supports our working hypothesis that the neck muscle synergy in the horizontal canal system is represented in the projection pattern of single MVST axons. On the other hand, our electrophysiological results indicated that in the vertical canal system, not all but only a part of neck muscles are activated or inhibited by a given vertical canal. The projection pattern of single vestibulospinal tract axons in the vertical canal system is yet to be analyzed to answer the question if our working hypothesis is applicable to the vertical canal system.

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Annual report for research project A03-3

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***Abstract*—The aim of this research project is to visualize neural signaling and muscle synergies during hand and foot movements using non-invasive recording methods. This technique could contribute to rehabilitation programs by allowing for visualization of changes over time in neural signaling and muscle synergy organization following short and long-term motor learning. We have shown the possibility of a decoding method using electroencephalography (EEG) cortical current source (CS) signals as a synergy representation analysis in the previous years. In the academic year of 2018, towards the application of the method to real life, we investigated reduced numbers of EEG electrodes [1] and suggested new methods to improve decoding performance [2]. These achievements were published in 3 international journals [1~3].**

I. INTRODUCTION

The project representative and colleagues succeeded in reconstructing two muscle activity signals relating to wrist flexion and extension by estimating signals of EEG-CS that were equidistantly distributed over the surface of the cortex [4]. We expect that this technique will allow us to identify neural representations of muscle synergies by associating brain activity signals with EMG signals.

II. AIM OF THE GROUP

Using EEG and functional magnetic resonance imaging (fMRI), we aim to visualize neural representations of hand and foot movements and to investigate their relationships to muscle synergies.

III. RESEARCH TOPICS

A. *Configuration and the minimum number of EEG sensors to maintain decoding performance using EEG-CS [1]*

Our project group had shown that EEG-CS enhanced decoding accuracies in ankle flexion and extension movements including force level decoding [5]. We further investigated the relationship between the number of EEG sensors and the decoding accuracy [1]. Our results showed no significant difference was observed in the accuracies when the number was reduced by half (i.e., 16 ch) and quarter (i.e., 8 ch) (Fig. 1, bottom). However, when the 8 electrodes were localized over the central brain area (8 sensors (2), Fig. 1, upper right), the accuracy significantly decreased even the area is close to sensory-motor area. The results showed electrodes should be placed to cover the whole brain rather than to localize over the regions of interest (ROIs) when using EEG-CS for decoding and to maintain the decoding performance with reduced electrodes. The result also provides a useful insight for future simplified implement towards general applications.

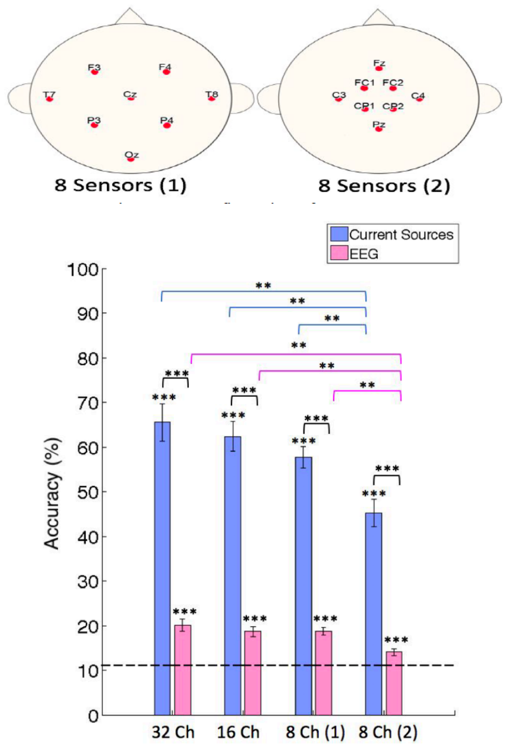

Figure 4 – Classification accuracies for four types of EEG sensor configurations. *** $p < 0.001$, ** $p < 0.01$ and * $p < 0.05$.

Fig. 1. The difference of decoding accuracies depending on the number of electrodes and configurations.

B. *A fast, robust, and generalized decoding method using sensory prediction errors [2]*

Movement intention decoding is one of the most popular targets for brain-machine interface (BMI) research, and event-related desynchronization (ERD) or synchronization (ERS) are mainly used for the purpose. The ERD/ERS is detected approximately a few hundred milliseconds (ms) after a user starts to imagine the movement of a specific body part. On the other hand, our newly suggested method published in *Science Advances* requires only 96 ms to detect users' movement intention with 87.2 % of decoding accuracy [2]. The method uses sensory prediction errors to decode Match and Mismatch of the actual movement to one's intended direction, which therefore provides fast decoding.

Moreover, the sensory prediction errors could be detected even using subliminal electrical stimulation to evoke movement direction, and users who could not show high decoding accuracies in ERD/ERS decoding also showed increased accuracies in Match/Mismatch decoding. The results suggest

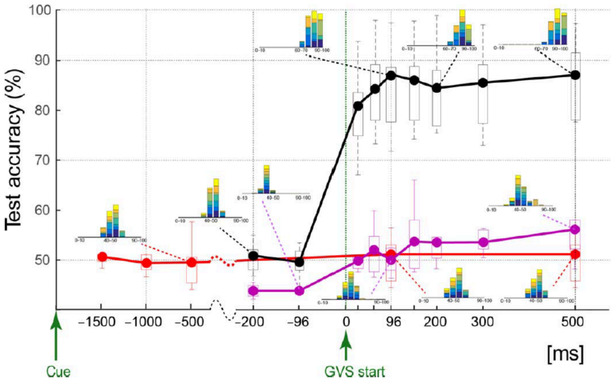

Fig. 2. The difference of decoding accuracies depending on the number of electrodes and configurations [2].

that the new method is used as a fast, robust, and generalized decoding method for movement intention.

C. Warped phase coherence combining phase and amplitude information for improved movement intention decoding [3]

We have found another method to improve decoding performance for movement intention and published it in the journal *Chaos* [3]. According to the method proposed, a constant parameter is summed to the analytic signals calculated for the EEG oscillation. This causes warping of the phase angle, conferring sensitivity to additional aspects of the dynamics. The constant parameter is a sort of coherence that represents the level of phase synchronization between EEG in different tasks. By introducing the warping operation before calculating feature for machine learning input, the differences between tasks were enhanced.

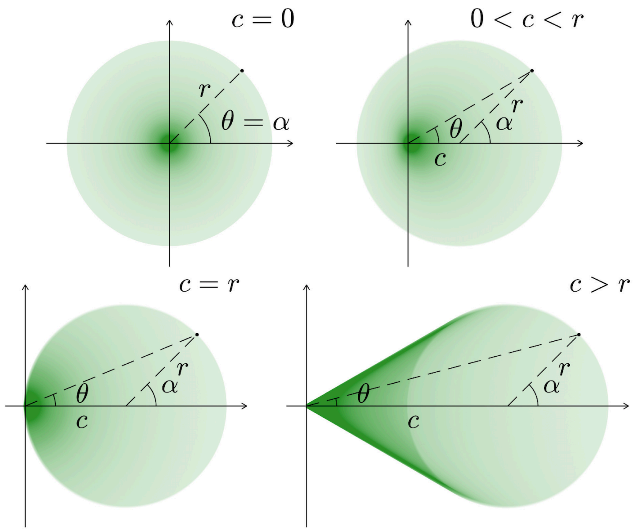

Fig. 3. The relationship between the amplitude (r) and the parameter (c) that warps the phase (α) into the angle (θ) [3].

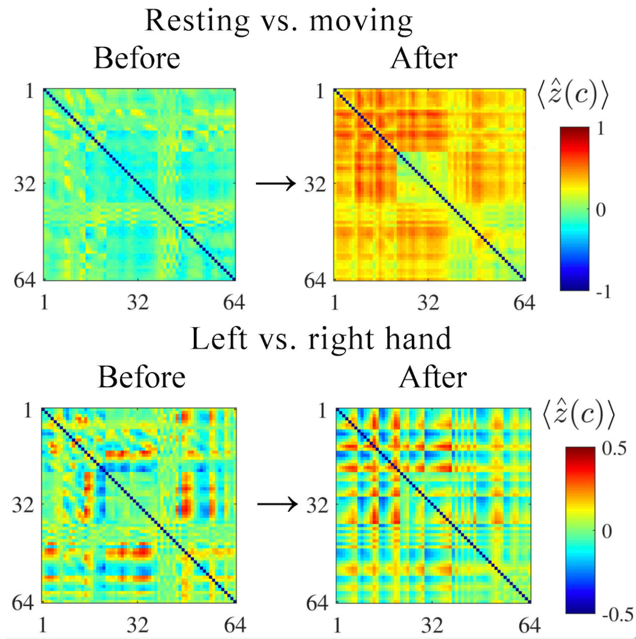

Fig. 4. The phase synchronization level of 64 channels during two tasks were dissociated much clearer after the warping operation. Top: resting vs. imagery movement tasks comparison, Bottom: the left- vs. right-hand movement imagery tasks comparison [3].

This parameter was found from mathematics and electrics approaches using chaotic non-linear oscillators. EEG is also a chaotic system including various oscillating signals that are synchronizing each other partly or fully depending on brain activity events. Therefore, we applied the warping operation to EEG signals and found that the differences between resting and performing the imaginary movements, and between imagining to move to the left or the right hand were enhanced and the decoding accuracy was increased by 7%.

IV. Future Perspective

Utilizing these supportive methods for improving decoding performance, in the next step, we are going to perform muscle synergy representation analysis using decoders calculated from EEG cortical current sources.

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Annual report of research project A03-4

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Abstract*—The implantation of subdural electrode grids over the fronto-parietal area for the presurgical evaluations of patients with partial epilepsy offers the rare opportunities to record neural activities with wide-band ECoG, and apply electrical stimulation (cortical mapping and connectivity mapping) to delineate the fronto-parietal network through the SLF III. Within the left network, functional differentiation was observed within the ventral premotor area (BA44 vs. ventral BA6). Within the right network, we have explored the neural activity for self-consciousness and sense of agency (SoA). Patients undergoing resection of the right insula, but not the left insula, for brain tumor surgery showed dynamic alternation of SoA; immediate SoA impairment after surgery was followed by gradual compensation.

I. Introduction

For epilepsy surgery, it is important to fully resect the epileptic focus to cure the disease. At the same time, it is also important to preserve the brain functions. As a part of presurgical evaluations for intractable partial epilepsy, patients undergo chronic implantation of subdural electrodes when the focus is not well determined by non-invasive evaluations or the focus is located around the important functional cortices. For functional mapping, we usually record neural activities (e.g., ERPs, high gamma activities) while patients complete a task and then locate the cortex responsible for a particular task by delineating functional impairment during electrical stimulation. The functional interference is temporary (~5 s), discretely focal (~2 cm^2) [fast dynamics], and in sharp contrast to chronic lesions usually associated with cortical plastic compensation.

In the FYI 2017, we delineated the role of the negative motor area in praxis by combining 50 Hz (fast dynamics alternation) and 3D motion capture system. We also elucidated the connectivity of the frontal aslant tract (FAT) between the medial frontal lobe and inferior frontal gyrus, which is associated with the motor/language function. In the FYI 2018, by further developing collaboration with the research group A01-1 & A02-1, we were able to integrate our invasive neurophysiology methods with sophisticated neuropsychology, decoding and imaging techniques for comprehensive elucidation of the ventral fronto-parietal network for praxis (left hemisphere), corporeal awareness and sense of agency (right hemisphere). We aimed at i) identifying the surrogate markers reflecting these clinically relevant brain functions, and ii) revealing transition from fast to slow dynamics for plastic compensation.

II. Aim of the Group/Methods

Subjects are patients with intractable partial epilepsy who underwent chronic subdural electrode implantation in the frontal & parietal areas for presurgical evaluations and gave written consent to the research protocols IRB#C533, 443 and 1062. By means of wide-band electrocorticographic (ECoG) recording, we probed neural activities in the ventral fronto-parietal network where the SLF III subserves the major white matter pathway. We focused on the functions related with “SLF III network” such as tool use, reaching, grasping and fine hand movements in the left hemisphere, and self-other face discrimination and sense of agency (SoA) in the right hemisphere. We employed an electrical tract tracing method (1 Hz electrical stimulation) of cortico-cortical evoked potential (CCEP), which we originally developed [1], to probe cortico-cortical connections in the fronto-parietal network. Based upon the direct neural recording and connectivity findings, we extracted the neural surrogate marker representing the SLF III related functions. We then applied 50 Hz electrical stimulation to the praxis-related fronto-parietal network during praxic tasks to elucidate the transient functional alternation, namely, fast dynamics alternation of the motor control and somatognosia. In the patients with electrode implantation in the right fronto-parietal areas, we recorded the ECoG during the Keio method task for assessment of SoA. We also recruited patients who underwent resection of the brain tumors in the right fronto-parietal network for the longitudinal neuropsychological assessment of SoA before and after the neurosurgery. We attempted to identify the cortex responsible for SoA and delineate the transition from the fast (functional impairment) to slow (plastic change, reorganization) dynamics alternation for SoA.

III. Research Topics

We have carried out the following three research projects.

A. Left fronto-parietal netwrok : functional mapping and its fast dynamics alternation

We recruited 6 patients with intractable left partial epilepsy, who underwent subdural electrode implantation in the left frontal area for presurgical evaluations and quantitatively evaluated the mode of impairment when stimulating the precentral gyrus and the inferior frontal gyrus (IFG) at lower intensity, where a negative motor response or the complete arrest of fine movements was elicited at higher intensity. We had revealed that precentral negative motor area (NMA) seems to play a more role in controlling elementary finger movements and could be responsible for limb-kinetic apraxia. More rostral NMA is likely associated with more complex movements and could be responsible for higher order apraxia [2]. We have studied CCEP response when the precentral gyrus or the ventral premotor area was stimulated, for exploring the neural basis of the functional differences between these two areas. CCEP responses by stimulating the precentral gyrus distributed around the precentral sulcus, whereas those by stimulating the ventral premotor area distributed from the intraparietal sulcus to the inferior parietal lobule. The difference of connectivity suggested the basis of the functional difference between the precentral and the premotor NMA. In addition, we also investigated the distribution of intrastimulus discharge (ISD), which was observed in the remote cortices during the electrical cortical stimulation, for the purpose of elucidating whether the symptom elicited by electrical stimulation is due to the impairment of the local cortex or due to the disturbance of the global network. ISD occurred within the areas where CCEP responses were observed, but high frequency stimulation of these areas showed the negative motor response only infrequently (~10%). The findings suggested most of the symptoms elicited by electrical cortical stimulation is attributed to the impairment of local cortical function [3].

Less-invasive electrophysiological methods were investigated for motor-related functional mapping with the ECoG recordings. Three cortical electrical activities, movement-related cortical potential (MRCP), event-related desynchronization (ERD), event-related synchronization (ERS) allowed the functional mapping of the primary motor area with wide-spectrum intrinsic-brain activities. This less invasive, and more sensitive mapping strategy can be the alternative to electrical cortical stimulation [4, 5].

In the future, we plan to elucidate the mode of alternation at the network level by stimulating simultaneously the two hub areas within the fronto-parietal network.

B. Fronto-parietal network mapping by CCEP

We recruited 9 patients to study the functional connectivity for the dorsal/medial parietal and frontal areas and delineated distinct connectivity patterns among the precuneus, the dorsal posterior cingulate cortex (dPCC) and the paracentral lobule (PCL): the precuneus connected more with the lateral convexity (e.g., dorsal premotor area, inferior parietal lobule [the supramarginal gyrus and the angular gyrus]), dPCC more with the medial area and the angular gyrus, and PCL mainly with pre- and post-central gyri. Within the parietal lobe, SPL had bidirectional connections to the medial parietal areas (the precuneus and dPCC) [6]. We found that these connectivity patterns resembled those of resting-state fMRI functional connectivity. We also revealed the asymmetry of the connectivity between the frontal and temporo-parietal cortices by means of CCEP [7].

C. Right fronto-parietal network for corporeal awareness: transition from fast to slow dynamics

We further developed the collaborative research with the research group A02-1 (Dr. Naito). By applying wideband ECoG recording during the self-face judgment task, we found high gamma activation around the postcentral sulcus and IFG. We will further recruit patients and decode the activity of SLF III network during self-other face discrimination.

In close collaboration with Dr. Kazumichi Yoshida (co-investigator at Kyoto Univ.), we continued a collaborative research with the research group A01-1 (Drs. Imamizu & Maeda) and B01-1 (Dr. Shiro Yano). We recruited 7 patients (right 4, left 3) with brain tumor who were planned to have the resection of the right parietal lobe or insula. We sequentially performed the SoA task (Keio method) before and after surgery to quantitate how the sense of agency changes in the acute to subacute postoperative periods. The results from patients with the right insula lesion revealed dynamic change of SoA after surgery, whereas no evident change was revealed in the patients with the left insula lesion. Those results indicated the resected area in the right insula as a responsible region for SoA [6]. We continued investigation of the dynamic change of network associated with SoA by the analysis of resting-state fMRI connectivity before and after surgery.

In 2 cases, who had intracranial electrode implantation in the right frontal lobe, we have successfully recorded the ECoG during the Keio method task. High gamma activity was observed from the right insula or premotor ventral area, implying the significance for SoA in these areas. We continued the decoding analysis of the recorded ECoG. We plan to recruit more subjects and combine the longitudinal neuropsychology assessment before and after the resection surgery, with sequential rs-fMRI evaluation in order to elucidate plastic compensation of SoA at a network level.

IV. Future Perspective

We have developed the inter-group collaboration to establish a comprehensive approach (combining our invasive neurophysiology techniques with ECoG decoding, Keio SoA method, and sequential rs-fMRI) for elucidation of the left and right SLF III network. We, in particular, focused on delineating the fast dynamic alternation (functional impairment) and its transition into slow dynamics alternation (plastic change, reorganization), so that these valuable findings can be translated into clinical neuroscience and finally into patient care. We believe our clinical system neuroscience findings contribute to the Embodied-brain System Science as important clinical reference data for the construction and verification of engineering models, and the elucidation of the long-term compensatory mechanism by rehabilitation.

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Annual report of research project A03-5

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***Abstract*— Tactile stimuli can decrease the perception of pain. This mechanism of neural network has been explained by the gate control theory in the spinal cord. However, noxious stimuli can decrease the tactile sensation. This "reverse" effect could not be explained by the classical gate control theory and indicates that tactile and nociceptive information could affect each other. In this project, we aimed to find the neural network. We found that nociceptive neurons locate in the dysgranular area in the primary somatosensory cortex (S1) of mice. Noxious heat stimulation suppresses the activity of S1 barrel field. This indicates that nociceptive input could suppress the tactile sensation through this network. We also found that the inhibitory input from the primary motor cortex into S1 had an important role for sensory information processing in S1. This M1-S1 network might explain the mechanism of tactile input suppress nociceptive information processing. By combining these findings, we propose the hypothesis that tactile and nociceptive information processing would modulate each other through thalamocortical or cortico-cortical circuits.**

I. Introduction

Melzack and Wall proposed the gate control theory, which tactile information from the skin conveyed through fast Aβ-fiber suppresses nociceptive information transmitted through slow c-fiber at the spinal cord[1]. The psychophysical studies have shown that not only tactile input suppresses nociceptive information processing, but also noxious input suppresses somatosensory processing. Therefore, tactile and nociceptive information could affect each other. It is hard to explain this interaction by the gate control theory at the spinal cord. It suggests that higher order area such as cortex may involve. However, nociceptive information processing in the primary somatosensory cortex (S1) has not been understood well including the interaction between tactile and nociceptive information.

II. Aim of the Group

Our group aims to explore the representation of nociceptive information in S1 and to find the phenomenon that the competition between tactile and nociceptive information in S1. In the last year of our study, we found the somatotopic map of nociception locates in the dysgranular area (Dys) in S1 by using the intrinsic signal imaging and the immunohistochemistry of c-Fos to report neural activation. In the current year, we compared neural properties between Dys and whisker sensory area in S1, known as barrel field (BF) to noxious stimulus by using an extracellular multiunit recording. Also, we tried to explore the role of the primary motor cortex (M1) for sensory information processing in S1 by using the focal M1 infarction model. Finally, we developed the new system to observe the effect of specific neuronal circuit activation on the animal behavior.

III. Research Topics

A. The distribution of nociceptive neurons in S1

Previous studies have shown that nociceptive neurons mainly locate in the deep layer in S1 granular area[2]. To compare nociceptive neuronal response between Dys and granular area, we recorded simultaneously from Dys and BF. By counting the number of nociceptive neurons, we found that the number of nociceptive neurons was larger in Dys than in BF. This indicates that Dys is more selective to nociceptive information than BF[5].

We also found that noxious input suppressed the activity of BF. This suppressive mechanism of noxious input to tactile responsive area would explain why noxious stimulus suppresses the function of tactile discrimination in human psychophysical studies[3,4]. This phenomenon was also observed by optogenetic activation of thalamocortical fibers. This supports the existence of an interaction between nociceptive and tactile information within the cerebral cortex.

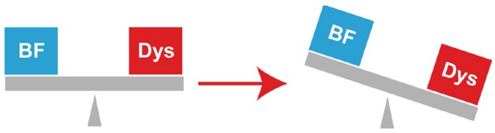

Fig. 1. Noxious stimulus activates S1 Dys and suppresses BF.

B. The role of inhibitory input from the primary motor cortex to S1

Repetitive transcranial magnetic stimulation of M1 improves neuropathic pain in human[6]. However, the neuronal mechanism of this effect has not been explained well. We tried to explore the function of M1 for sensory information processing in S1 and the affect of M1 focal infarction.

To evaluate the role of M1 for modulating S1 activity during sensory information processing, we simulated the effect of M1 input in two steps. First, we determined the parameters, which explain well the responses transferred from S1 to M1 and vice versa. For this, M1 responses were simulated from the S1 responses and compared with the recorded M1 responses. Second, the effect of M1 was simulated from the simulated M1 responses. In both steps, the simulated responses were calculated using the integrate-and-fire model[7].

The simulated M1 response (M1simR) was calculated as a summation of S1 responses (S1R) from the following equation (1):

$$M1simR(t) = \frac{1}{TW}\sum_{i=1}^{TW} S1R(t - i - \tau) \quad (1)$$

TW is the time window (ms) for integration of presynaptic input, i.e., a summation of spike activity and τ is the time delay to fire (ms) between M1 and S1 responses.

In this simulation, we successfully simulated the role of M1 and found that M1 inhibits S1 activity during sensory processing. Therefore, S1 activity was disinhibited after M1 infarction and affected temporal coding in S1[6].

This finding suggests that M1 would work as a modulator of S1 activity and change the balance of activity between Dys and BF (Fig. 2). This modulatory input from M1 into S1 may have an important role for pain relief after M1 activation.

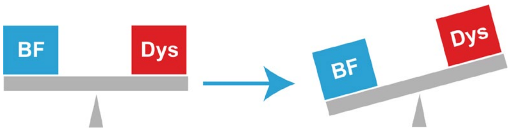

Fig. 2. Tactile input changes the balance of activity through M1 input.

C. *Developing galvo mirror controlled photoactivation combined with spherical treadmill system*

We have found that the nociceptive information is represented within Dys. This suggests that the nociceptive behavioral response according to the stimulated area in Dys. For this experiment, we developed galvo mirror controlled laser stimulation system. By using the system, we can stimulate channel rhodopsin 2 (ChR2) expressing neurons *in vivo* according to the somatotopic map of nociception. The head plate implanted animal can move freely on the spherical treadmill. The locomotion is monitored by the motion of the ball and other behavior is monitored by web cameras (Fig. 3). Currently, by using this system, we activate the specific circuit related to nociceptive information processing and monitor the behavior.

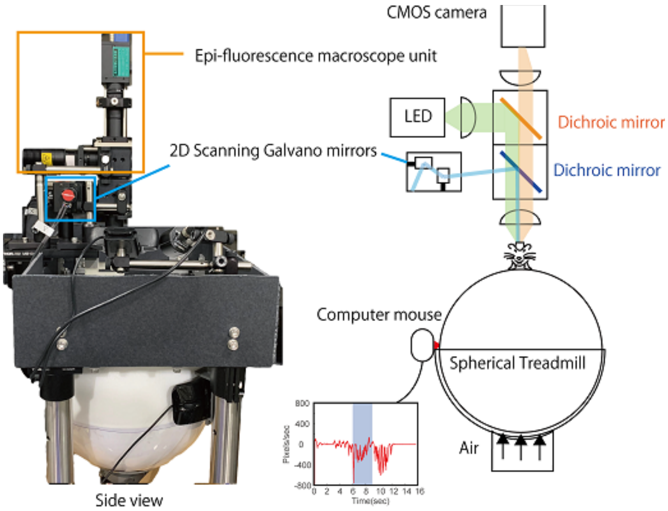

Fig. 3. Galvo mirror controlled photoactivation system with spherical treadmill system.

IV. Future Perspective

In this research project, we found that Dys in S1 are more selective than BF and suppressive effect on BF by noxious input. These findings could explain the modulatory effect of noxious input on tactile information processing. The M1 focal infarction study suggests that M1 activation would suppress S1 activity and have an important role to modulate S1 function. We try to combine these findings and adapt to the behavioral animal studies by using the circuit-specific photoactivation system of freely moving animal on spherical treadmill.

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Annual report of research project A03-6

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***Abstract*— We have investigated neuronal plastic changes, which underlie both functional recovery and pain syndromes after brain damage, using macaque models. In the studies reported here, we examined the localization of secreted phosphoprotein 1 (SPP1), which is suggested to have a role in dexterous hand movements, in the primary motor cortex (M1) of the macaque. SPP1 was localized in the cell bodies of pyramidal neurons, but not outside the cells, indicating that the protein was not secreted from these neurons. The distribution of SPP1 was also investigated in macaques whose M1 had been lesioned. We found that SPP1 was secreted by proliferated microglia in the lesioned area. Success rates in the small-object-retrieval task were positively correlated with SPP1 immunoreactivity in the neurons in the perilesional area. These results indicate that SPP1 has multiple roles in the macaque motor cortex, and it may be a key protein during recovery of hand movement after brain damage. We also investigate changes in brain activation associated with central post-stroke pain (CPSP). Brain imaging with fMRI showed activation of pain-related brain areas, including the anterior cingulate cortex (ACC) and posterior insular cortex (PIC), in animals with behavioral signs of allodynia. When either ACC or PIC was pharmacologically inactivated, the signs of tactile allodynia were dampened. Our results demonstrate a causal relationship between the increased activity in pain-related cortical regions and the symptoms of CPSP.**

I. Introduction

Neural plasticity is crucial for functional recovery after brain damage. This plasticity is exploited by rehabilitation for stroke survivors. On the other hand, central post-stroke pain (CPSP) developed as a result of maladaptive plasticity after stroke in thalamus and other brain regions involved in somatosensory processing. CPSP is characterized by not only spontaneous pain but also evoked pain in which normally innocuous stimuli are perceived as painful, *i.e.*, allodynia, and it decreases the quality of life and frequently interferes with rehabilitation of the affected patients. We have examined the process of functional recovery after brain injury in the macaque monkey, as it has cerebral and musculoskeletal structures in similar to those of humans. Our behavioral analyses suggested that recovery of dexterous hand movements can be induced by intensive postlesion training [1]. Moreover, our brain imaging analysis suggested that changes of brain activity occur in uninjured motor areas during recovery of precision grip after M1 lesions [2]. To bridge the gap between the results obtained in M1-lesioned macaques and the development of clinical intervention strategies, it is important to establish a non-human primate model of stroke at subcortical structures [3].

II. Aim of the Group

The aim of the present study is to investigate molecular basis of neuronal functions that underlies functional recovery after brain lesion. We also aimed to investigate brain activity changes underlying CPSP, using macaque monkeys as a model animal.

III. Research Topics

A. *Localization of SPP1 protein in the primary motor cortex-lesioned macaque monkey*

We previously reported that mRNA encoding secreted phosphoprotein 1 (SPP1), also known as osteopontin, is preferentially expressed in large neurons in layer V of the macaque motor cortex, most of which are presumed to be corticospinal tract neurons [4, 5]. As a first step to elucidating the cellular function of SPP1 in macaque neurons, we examined the localization of SPP1 in the primary motor cortex (M1) of the macaque by using immunohistochemistry. SPP1 immunoreactivity was found to be localized in the cell bodies of neurons, but not outside the cells (Fig.1), indicating that SPP1 was not secreted from these neurons. The results of electron microscope analysis and double-labeling analysis with marker proteins suggested that SPP1 was localized in the mitochondria of neurons. The distributions of SPP1 in the neurons corresponded to those of integrin αV, a putative receptor for SPP1. The distribution of SPP1 was also investigated in macaques whose M1 had been lesioned. We found that SPP1 was secreted by proliferated microglia in the lesioned area. Double-labeling analysis indicated that SPP1 immunoreactivity in the microglia was colocalized with CD44, another putative receptor for SPP1. Success rates in the small-object-retrieval task were positively correlated with SPP1 immunoreactivity in the neurons in the perilesional area. SPP1 has multiple roles in the macaque motor cortex, and it may be a key protein during recovery of hand movement after brain damage. A series of studies in rodents indicated that SPP1 combined with other growth factors promotes axon regeneration in both axotomized retinal ganglion cells and corticospinal neurons. Although the pyramidal neurons in the perilesional area were not directly affected by the lesioning, SPP1 may be involved in structural remodeling of these neurons, because our previous brain imaging study indicated that the perilesional area does not function immediately after M1 lesioning but comes to be involved in hand movements during the recovery period [2].

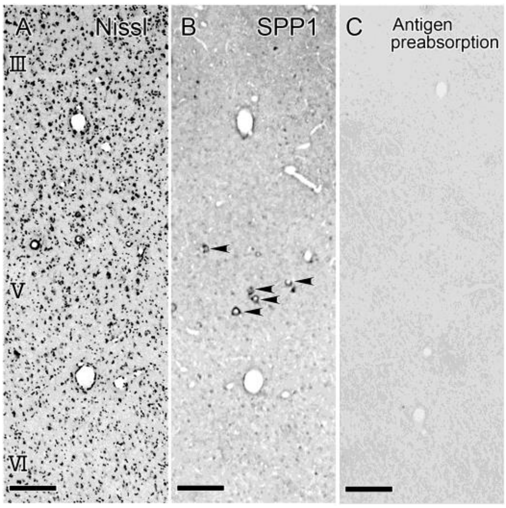

Fig. 1. SPP1 production in the primary motor cortex (M1) of the intact macaque. (A, B) Low-magnification photomicrographs of a Nissl-stained section (A) and the adjacent section stained immunohistochemically with monoclonal anti-SPP1 antibody (B). SPP1 immunoreactivity was observed mainly in large pyramid-shaped cells (30 to 50 µm in diameter) of layer V (arrowheads). (C) Control section incubated with antibody preabsorbed with SPP1; no specific signaling is observed. Scale bars = 200 µm.

B. Brain activity changes in the macaque model of central post-stroke pain

Central post-stroke pain (CPSP) can occur after stroke in the brain regions involved in somatosensory processing. Tactile allodynia, in which innocuous tactile stimuli are perceived as painful, is common in patients with CPSP. Previous brain imaging studies have reported plastic changes in brain activity in patients with tactile allodynia after stroke, but a causal relationship between such changes and the symptoms has not been established. We recently developed a non-human primate (macaque) model of CPSP based on thalamic lesions [6]. After these lesions, the animals show behavioral changes consistent with the occurrence of tactile allodynia, i.e., a decrease in the withdrawal threshold to innocuous mechanical stimulation. Here we performed functional magnetic resonance imaging under propofol anesthesia [7] to investigate the changes in brain activation associated with the behavioral change in this CPSP model. Before the lesion, innocuous tactile stimuli significantly activated the contralateral sensorimotor cortex. When behavioral changes were observed after the thalamic lesion, equivalent stimuli significantly activated pain-related brain areas, including the posterior insular cortex (PIC), anterior cingulate cortex (ACC), and amygdala (Fig.2). Moreover, when either the ACC or PIC was inactivated by muscimol microinjection during the post-lesion period, the withdrawal threshold increased to the level seen before the lesion. The present results demonstrate a causal relationship between increased brain activities and CPSP, suggesting that plastic changes in the pain areas of the brain are crucial for the development of the symptoms of allodynia.

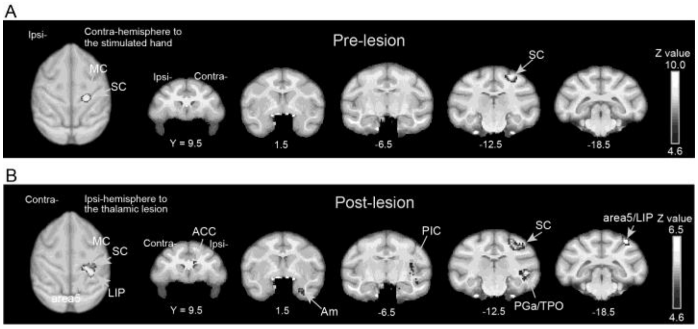

Fig. 2. Brain activity changes associated with tactile allodynia. A, B, Brain activity associated with mechanical stimulation to the contra-lesional hand (or the corresponding hand before the lesion) compared with that during mechanical stimulation to the ipsi-lesional hand during the pre-lesion (A) and post-lesion (B) periods. ACC, anterior cingulate cortex; Am, amygdala; LIP, lateral intraparietal; MC, primary motor cortex; PGa, anterior subdivisions of the angular gyrus; PIC, posterior insular cortex; SC, primary somatosensory cortex; TPO, temporo-parieto-occipital junction.

IV. Future Perspective

To obtain direct evidence of causality between SPP1 production and recovery of hand movements, a future study using virus-induced regulation of SPP1 production in the macaque central nervous system will be an important challenge. Investigating the changes of neural structure that underlie the development of CPSP is also important to elucidate the mechanism for CPSP

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Group B：Systems engineering

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I. Objective in Group B

Group B (systems engineering group) aims at establishing computational functional models of the body representation in the brain that realize sensor-motor association, through the integration of the knowledge of brain science (mainly obtained by researchers in Group A) and that of rehabilitation medicine (mainly obtained by researchers in Group C). Projects B01 and B02 construct the multi-time frequency dynamical model of the body representation in the brain with respect to its activities (fast dynamics) and its long-term changes (slow dynamics). The proposed models are verified with the experimental data from neurophysiology and the clinical data during rehabilitation treatments . Project B03 is for subscribed research projects. Members of the projects direct novel constructive approaches for modelling studies in embodied-brain systems science. Relationship between projects B01, B02, and B03 are shown in Fig. 1.

II. Research products in Group B

B01 is a planned research in systems engineering group directed to approaches from body cognition, which involves Hajime Asama (Univ. of Tokyo), Toshiyuki Kondo (Tokyo Univ. of Agriculture and Technology), Hirokazu Tanaka (JAIST), Shiro Yano (Tokyo Univ. of Agriculture and Technology), and Jun Izawa (Univ. of Tsukuba).

In this team, mechanisms that multi-modal sensory information or motion intention modulates the body consciousness (i.e., sense of agency/ownership) and modeling of the body consciousness are investigated in constructive approaches as well as identification quantitative biomarkers. Moreover, motor control models are constructed, and methodologies for model-based rehabilitation are studied.

Towards the aim, Prof. Asama examined the perception of a change in control, collaborating with A01-1. The results showed that the sensitivity in detection of an increase or decrease in control depends on the context of control. Furthermore, the group continued collaboration to find out the neural basis underlying the detection of increase and decrease in control using fMRI. Prof. Yano has engaged in mathematical modeling both of the sense of agency and the sense of ownership. He continues to propose and verify the testable experiments derived from these models in collaboration with A01-1 and A03-4. Prof. Tanaka found that the current activities of dentate cells linearly predicted future activities of mossy fibers, providing neural evidence of internal forward model in the cerebellum (with A02-1). Prof. Izawa focuses on a computational mechanism of the human motor learning which can be a basis for us to understand motor recovery and neurorehabilitation. Specifically, he found that the long-range memory for motor control which takes longer time to forget is formed by the sensory-prediction error no matter how the performance error was given to the human subject. Prof. Kondo developed a portable VR rehabilitation system with C01-1, which enlarge a visual feedback of paralyzed limb movement in VR environment. Moreover, his group investigated the requirements for a Fugl-Meyer Assessment (FMA) evaluation support system using wearable Mocap and Unity software (with C03-3).

B02 is a planned research in systems engineering group directed to approaches from motor control, which involves Jun Ota (Univ. of Tokyo), Shinya Aoi (Kyoto Univ.), and Ryosuke Chiba (Asahikawa Medical Univ.). This team aims to develop fast and slow dynamics models by focusing on muscle synergy to elucidate mechanisms of the body representation in brain for adaptive motor control under the assumption that the alteration of muscle synergy structure reflects the alteration of the body representation in brain.

Members of B02 constructed postural control model with muscle tonus controller by adding to conventional feedback controller. We verified necessity of the muscle tonus controller by using of detailed musculoskeletal simulations. And we obtained the results which similar to the human results in experiments of sliding platform. We also obtained a hypothesis that the muscle tonus control may increase body stiffness to reduce perturbation by experiments of multisensory alterations when there are errors between sensations. For the locomotion control model, we measured the hindlimb split-belt treadmill walking by rats to verify the fast and slow dynamics models proposed previously. In addition to the joint kinematics, we measured EMG data this year. We also investigated the muscle synergy structure from the muscles of the lower limbs, upper limbs, and trunk of Japanese macaques during bipedal and quadrupedal walking in collaboration with A02-2. We found common and specific spatio-temporal structures between the gait patterns.

Project B03 is a subscribed research group and deals with the problems in embodied-brain systems science from novel constructive approaches. The concrete issues are analysis of muscle synergy (Prof. Tetsuro Funato @ The Univ. of Electro-Communications, artificial thumb (Prof. Yasuhisa Hasegawa @ Nagoya Univ.), artificial muscles and tendons (Prof. Ko Hosoda @ Osaka Univ.), and finger movement (Dr. Natsuki Miyata @ AIST).

B03-1 (Funato), B03-1, in collaboration with C02-1 and C03-1, obtained new knowledge about muscle synergy in Congenital insensitivity to pain patients. Moreover, in collaboration with 02 groups, B03-1 revealed a relationship between muscle synergy and the efficiency of rehabilitation after stroke.

B03-2 (Hasegawa) investigated possibility of robotic finger's embodiment when the finger is controlled based on contraction of auricularis posterior muscles. The performances of the robotic finger were compared in two cases: the finger is controlled with or without vibration stimulation which could be a substitute of a deep sensation about finger position.

B03-3 (Hosoda) develops several kinds of sensors to observe the state of the pneumatic artificial muscles of a humanoid robot that has a human-comparative muscular-skeletal structure, for realizing reflex of the muscles. It studied on machine learning methods for learning kinematics/dynamics of a robot arm for acquiring the body image.

B03-4 (Miyata) studied the grasping strategy by the healthy hand with the artificially-disabled thumb in terms of joint range of motion. Taping technique was introduced to realize artificial disability and the grasps were analyzed focusing on contact regions.

III. Activities in Group B

Meetings of Group B and activities mainly organized by members in Group B are described as follows:

-The 36th Annual Conference of the RSJ (RSJ2018)
Date: September 6, 2018
Place: Chubu University, Kasugai, Aichi
Contents: Organized session: 10 presentations

- Group B meeting
Date: December 11, 2018
Place: Nagoya University, Nagoya, Aichi
Contents: Two presentations (Dr. Wen and Dr. Shirafuji)

-IEEE MHS 2018 (Micro-NanoMechatronics and Human Science)
Date: December 11, 2018
Place: Nagoya University, Nagoya, Aichi
Contents: Plenary Talk (Dr. Y.Hayashi, Univ. of Reading), Organized session（5 Oral Presentations, 3 Poster Presentations), Keynote speech (Dr. Izawa)

-31th SICE distributed autonomous system symposium
Date: January 24-25, 2019
Place: National Museum of Ethnology, Osaka
Contents: Organized Session (4 Oral Presentations)

IV. Future plan

Group B is going to hold academic society activities in 2018 like 2017.

As for research direction in Group B from the viewpoint of modelling aspect, members of Group B deal with two problems as a final year of the project: formulation of slow dynamics, and collaboration with Group A members and Group C members.

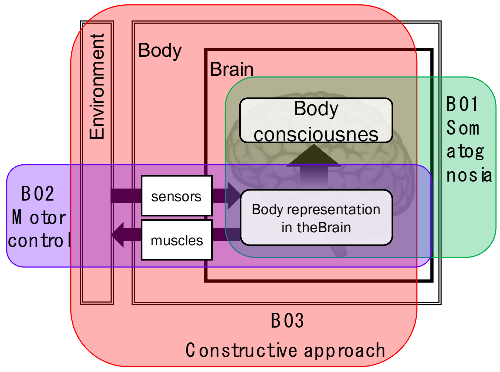

Fig. 1 Whole structure of Group B

Annual report of research project B01-1

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The University of Tokyo

***Abstract*— Body consciousness such as sense of agency and sense of ownership is generated in real time based on the body representation in brain. This process can be called "fast dynamics." On the other hand, the body representation is created, updated and transformed through perceptional and motion experience, which can be called "slow dynamics." In this group, these dynamics on the process creating and updating body representation in brain related to body consciousness are investigated and modelled mathematically.**

I. Introduction

Body consciousness such as sense of agency and sense of ownership is generated in real time based on the body representation in brain. This process can be called "fast dynamics." On the other hand, the body representation is created, updated and transformed through perceptional and motion experience, which can be called "slow dynamics." In this group, these dynamics on the process creating and updating body representation in brain related to body consciousness are investigated and modelled mathematically.

II. Aim of the Group

The concrete objectives of B01 research group are mathematical modeling of creation of body consciousness and transformation of body representation of brain, verification of cognition-body mapping model, and examination of its application to model-based rehabilitation. Fig. 1 shows the conception of body representation generation basing on body consciousness and the group structure.

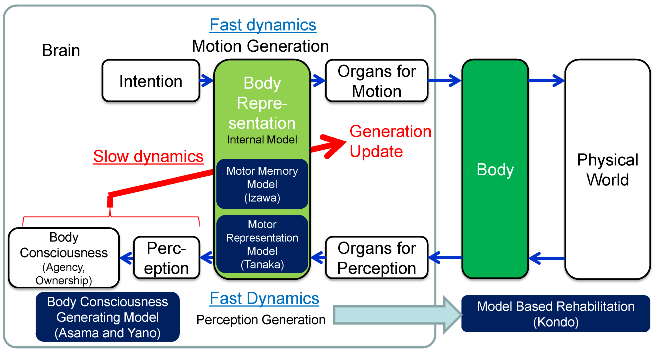

Fig. 1 Generating processes of body representation basing on body consciousness

III. Research Outcomes

A. Body Consciousness Generation Model

Asama's group (University of Tokyo) examined the perception of a change in control, collaborating with Imamizu's group (A01). The results showed that the sensitivity in detection of an increase or decrease in control depends on the context of control. Furthermore, Asama and Imamizu's group continued collaboration to find out the neural basis underlying the detection of increase and decrease in control using fMRI [1].

Furthermore, Asama's group conducted experiments using virtual reality (VR) to the sense of agency and body consciousness. The results showed that the visual replacement, which visually reduced performance error, greatly enhanced the sense of agency [2, 3]. Moreover, Asama's group found that the structure of body representation of upper limb changes only with both sense of agency and ownership [4, 5].

At last, Asama's group examined how the sense of agency influences people's reacting actions during driving. When people receive assistance of steering or cruise control, their sense of agency over the vehicle decreases because they do not fully control it. This project examined how the reaction speed changes in such circumstance [6].

Yano (Tokyo University of Agriculture and Technology) has engaged in mathematical modeling both of the sense of agency and the sense of ownership. He continues to propose and verify the testable experiments derived from these models collaborated with A01 Imamizu Group, Maeda Group and B01 Kondo Group [7]. As another project, he analyzed the long-term SoA data on a monthly basis. These data are observed from the subjects after some brain surgery operation [8]. The project is collaborative work with A01 Imamizu Group, Maeda Group, A03 Matsumoto Group. Based on the relationship between Bayesian inference and Mirror descent algorithm, he showed the algorithm similar to the Bayes' rule can also solve the decision-making problem, reinforcement learning problem and so on [9, 10]. Thus, his project currently tries to clear up the confusions related to the Bayesian learning in cognitive science area.

B. Embodied-brain Motor Representation Model

Toward understanding body consciousness, it is crucial to understand how the brain represents body movements. Tanaka's group (JAIST) and Kakei's group (A02) collaborated to analyze cerebellar neural activities of monkey during wrist movements for understanding input-output representations of a forward model [11, 12]. We examined the activities mossy fibers (cerebellar inputs), Purkinje cells (output from the cerebellar cortex), and dentate cells (cerebellar outputs), and found that they were well explained by linear models. Also, we found that the current activities of dentate cells linearly predicted future activities of mossy fibers, providing neural evidence of internal forward model in the cerebellum. The linear equations derived here were found to correspond to those of Kalman filter used in optimal estimation.

Furthermore, we tackled the neural representations of body movements and body consciousness through high-density EEG and novel signal processing methods [13-16]. Using a representation similarity analysis, we clarified directional tuning of upper-limb movements and its postural dependence represented in cortical sources [13, 14]. This result indicates that scalp EEG signals contain more detailed representations of body movements than previously thought. We also developed signal processing methods for high-density EEG to extract components that are trial-by-trial reproducible [15, 16]. We demonstrated that the proposed methods could extracts reproducible components that corresponded to mismatch negativity, steady-state visual-evoked potentials, or traveling waves in ECoG data.

C. Motor Memory Model

Izawa (Univ. Tsukuba) focuses on a computational mechanism of the human motor learning which can be a basis for us to understand motor recovery and neurorehabilitation. Specifically, he found that the long-range memory for motor control which takes longer time to forget is formed by the sensory-prediction error no matter how the performance error was given to the human subject. This suggest that the persistent motor memory is built based on internal forward model which predicts sensory change caused by the motor commands [17].

D. Model based Rehabilitation

To realize the findings in the research program as actual rehabilitation applications, Kondo's group (Tokyo University of Agriculture and Technology) (1) investigated whether the extent of event-related desynchronization (ERD) induced by actual motor execution is related to grasping intensities (%MVC) and/or visual feedback of grasping force [18], (2) developed a portable VR rehabilitation system, which enlarge a visual feedback of paralyzed limb movement in VR environment [19], and (3) investigated the requirements for a Fugl-Meyer Assessment (FMA) evaluation support system using wearable Mocap and Unity software [20].

In the first topic, this group executed EEG analysis, and found that not a motor neurons recruitment process but a motor planning/re-planning processes dominates the ERD caused by motor attempt. In the second topic, experimental result suggests that the intervention by visual amplification would encourage the frequency of use of disabled limb. It is expected to be applied to neurorehabilitation of stroke patients. In the third topic, in collaboration with Kaneko's group (C03-3), the effectiveness of the developed FMA evaluation support system was verified in healthy subjects.

IV. Future Perspective

Research on modeling of the process of generating body representation in the brain based on body consciousness and the model-based rehabilitation has been conducted by collaboration with other groups, and many novel and important results have been obtained. It is important to continue this research, utilize this result for rehabilitation, evaluation of effectiveness, and seek for deeper understanding of human adaptation function in future.

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Annual report of research project B02-1

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Abstract— **To elucidate mechanisms of the body representation in brain for adaptive motor control, we aim to construct fast and slow dynamics models by focusing on muscle synergy. We assume that the alteration of muscle synergy structure reflects the alteration of the body representation in brain, and we clarify the contribution of the body representation in brain through modeling the fast and slow dynamics of synergy structure. In this year, we verified the proposed postural controller in movable platform by simulations with musculoskeletal model. And the simulator was developed to a predictive simulator to contribute the rehabilitations. In addition, we measured EMG data from rats walking on a split-belt treadmill by their hindlimbs to verify our proposed fast and slow dynamics models in locomotion.**

I. Introduction

Body representation in brain plays an important role for the generation of adaptive motor functions (fast dynamics), while it gradually alters to adapt to the changes of several conditions by brain plasticity (slow dynamics). Meanwhile, muscle activities are represented by low dimensional structure composed of characteristic spatiotemporal patterns depending on tasks. This structure is well-known as muscle synergy and viewed as a neural strategy for simplifying the control of multiple degrees of freedom in biological systems.

In this project, to elucidate mechanisms of the body representation in brain for adaptive motor control, we aim to construct fast and slow dynamics models by focusing on muscle synergy. We assume that the alteration of muscle synergy structure reflects the alteration of the body representation in brain, and we clarify the contribution of the body representation in brain through modeling the fast and slow dynamics of the synergy structure.

II. Aim of the Group

The aim of our research project is as follows;

1. Modeling of generation of muscle activities (fast dynamics) based on muscle synergy generator and controller.
2. Modeling of alteration of muscle synergy controller (slow dynamics), which may reflect the alteration of body representations in brain.
3. Estimation of muscle synergy controller and its application for rehabilitation.

III. Research Topics

A. *Modeling of fast dynamics for postural control*

Ota's (The University of Tokyo) and Chiba's (Asahikawa Medical University) group aims to construct models focusing on fast and slow dynamics in postural controls to keep upright standing in collaboration with Takakusaki group (A02-2, Asahikawa Medical University). The model will reveal mechanism of the body representation in brain corresponding to human motion.

In this year, we investigated the validity of the postural controller which have been proposed with the muscular tonus control and the somatosensory feedback control collaborated with A02-2 research group. Tasks in this investigation were to keep a quiet up-right standing under perturbations which were to slide platform to horizontal direction of 360 degree (12 directions every 30 degree). We constructed the postural controller with a musculoskeletal model to achieve these tasks. The results showed that activities of muscles in simulations are very similar to those of human experiments. From the results, we conformed the validity of the proposed postural controller against the tasks with the perturbations [1].

We developed a predictive simulator using the proposed controller and a musculoskeletal body model. We observed alterations of postural control strategies by changings of parameters in the body model and the controller (muscle strength, noise in sensation and muscular tonus level) against the tasks to slide a platform backward. The alterations of the postural control strategies were known well as ankle and hip strategies associated with aging and we searched dominant parameters to generate the alterations in this predictive simulation. The results showed that the dominant parameters were the muscle strength and muscular tonus level and the hip strategy was generated by these parameters to be low. We expect that these findings can help to consider a scheme of rehabilitation. We also found that decrease of the muscular tonus level may be one of the reasons to generate hip strategy by aging [2].

We also aim for an evaluation of disorders' posture using our proposed simulator in cooperation with C03-4 research group. We made a comparison of postures between healthy and stroke patient and made an identification which parameters are different between them. This work will contribute a rehabilitation [3].

B. *Modeling of fast, slow dyanmics for locomotion*

Aoi's group (Kyoto University) aims to clarify the adaptation mechanism via fast, slow dynamics in motor control in locomotion in collaboration with Funato's group (B03-1, The University of Electro-Communications). In this research project, we conduct the analysis of measured data of animals and simulation studies using mathematical models of the neuromusculoskeletal system. In the last year, we developed fast dynamics model of motor control in locomotion from the reflex control of muscle synergy structure. Through the integration with a musculoskeletal model of rat hindlimbs, we performed forward dynamic simulation of split-belt treadmill walking. We compared the simulation results with measured data in rats to verify the validity of the model [4]. In addition, we developed slow dynamics model from the learning control of muscle synergy and found that the temporal pattern of the kinematic synergy showed a rapid phase shift after the environmental change, and furthermore it slowly returned after the rapid change. There trends were observed in our simulation result and verified the validity of our mathematical model in the kinematic level. In this year, we further measured EMG data in rats and found rapid and slow changes in the EMG data, which suggests the validity of our fast and slow dynamics models in locomotion.

In collaboration with Yury Ivanenko (Laboratory of Neuromotor Physiology, IRCCS Santa Lucia Foundation, Italy}), who is the leading researcher of the muscle synergy studies in locomotion, we investigated common and specific motor control structures between human walking and running. We developed a motor control model based on the physiological hypothesis obtained from the muscle synergy analysis and performed forward dynamic simulation through the integration with a musculoskeletal model. We found that the neuromusculoskeletal model can walk and run by changing only a few motor control parameters [5].

Furthermore, in this year, we investigated the relationship between the low dimensional structures in muscle and supplementary motor area (SMA) activities of the Japanese macaque during bipedal and quadrupedal walking in collaboration with Nakajima's group (A02-2, Iwate Medical University). We analyzed measured EMG data of nine muscles from the lower limbs and trunk and corresponding 26 neuronal activity data in the SMA of two bipedally trained Japanese macaques by using singular value decomposition. We found that a large portion of the muscle and neuronal activities are reproduced by four sets of spatial and temporal patterns irrespective of the gait. In addition, the four temporal patterns are similar between the muscle and neuronal activities. These will improve the understanding of motor control strategy for locomotion in the Japanese macaque.

Research achievements were presented at the poster session of the 2nd International Symposium on Embodied-Brain Systems Science at Senri Life Science Center on 5-6, December, 2018 [3, 6, 7, 8, 9] and at the organized session "Embodied-brain Systems Science" of 29th 2018 International Symposium on Micro-NanoMechatronics and Human Science at Noyori Conference Hall, Nagoya University on 9-12, December, 2018 [10, 11, 12].

IV. Conclusion

As the last year of this project, we developed models of fast and slow dynamics for postural control and locomotion. These models were verified by forward dynamic simulation of musculoskeletal models and by comparing the simulation results with measured data in humans and animals. These results will improve the understanding of the body representation in brain for adaptive motor control. We also developed the proposed method to apply rehabilitations and showed the possibility of them.

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Annual report of research project B03-1

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The University of Electro-communications

***Abstract*—In order to approach the mechanism of dysfunction due to neural ataxia and effective rehabilitation, this group studies the functional role of synergy and control system of patients with neural ataxia. This year, we analyzed synergy of stroke pattens during tasks in Fugl-Meyer Analysis (FMA), and analyzed the synergy of walking rats with cerebellar stroke. As a result, merging rate of synergies during the FMA tasks reflected the severity of stroke. This relationship could be found with 9 tasks selected from 37 FMA tasks. By the effect of cerebellar stroke in walking rats, the temporal coordination of limb rotation changed while intersegmental coordination remained.**

I. Introduction

When human and animals perform a whole body movement such as walking or standing, coordination of multiple segments or muscles called synergy is observed. Such a coordination of motor elements provides a simple representation of complex and redundant neuro-muscloskeletal system, and thus it is considered to reflects the body scheme. Synergies has been reported to change characteristically by neural ataxia [1], thus the possible use of synergy for rehabilitation is expected. In this year, we performed (A) synergy analysis of the stroke patients for synergy-based rehabilitation, and (B) an analysis of the walking motion of rats with cerebellar stroke.

II. Aim of the Group

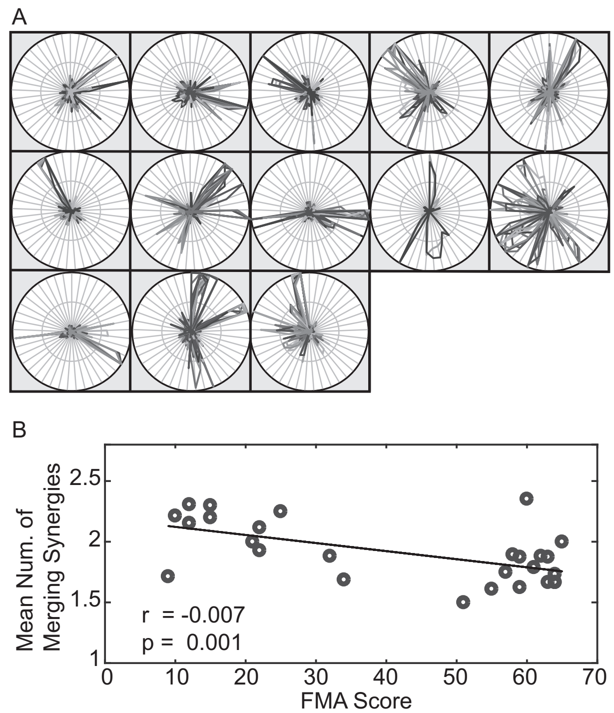
The aims of this research group are (1) to approach the mechanism of motor dysfunction due to neural ataxia through the evaluation of motion and dynamical analysis, and (2) to construct the rehabilitation method through the evaluation in motion and synergy analysis of patients with neural ataxia.

III. Research Topics

A. *Evaluation of severity in stroke patients using synergy*

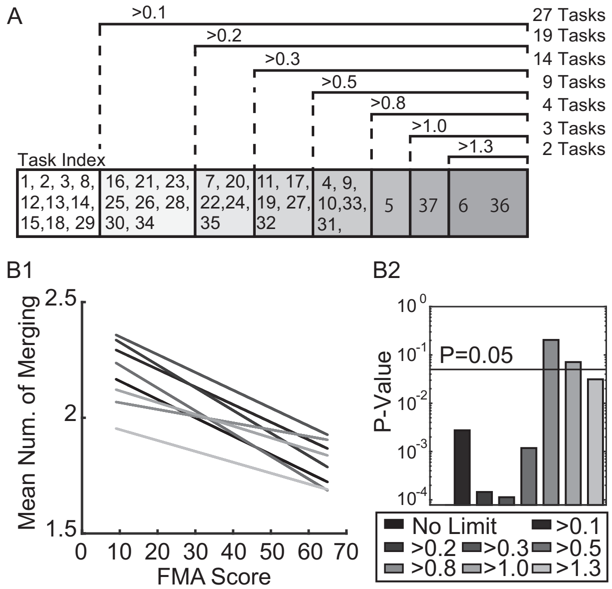
Stroke causes paralysis and reduces the functionality of movements. Rehabilitation is one of the main treatments for the stroke, and effective rehabilitation needs a good measure of the severity and recovery. For evaluating the severity of the stroke, Fugl-Meyer Assessment (FMA) is widely used. In the FMA, patients perform several movement tasks and medical professions visually evaluate their achievements as FMA score. Here, in order to evaluate the recovery, patients have to perform more than 30 tasks and which is a heavy duty for both patients and evaluators. In order to tackle this problem, our group measured the EMGs of the patients during FMA tasks. The measured EMGs were compared with FMA score and change in the EMGs with the FMA score was investigated. Moreover, by considering which tasks most contribute and which tasks less contribute to the changes in EMGs, we investigated the importance of tasks for observing the change in EMGs. Based on the importance of the tasks, we selected minimal task-set for the severity of stroke.

Fig. 1. A: Standard synergies. Each color shows one trial of healthy subject, and synergies with similar patterns are gathered in one circle as one standard synergy. B: merging rate of each subject. Each point shows the merging rate of stroke patients with FMA score. Black line is the linear regression line. r: regression coefficient and p: significance of the incline.



In order to investigate the characteristic of the EMGs in the FMA tasks, muscle synergy was analyzed. Muscle synergy of stroke patients was reported to form merged patterns of multiple synergies of healthy subjects, and this merging rate became higher with increasing severity[1]. We measured 41 muscles of 14 stroke subjects and 7 healthy patients during 37 FMA tasks and analyzed the muscle synergies. Common patterns observed in muscle synergies of healthy subjects were then searched and defined to be standard synergies. Change in the synergies due to stroke was evaluated as differences of synergies from these standard synergies. By analyzing the muscle synergies of FMA tasks, approx. 16 synergies were found both as synergies of stroke patients and as those of healthy subjects, and 13 standard synergies were found from healthy synergies (Fig. 1A). By comparing the standard synergies and stroke synergies, stroke synergies were different from standard synergies as the several standard synergies

Fig. 2. Selection of FMA Tasks. A: task index with importance. The numbers in the table are the task index summarized with importance. Numbers over the table indicate the importance, and right numbers shows the number of tasks those categorized in each task-sets. B1: linear regression result of the merging rate and B2 the P-value of the significance of the incline of the linear regression.



merging (Fig. 1B). The merging rate was higher in severe stroke patients.

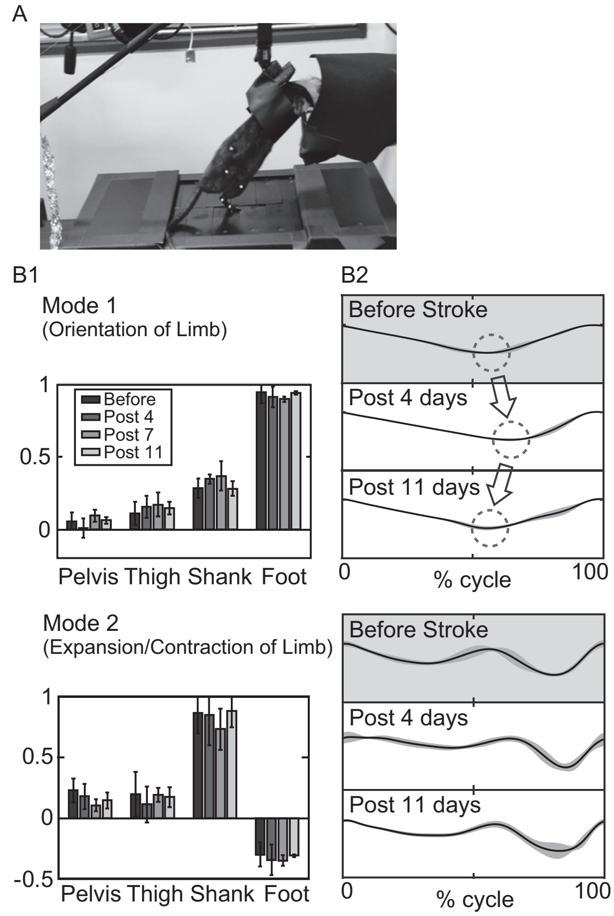
Result of the synergy analysis showed that several tasks used the same synergies. This means that some tasks were redundant for evaluating synergies. In order to find the minimum number of tasks for the evaluation of severity, we determined the importance of tasks based on the synergies. Fig. 2A shows the importance of tasks. Tasks in left are with low importance and tasks in right are with high importance. We removed the tasks with low importance and evaluated the merging rate of the synergies (Fig. 2B1B2). As a result, merging rate calculated for over 9 tasks with importance higher than 0.5 increased in correspondence with severity (FMA Score), and merging rate calculated for less than 4 tasks did not show such a relationship (Fig. 2B2). This result showed that 9 tasks pick-upped from 37 FMA task possessed enough ability for evaluating the severity using synergies.

B. Change in the walking synergies by cerebellar stroke

In order to approach the mechanism of cerebellar stroke, we constructed an experimental environment of bipedal walking in rats (Fig. 3A). We measured bipedal walking motion in both intact rats and cerebellar-stroke rats using motion capturing system, and compared the motion before and after stroke for evaluating the effect of stroke. Four rats (Wistar, male) participated in the experiment, and their motions were measured before stroke, and 4 days, 7 days, 11 days after stroke. Stroke was generated in a small area at the intermediate parts of the cerebellar hemispheres using photothorombosis method.

From the measured motion, touch-down and lift-off timing, and kinematic synergies of lower limbs were analyzed. As a result, motions of both healthy and cerebellar stroke rats were composed with two kinematic synergies, and there were no significant changes with the stroke in contribution ratio and intersegmental coordination (Fig. 3B1). In the meanwhile, first mode (limb rotation mode) of temporal coordination of the kinematic synergies changed with stroke (Fig. 3B2). Peak timing of the temporal coordination delayed with stroke and it gradually returned. Moreover, touch-down timing of stroke side and lift-off timing of healthy side delayed.

Fig. 3. Synergy analysis of walking rat with cerebellar stroke. A: Experimental system. Rats walked bipedally on a treadmill and their motion were measured using motion capturing system. B1,B2: Results of the synergy analysis of segmental motion. B1: intersegmental coordination. B2: temporal coordination.



Above all, we found the stroke at the intermediate parts of the cerebellar hemispheres affected the motion timing of limb rotation.

IV. Conclusion

- Severity of stroke can be evaluated using the merging rate of FMA synergies.
- Cerebellar stroke affects the motion timing of limb rotation.

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B03-2 Control of a Robotic Thumb by Using the Posterior Auricular Muscle

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***Abstract*—The purpose of this research is to identify the key factors of robotic embodiment, and to develop a robot control interface with better operability. This year we conducted robotic thumb control experiments using posterior auricular muscle. Based on experimental results, the improved operability of a robotic thumb implies acquisition of an internal model through repetitive operational learning process. In addition, we confirmed that use of vibration stimulation to display the position of the robotic thumb is efficient for acquiring the internal model of the robotic thumb.**

I. Introduction

Extra robotic limbs, which are designed to augment and extend human abilities, have recently attracted enthusiastic interest from robotics researchers [1]. In our previous research, we developed an extra robotic thumb that could be controlled with the user's right thumb. The body representation update after operating this extra robotic thumb by user's right thumb is investigated and discussed [2], [3]. In this year's study, instead of facilitating the update of a pre-existing body representation through training, we controled the robotic thumb using a body-part (posterior auricular muscle) which does not have a pre-existing body representation, and then evaluated its operability.

II. Research topics

This research aims at acquiring a new body representation to facilitate an extension of human body function, through the operation of a robotic thumb by using posterior auricular (PA) muscle which are not used in daily life. We intend to acquire an internal model of the robotic thumb by adding sensory feedback about the robotic thumb's position.

III. Achievements

This year we developed a PA muscle based robotic thumb control system and a vibration stimulation for position feedback, and carried out robotic thumb control experiments.

A. PA muscle-based robotic thumb control system

Fig. 1 shows an overview of the system and its architecture. The control system consists of a sEMG measurement electrode (DELSYS, sampling frequency 2,000 Hz), a PC for sEMG signal processing, a microcomputer (Arduino Mega 2560 Rev3), and the robotic thumb. First, the measured sEMG signal was rectified (sampling frequency: f_s [Hz]). Second, rectified EMG signals were sent through a low-pass filter (cut-off frequency: f_c [Hz]). Finally, the filtered EMG signals $x_i(t)$ (i=1: left side, i=2: right side) were subsequently normalized.

$$X_i(t) = \frac{x_i[t] - x_{i,min}}{x_{i,max} - x_{i,min}}, \tag{1}$$

where $x_{i,min}$ is the EMG signal measured in resting state, and $x_{i,max}$ is the EMG signal measured in the maximum contraction. In this manner, a proportionality constant, c, was used to define angular displacement of the CM joint, $\Delta\theta_{cm}$, as follows:

$$\Delta\theta_{cm} = c(X_2(t) - X_1(t)). \tag{2}$$

When a PA muscle contracted, the robotic finger moved toward little finger where the contraction was stronger. The angular displacement was used to determine the desired CM joint angle θ^d_{cm} in the following control loop:

$$\theta^d_{cm} = \theta_{cm} + \Delta\theta_{cm}, \tag{3}$$

where θ_{cm} is the current CM joint angle. θ^d_{cm} was sent to a microcomputer from a PC via serial communication. The microcomputer converted θ^d_{cm} into a PWM signal to move the servo motor (CM joint) in the robotic thumb, while the other two motors for IP and MP joints' drive remained fixed.

B. Vibration stimulation based position feedback system

Vibrotactile phantom sensation is used to feedback CM joint angle of the robotic thumb. Vibrotactile phantom sensation refers to a perceptual phenomenon where spatially separated vibrotactile actuators, which stimulate different skin zones, induce a single tactile sensation midway between the two stimulation points (the sensation will shift in proportion to intensity of the stimulation points). In this system two LRA vibration units (Nidec, LD14-002) were attached separately to the base of index finger and little finger located on the back of lefthand. The intensities of the motors were modulated according to the CM joint angle of the robotic thumb to display the position.

C. Robotic thumb control experiments and results

1) Training 1 - Acquisition of ability to contract PA muscle voluntarily: This training is conducted for acquisition of ability to contract PA muscles voluntarily. Three subjects (A through C) who can not move their PA muscles were participated. Subjects contracted their PA muscles four times for 40 seconds without EMG biofeedback. The training session consisted of six rounds, each lasting 40 seconds. In odd/even numbered rounds, subjects trained with/without EMG biofeedback, respectively. Following this procedure, four measured signals were averaged for evaluation. As a result, subject A developed his ability contract his left PA muscle after set 1.

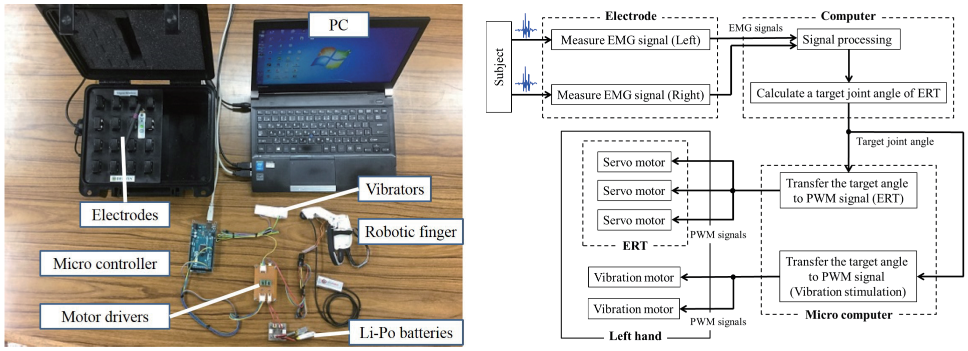

Fig. 1. Overview of the system and system architecture.

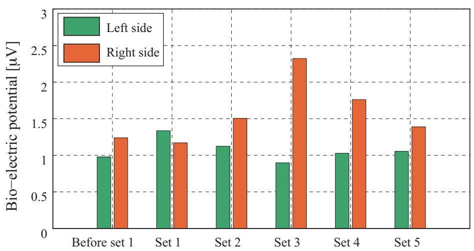

Fig. 2. Training result of Subject C

Fig. 3. Training result of Subject D

Subject B was not able to voluntarily contract his PA muscles during this training. Subjects C (Fig. 2) shows that his ability to contract PA muscles improved after set 3.

2) Training 2 - Acquisition of ability to contract seperately: Separate contraction of the PA muscle is necessary to control the robotic thumb. The training is performed with four subjects (D through G) who can contract their PA muscles. An invader game (a shooting computer game) is used during the training sessions. Subjects control a tank position toward left or right by contracting their PA muscles to shoot the targets. The training experiment consisted of nine trials. Each trial lasted a maximum of 5 min. The contraction performance was measured four times for evaluation. As a result, subject D improved the ability to contract PA muscles through training (Fig. 3). Subjects F and G were able to contract their PA muscles separately with high success rate before that the training was stopped. Subject E was able to contract the muscle independently from the beginning of the training.

3) Control of the robotic thumb by PA muscle: A reaching experiment was conducted using the robotic thumb and vibration stimulation device to verify the effectiveness of position feedback. One subject who is able to independently contract PA muscle participated this experiment. During this

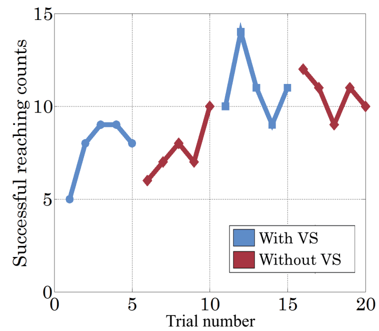

Fig. 4. Training result of Subject D

experiment, the subject was unable to see his left hand as well as the robotic finger. The experiment was performed in two sessions. A session consisted of 10 rounds. In the first five rounds, the subject received position feedback via vibration stimulation. In the second five rounds, the subject performed the task without vibration feedback. As a result, the number of successful reaching counts increased when the positions are displayed by vibration stimulation ($p<0.1$). After this experiment, the subject reported that he was able to perceive the position of the robotic thumb via vibration stimulation. Increase in successful reaching counts was observed (Fig. 4).

IV. Future perspective

In this paper, an experiment on robotic thumb control by PA muscles is carried out. It is confirmed that some of the subjects acquired an ability to contract PA muscle voluntary and separately. Moreover, as the experimental result suggests, an operability increases through repetitive operational learning.

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Annual report of research project B03-3

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***Abstract*— this research proposal studies on the body image of a human, which can be obtained through the relation between image of the body in the vision and output from proprioceptive receptors of the muscles. We use a muscular-skeletal humanoid robot and brain-like neuron model to construct the system.**

I. Introduction

There are two major ways to acquire the body image in the viewpoint of system theory. One is utilizing physical consistency of the body, and the other is utilizing operability: deriving the body image from invariance through learning of a number of tasks. The latter is not really investigated thoroughly in engineering. It is important to study about it since it has a strong relation with the expression of the body image in the cognitive mechanism (Academic year 2017-2018).

Aim of the Group

This research project studies how and where a human build body image and how a human learns the relation between the body image and information acquired through proprioceptors, by a constructive approach using a humanoid robot with human-like muscular skeletal system and brain-like neuron model.

II. Research Topics

A. Development and Improvement of a humanoid robot experimental platform with anthropomorphic muscular-skeletal strucutre

The research project has developed an anthropomorphic humanoid robot experimental platform that has similar muscular-skeletal structure as a human. The platform will be used for experiments of body image acquisition, and the roll of the muscular-skeletal structure will be investigated in a constructivistic viewpoint. The platform is shown in Fig. 1. It has shoulder, elbow, and wrist joints, and a 1 DOF hand. These joints are driven by 28 artificial muscles and 1 spring.

The structure of the artificial pneumatic muscles and bones is already completed, but it only had pressure sensors to sense the states of the artificial muscles. To implement reflex such as stretch reflex, the robot should observe the length of the muscles. It needs additional sensors to observe/sense the length. This year, the project adopt a tension sensor and a new sensor that observe expansion of the muscle, which can estimate the length, and test them on the real robot.

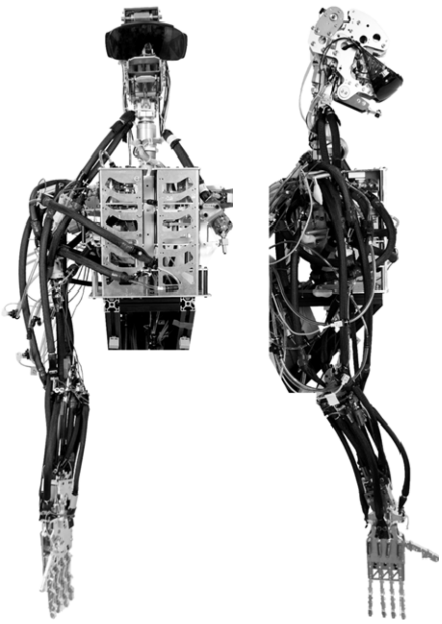

Fig. 1. Muscular-skeletal humanoid upper-body. *(The robot is equipped with 28 artificial pneumatic muscles and 1 spring. It has shoulder, elbow, an wrist joints, and a 1 DOF hand. The muscular structure is similar to that of a human.)*

B. Learning of Motion Control based on ReLU

To obtain the body image through invariance of the operation, it is necessary for the robot to learn the operation. A human is also learns its feedforward model though learning of the task, and obtains the body image.

A muscular-skeletal robot has strong non-linearity and highly complicated structure. It is very difficult for the robot designer to build its formal mechanical model. Therefore, the designer adopted a trial-and-error manner to develop the pattern of the control input. In this year, the project develops a control method to solve such a trial-and-error problem by designing learning method of the forward dynamics.

In what follows, we introduce briefly about the motion learning method. We adopt a 3-layer forward neural network for modeling the dynamics of the robot. The input of the network is the current state of the robot and the control input; the output is the state in the next step (Fig. 2). The middle layer unit is a restricted linear unit (ReLU) as an activation function. The ReLU enables to select activated unit at a time, and derive piecewise linear state equations.

The robot can utilize the equations to derive optimal control gain. Therefore, we can control the complicated robot by switching the optimal gain base on selected linear model depending on the situations. We conducted some simulations of a 2-DOF robot and a 7 DOF robot (Baxter) to demonstrate the effectiveness of the method.

III. Future Perspective

In the next year, we plan to conduct experiments to develop the relationship between the antagonistic drive and the body image.

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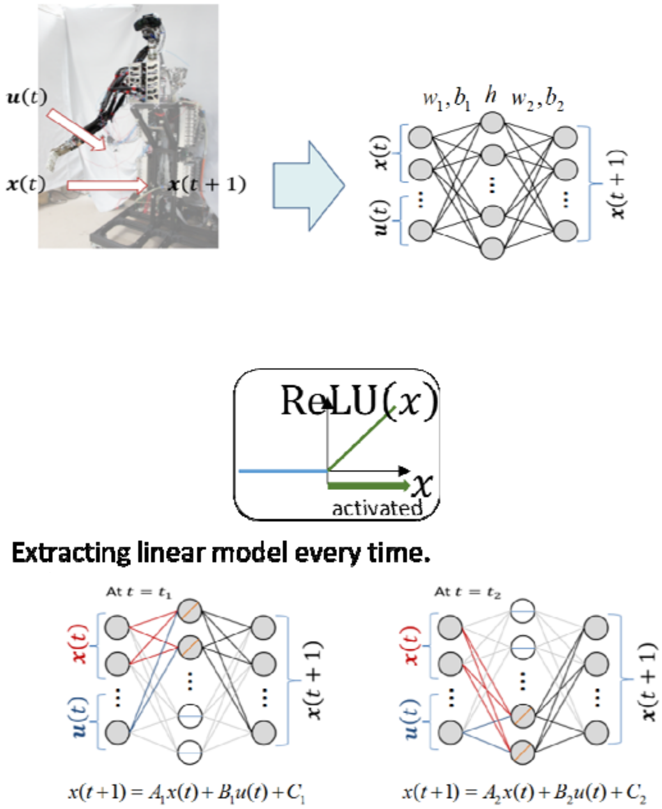

Fig. 2. A neural network for learning the forward dynamics of the muscular-skeletal humanoid upper-body. It has a restricted linear unit (ReLU) as activation function of the middle layers. The ReLU enable to pick the activated unit at the time, and derive linear state equation.

Annual report of research project B03-4

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National Institute of Advanced Industrial Science and Technology, Artificial Intelligence Research Center

***Abstract*— This paper proposes a measurement of grasping strategy by healthy volunteers with artificially-disabled hand to substitute measurement of patients with disabilities in hand function to model such patients grasps for product design. As a first step of this research, we focused on limitation of the thumb and observed grasping strategy change when fixing the thumb joints range of motion using a taping technique. Different grasping styles and some typical contact regions were observed for the artificially-disabled hand.**

I. Introduction

To arrange rehabilitation plan for patients with the functionally-limited upper extremity and to design human-friendly products for such patients, we need to understand the relationship between the degree of disability and the executable function by such disabled hand. It is, however, ethically difficult to collect such reference data adequately by observing actual patients. Therefore, we aim to clarify adaptation process of the human upper extremity due to functional limitation by observing artificially-disabled healthy hand and to estimate and evaluate behavior of the disabled hand.

II. Aim of the Group

We concentrate on human hand grasp as a task to be executed and joints' range of motion as a target of functional limitation of the upper extremity. The aim of this group is to clarify change of grasping style according to the limitation of joint range of motion (ROM).

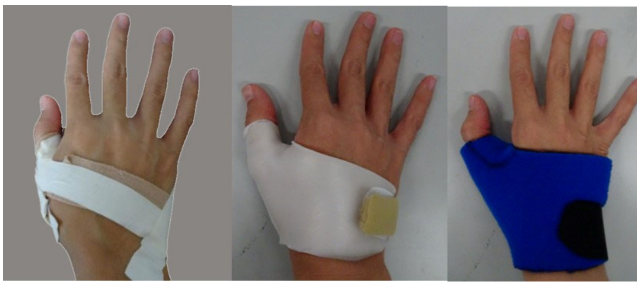
III. Research Topics

This year, we compared our ROM limitation method for the thumb joints by a taping technique with other orthoses made of different materials. Then we studied change tendency in grasping styles according to the limitation of the thumb joints' ROM for three subjects.

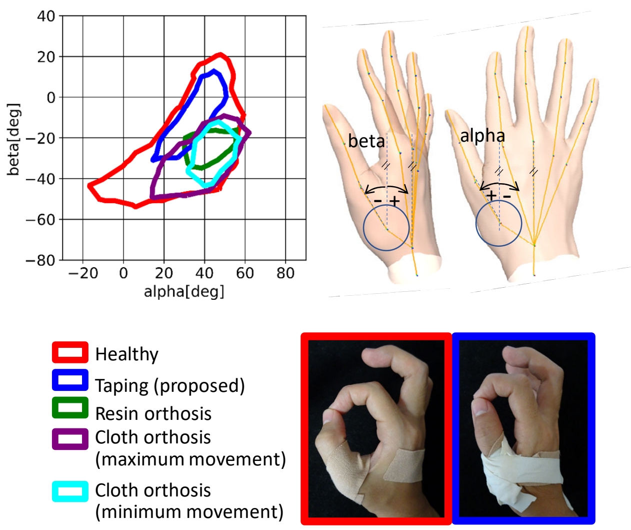
A. Comparison of the artificial ROM limitation method with other orthoses

As the thumb plays an important part in grasps [1], the author's group have tried to emulate the patient's hand that suffers from carpal tunnel syndrome (CTS), which is known to be strongly limited in the palmar abduction of the carpometacarpal (CM) joint due to atrophy of the thenar eminence. In the first year, we proposed a taping technique to realize artificial ROM limitation safely (Fig. 1(a) left). Their coupled ROM were derived using the method proposed in [2] as in Fig.1(b). The taping worked well and the joint ROM of the fixed hand (drawn as a blue boundary) were quantitatively shown to be smaller than that of the healthy hand without any limitation (drawn as a red boundary) and its function of opposition was especially limited as planned.

This year, we compared our taping method with orthoses made of resin (Fig. 1(a) center) and cloth (Fig. 1(a) right), which were prepared manually to fit the same subject thanks to the cooperation of Tokyo Medical and Dental University. ROM of the hand with these orthoses were modeled and the area ratio against the healthy hand's ROM was derived. Limitation by the orthosis made of resin was too strong to grasp any object and its ROM area was 13 % of the healthy hand's (Fig. 1(b), green boundary). In contrast, ROM area with the orthosis made of cloth (Fig. 1(b), purple boundary) was 40% of the healthy hand's ROM. Its limitation effect could be regarded as weak considering the ROM with taping method is



(a)Artificial limitation by taping, by resin orthosis, and by cloth orthosis



(b)ROMs of the CM joint limited by various orthosis and perfect-O sign by the healthy hand (left) and the limited hand by taping method(right)

Fig.1 Comparison of range of motion of the thumb joints among different artificial-limitation

24% of the healthy hand's ROM.

We also checked the perfect-O sign by the thumb and the index finger of the artificially-limited hand. Perfect-O sign is one of the simple tests to check the CTS possibility. As general CTS patients, the subject's O-sign was slightly deformed into an elliptic shape.

From these, we concluded that the taping technique can be used for the purpose of emulating the hand whose ROM was limited.

B. Adaptation of grasping style under the thumb ROM limitation among different indiiduals

In the first year, we observed grasps by a volunteer with artificially-disabled healthy hand to see the change in the time to execute a given task and contact regions in accordance with 10 repetition. The subject was asked to execute two tasks, "to lower a hammer" and "to transfer changing its posture", for two differently-sized cuboids. In the three of four conditions, the execution time decreased to the similar amount of the time by the healthy left hand. Also, the subject was observed to prefer the radial or ulnar aspect of the thumb by defining hand surface division into 34 [3].

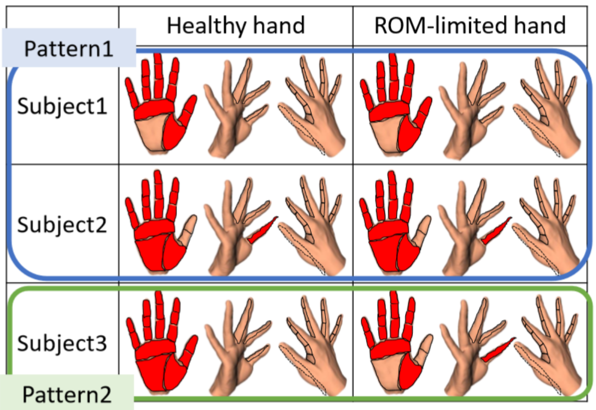
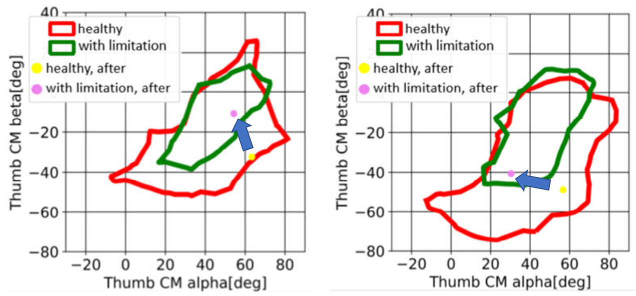


Fig. 2 Two types of the contact region change under the thumb CM joint's limitation



(a) Pattern 1 (the same contact region region preferred)

(b)Pattern 2 (different ccontact region used)

Fig. 3 Two types ontact regions under the limited range of motion of the thumb joints

This year, an experiment was conducted for three subjects to check if the above tendency would be observed commonly for other subjects. To reduce time required for the experiment, we asked each subject to try his/her grasp once to check initial guess and then give them adequate time to search for the "best" grasp for their artificially-limited hand. The experimental results showed as in Fig.2, one of the three subjects preferred to use radial or ulnar aspect of the thumb (Pattern 2) but other two preferred not to keep the same contact regions as that by the healthy hand (Pattern 1). Regarding the posture difference, the subjects in Pattern 1 reduced its palmar abduction (opposition) but the subject in Pattern 2 increased radial abduction both managing to grasp a given object.

IV. Future Perspective

This year, the grasp observation experiment was conducted for three healthy volunteers that emulated CTS patients by our taping method. The authors will incorporate the observed preference in contact region usage and posture change strategy in our system that estimates grasps according to given ROM limitation.

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Activities of Group C (Rehabilitation medicine)

Shinichi Izumi
Graduate School of Biomedical Engineering, Tohoku University

I. Purpose of the Research

In the group C, our aim is to measure the effect of rehabilitation to motor impairment after brain damage by using the biomarker of the body representation. We will provide a model-based neurorehabilitation based upon the body representation and will predict a prognosis for improvement by our method in motor impairment of the patients with hemiparesis. To achieve these goals, we set 2 research projects below.

C01：Neurorehabilitation based upon brain plasticity on body representations

The body representation stored in the brain cannot be seen by outside person objectively and thus, we alternatively try to visualize and reveal the representation of body in psychophysical way by focusing on the phantom limb, which is the vivid sensation of existing lost limb after limb amputation, because this phantom limb is a subjective experience coming not from actual sense but non-updated internal representation of body stored in the brain. By this approach, we understand the representation of body and purpose a new neurorehabilitation for motor impairment after brain damaged aimed at correcting the distorted body representation by maladaptive change.

C02：Rehabilitation for postural/movement impairments using sensory intervention

In posture/movement impairments, the temporal and spatial activity patterns of systemic muscles are impaired, and muscle synergy control may have abnormalities. This project aims to elucidate abnormal muscle synergy control in motor impairment and to propose new theories for rehabilitation using sensory intervention.

II. Members

Research Project C01

Shin-ichi Izumi (Tohoku University)
Tetsunari Inamura (National Institute of Informatics)
Naofumi Tanaka (Teikyo University)
Yutaka Oouchida (Osaka Kyoiku University)
Kazumichi Matumiya (Tohoku University)
Hiroaki Abe (Konan Hospital)
Yusuke Sekiguchi (Tohoku University Hospital)
Masahiko Ayaki (Keio University)
Mitsuhiro Hayashibe (Tohoku University)

Research Project C02

Nobuhiko Haga (The University of Tokyo)
Takashi Hanakawa (NCNP)
Hiroshi Yokoi (The University of Electro-Communications)
Dai Owaki (Tohoku University)
Akio Ishiguro (Tohoku University)
Arito Yozu (Ibaraki Prefectural University of Health Sciences)
Masao Sugi (The University of Electro-Communications)
Kahori Kita (Chiba University)
Shin-ichi Furuya (Sofia University)
Kazumasa Uehara (NCNP)

Research Project C03 (2nd period)

C03-1 The relationship between body consciousness and motor control aspects of body representation in the brain
Arito Yozu (Ibaraki Prefectural University of Health Sciences)
C03-2 Motor Skill Training/Analysis of brain plasticity Through Muscle Contraction Pattern-Based Direct Rehabilitation
Keisuke Shima (Yokohama National University)
C03-3 Study on kinesthetic illusion induced by visual stimulation under the mixed reality and brain functional connectivity
Fuminari Kaneko (Keio University)
C03-4 Development of comprehensive measurement system of balance function to monitor the effect of rehabilitative interventions
Masahiko Mukaino (Fujita Health University)
C03-5 Effect of “Hybrid-Neurorehabilitation to improve Sense of Agency” for patients with stroke hemiplegia
Shu Morioka (Kio University)

III. Activities

A, B, C group meeting

Date: Dec. 07. 2018
Place：CiNet
Contents: Research reports by each group member and general discussion.

Annual report of research project C01-1

Shin-ichi Izumi
Graduate School of Biomedical Engineering, Tohoku University

I. Introduction

The number of those who have disorder in brain function, motor and sensory functions after stroke has been rising because the number of stroke survivors is increased owing to the advance of clinical medicine. This situation creates a great need for effective rehabilitation for motor impairment and many types of rehabilitative approaches have been produced. Although some techniques improve temporally motor impairment immediately after intervention, the patients with hemiparesis tend not to use a paretic limb gradually in everyday life, because they cannot control their paretic limb as they intend. This is because the current rehabilitation approaches are not enough for a paretic limb to be a functional limb, which is a limb the patients want to use for some purpose in daily living. To make a paretic limb functional one is not only that the paretic limb is improved in function but also that brain can recognize a paretic limb as an own body part and send an appropriate motor command to the paretic limb. For this purpose, we focused on the body representation in the brain from the perspective of body cognition and observe the change so that paretic limbs are properly represented as practical limbs.

The internal body representation is a neural mechanism that mediates motor control, estimating the state of the environment surrounding the body and the body state from multisensory integration of sensory and visuo-motor information. According to previous studies, along with the plastic transformation of body representation in the brain, the body consciousness is also considered to change. It is difficult know directly what the internal body representation in our brain is. Therefore, our research group has developed a tool for quantitatively measure body-specific attention using psychophysical methods by research to search markers of internal body representation in the brain. By using this method, proactive intervention on quantitative and visualized body representation can be expected to improve the effect of neurorehabilitation.

II. Aim of the Group

For a new approach in rehabilitation, we try to measure and visualize the representation of body in psychophysiological method by focusing on the phantom limb, which is the vivid sensation of existing lost limb after amputation. Furthermore, we aim to understand the representation of body and establish a new neurorehabilitation for motor impairment after brain damage by the way of normalizing the distorted body representation by maladaptive change.

III. Research Topics

A. Longitudinal change of body representation by rehabilitation intervention

Izumi group (Tohoku Univ.) is aiming to visualize the body representation in the brain by describing the distribution of the body-specific attention around the body with a visual detection task. Our body continues to be directed by attention in order to monitor the configuration and state of it for body perception and motor control. It is known that a visual target in space near and on the body could be detected faster than that in the space far from the body. This effect is induced by the attention directed to the body, which is called as “body-specific attention”.

1) Alteration of paretic limb function and the body-specific attention

We have conducted some experiments to measure body-specific attention to the paretic and intact hand in stroke patients by last year, elucidating the relationship between the bodily attention and motor function, and further bodily consciousness. In this year, we further conducted the same experimental protocol to the lower-limb amputees in order to examine the relationship between the proficiency of using a prosthesis and the body-specific attention to the prosthesis. In this experiment, we measure the body-specific attention toward the prostheses of the amputees at the two time points, immediately after starting to use a prosthesis and just before discharge of hospital. Comparing the two time points of the body-specific attention to the prosthesis, the higher maximum gait speed with highly skilled in using prostheses, the more body-specific attention paid to the prosthesis, suggesting that a prosthesis become a body part in the brain. Thus, the amount of the body-specific attention to prostheses reflects the proficiency of using the prosthesis objectively, and is possibly one of the scales for the embodiment of artificial body like a prosthesis and tool.

2) Change of body-specific attention and brain activity in subacute stroke patients.

In the course of rehabilitation treatment of subacute stroke, we examined how body-specific attention to paretic hands, frequency of paretic limb use and brain activity change, in a longitudinal study. The outcome measures included frequency of paretic limb use measured by triaxial accelerometer, body-specific attention of paretic limbs measured by visual stimulus detection task, upper limb function (FMA, ARAT), and imaging data of brain activity during finger movement, and the evaluation was conducted at baseline, 2 weeks, 1 month, and 2 months.

All cases showed that the upper limb function improves and brain activity corresponding to paretic finger movements gradually shifted from a wide range of activities spreading in the sensory motor areas of intact hemisphere and damaged hemisphere to activity localized to the sensory motor area of damaged hemisphere. Focusing on frequency of paretic limb use, in patients with improved paretic limb frequency the body-specific attention approached the values of healthy individuals while patients with poor improvement in the frequency of paretic limbs remained low body-specific attention. Since upper limb function improved in all cases, there was dissociation between upper limb function and upper limb use frequency, and these changes were shown to be different depending on patient characteristics.

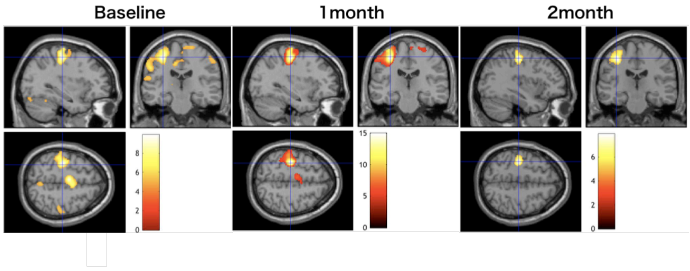

Fig. 1. Changes in brain activity during paretic hand movement

B. Development of rehabilitation support system based on VR

Inamura Group (NII) continued to build and improve the cloud-based neuro rehabilitation system based on SIGVerse to promote collaborative research in the whole project. This year, we have improved the system configuration to enable general researcher who do not belong to the project to design a variety of experimental application using the VR platform.

1) Motion Augmentation for hemiplegia

We started to investigate whether it is possible to influence the behavior of the patient with hemiplegia by exaggerating the motion using VR. The target body part is the fingers, knees, and ankles. We developed the system to display exaggerated motions in real-time using HMD. We are planning a preliminary experiment with the cooperation of the Yokohama New City Neurosurgical Surgery Hospital on verification of the effect on the actual patient for knee and ankle movement. Although the research period of the project will be over, the clinical experiment will be conducted in 2019.

2) Alien Hand Motion Experiment System

In collaboration with Prof. Shimada (C03-5 group), we improved the alien hand motion experiment system and continue to investigate the reaction of test subjects. The finger opening and closing movement were displayed on the VR in real-time and visual stimulus were inserted so that the finger motion of the VR avatar changes independently of the intention of the test subject even while instructing to stop the operation. At that time, we measured the induced finger movement (joint angle) caused by the visual stimulus, and conducted a questionnaire survey on the degree of sense of agency (SoA) and sense of body ownership (SoO). As a result of performing experiments on 16 subjects, it was found that an angle change occurred on an average of 3.2±1.3 [deg] in a stationary finger, and this value correlated with the degree of SoA and SoO.

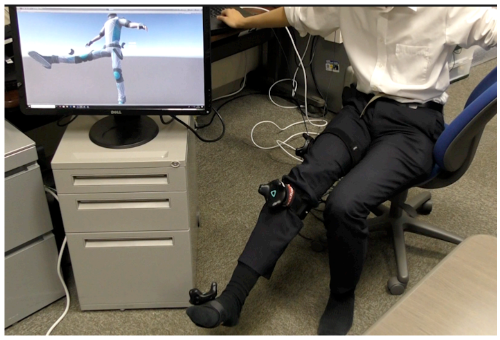

Fig. 2. An occupational therapy system using myoelectric sensor

3) Formulation of rehabilitation history data format

Various motion measurement devices are used in this project including the above case, and biosignal sensors such as a myoelectric sensor are also used. Even in experiments using various devices, the database should be uniform among all kinds of experiments. In collaboration with Prof. Kondo (B01 group), we formulate a data format to record the rehabilitation process, towards sharing the data among the research project. Specifically, we adopted a format based on Master Motor Map [5] as body motion and structure. We also developed a database system to store the recorded data in a cloud database in NII.

IV. Future Perspective

These results revealed that improvement of motor function against movement disorders can be evaluated quantitatively by measuring the body-specific attention. Furthermore, the basis of developmental platform utilizing SIGVerse based on Unity has been arranged. In the future, we will provide this platform for experiments with clinical populations, and contribute to longitudinal effects on rehabilitation.

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Annual report of research project C02-1

Nobuhiko Haga
The Tokyo University Hospital

I. Introduction

To perform motion properly, various types of sensory input must be reflected in posture/motor control prior to or concomitantly with the motion. Thus, the motor impairment is not just a musculoskeletal problem and related to sensory problems, and can be improved through sensory intervention. In posture/movement impairments, the temporal and spatial activity patterns of systemic muscles are impaired, and muscle synergy control may have abnormalities. It is not understood how muscle synergy control is altered in motor disorders. Moreover, while daily rehabilitation is an intervention for fast dynamics (FD), it remains to be elucidated what interventions provoke slow dynamics (SD) efficiently. This project aims to elucidate abnormal muscle synergy control in motor impairment and to propose new theories for rehabilitation.

Until last year researchers in project C02-1, in collaboration with other researchers in project in C02, A, and B, have started measuring muscle synergy and its related parameters in various disorders affecting motor system. They also tried to evaluate changes of the parameters after interventions like prosthetics transforming sensory modalities.

II. Aim of the Group

The aims of Haga/Yozu group (The University of Tokyo) are to clarify gait abnormality in patients with congenital insensitivity to pain (CIP) from the aspect of muscle synergy control, and to reveal whether the abnormality could be improved by interventions that compensate sensory disturbance.

The aim of Hanakawa group (National Center of Neurology and Psychaitry) is to discover imaging biomarkers of neural representation of body reflecting pathophysiology of movement disorders. To accomplish this aim, they conduct multi-modal imaging studies in patients with Parkinson's disease as a model of gait disturbance and those with focal dystonia as a model of impaired dexterity.

The aims of Yokoi/Sugi group (The University of Electro-communications) are to clarify abnormality in muscle synergy control as SD of stroke patients, and to conduct intervention in muscle synergy control as FD by using functional electric stimulation (FES). The analytical method based on fMRI, fNIRS, and EEG measurement is proposed for detecting neuroplasticity produced in motion of limbs induced by muscle synergy control as FD.

Owaki/Ishiguro group (Tohoku University) proposed a novel biofeedback prosthesis that transforms weak or deficient kinesthetic feedback into an alternative sensory modality, for rehabilitation of sensory impairments. The goal of this group is to verify the long-term effect of this prosthesis in patients with sensory impairments.

III. Research Topics

A. *Study on patients with motor impairments due to sensory disturbance*

Haga/Yozu group made the up-to-date summary of CIP. Based on the assumption that the gait abnormalities come from abnormalities in muscle synergy control, the investigators developed a measurement system for muscle synergy of gait in collaboration with Owaki and Funato groups. However, the system has shut down only after measurement of two participants. Thereafter, the immediate effect of intervention that compensates sensory disturbance was evaluated. Improvements were observed in kinematics, muscle synergy, and plantar pressure. They also developed a system to measure brain activity, and proposed new methodologies to express various types of gait.

B. *Changes of body representations in movement disorders*

Hanakawa group has found that resting-state functional connectivity in the basal ganglia reflects dexterity of healthy pianists and that this connectivity is disrupted in pianists with focal dystonia. With transcranial magnetic stimulation, pianists with focal dystonia showed decreased short intracortical inhibition and increased intracortical facilitation, the degree of which was correlated with the level of impaired hand dexterity. Moreover, embouchure dystonia showed disorganized somatotopy of mouth representation and abnormal network activity in the motor cortex, basal ganglia and cerebellum, which collectively explained severity of symptoms. Additionally, the group also found that performance of brain-computer interface is affected by on/off of medication in Parkinson disease, along with some other findings in neurological disorders with neuroimaging.

C. *Study on patients with motor impairments due to stroke*

Yokoi/Sugi group has studied muscle synergy control disorders caused by brain strokes. For the purpose of intervention in muscle synergy control FD by functional electrical stimulation (FES), Yokoi/Sugi group has developed an FES system with multiple stimulation electrodes and biphasic burst-modulated rectangular stimulation wave for rehabilitation of hand and upper limb. This FES system has various tunable parameters, e.g. stimulation patterns (anode/cathode/neutral setting for electrodes), stimulation wave profiles (sine and rectangular waves, and the ones with amplitude modulation), and phase offsets between electrodes.

In this year, the group has studied search method of stimulation patterns to express objective hand and finger postures of patients. Using artificial neural network (ANN), forward and inverse models is developed with respect to relations between stimulation patterns and hand-and-finger postures to be generated. The inverse model can determine stimulation pattern of electrodes that realize hand-and-finger postures that are close to a given posture robustly. Based on this inverse model, the group has also developed a faster search method where a neighborhood search starts from an initial search point designated by the inverse ANN model with same-subject, same-pattern, and multi-day dataset as training data. The group also improved multiple-electrode FES system in which electrodes are integrated in a single silicone rubber sheet, which enables easier installing and removing of electrodes.

D. Efficacy of prosthetics transforming sensory modalities

Owaki/Ishiguro group examined a one-month long-term walking rehabilitation (30min/day walking training on treadmill) for 2 stroke patients with severe sensory impairments. We conducted 7 times interventions with auditory biofeedback prosthesis during the first 2 weeks. We investigated the kinematic and kinetic effects of intervention at the pre-condition (before the intervention), 2w-condition (after 2 weeks), and 4w-condition (after 4 weeks) by using 3D motion capture system and force plate. To analyze rehabilitation effects and underlying mechanism, with the C01 group (Prof. S. Izumi's group), we measured an indirect biomarker (here, we employed "body specific attention") to capture the slow dynamics in the brain plasticity.

We confirmed the following results: (1) stride length during stance phase increased through the first 2 weeks but decreased through the second 2 weeks; and (2) body specific attention also increased through the first 2 weeks but decreased through the second 2 weeks. This fact suggests that increasing body specific attention enables stroke patients to load on paretic side, resulting in the increasing walking performance.

Owaki/Ishiguro group examined a 2-week long-term walking rehabilitation (30min/day walking training on treadmill) for 8 stroke patients with hemiparesis. They conducted 7 times interventions with auditory biofeedback prosthesis during the 2 weeks for AF group. For the control condition, they compared them with 8 patients with normal walking rehabilitation training on treadmill. Between the both groups, they did not find any significant differences on age, weight, height as well as clinical evaluations. They investigated the kinematic and kinetic effects of the intervention by comparing the pre-condition (before the intervention), 2w-condition (after 2 the intervention) using 3-d motion capture system and force plate. For the assessment of the rehabilitation effect, they focused on "Whole Body Angular Momentum (WBAM)" around the CoM, which relate to dynamic postural stability during walking. The results indicated that the peak to peak range of WBAM was reduced for the AF group, suggesting that the AF interventions would improve dynamic postural stability during walking in patients. Now, to analyze rehabilitation effects and underlying mechanism, with the C01 group (Prof. S. Izumi's group), they measured "body specific attention" as an indirect biomarker to capture the slow dynamics in the brain plasticity.

IV. Future Perspective

By this year, groups in C02 project had measured muscle synergy and related parameters in motor impairments, and started interventions such as prostheses transforming sensory modalities, collaborating with other researchers in project in C02, A, and B. These led to capturing change in FD and SD.

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Annual report of research project C03-1

Arito Yozu
Ibaraki Prefectural University of Health Sciences

ABSTRACT

To perform motion properly, human are creating, maintaining, and updating a model of the body in the brain (body representation in the brain). In our project, we study the relationship between the two aspects of body representation in the brain: somatognosia and motor control. This year was our second year and conducted some studies on healthy subjects and patientns.

I. INTRODUCTION

Japan in now facing a super-aged society. The number of care recipients is over 5 million. Most of their problems are motor dysfunctions. Thus, establishing effective rehabilitation techniques to overcome these motor dysfunctions is of paramount importance. To perform motion properly, human are creating, maintaining, and updating a model of the body in the brain (body representation in the brain) .

In this innovative project, two aspects of body representation in the brain has been studied: somatognosia (01 team) and motor control (02 team). However, study regarding the relationship between somatognosia and motor control are insufficient. Here, we elucidate the relationship in our study.

II. AIM OF THE GROUP

The aims of Yozu's group are to clarify the relationship between the two aspects of body representation in the brain: somatognosia and motor control. Patients with congenital insensitivity to pain (CIP) or stroke are included.

This year was the second year for the group. We conduct some studies with CIP or stroke, and evaluate our system

III. RESEARCH TOPICS

A. Study on patients with motor impairments due to sensory disturbance

We have made the up-to-date summary of CIP [1], and have reported on gait abnormalities in CIP patients [2]. Based on the assumption that the gait abnormalities come from abnormalities in muscle synergy control, the investigators have developed a measurement system for muscle synergy of gait in collaboration with Owaki/Ishiguro and Funato groups [3]. The system we made has broken down and the study was behind on the schedule.

Despite that, we report a case on whom the immediate effect of intervention that compensates sensory disturbance [4]. There were improvements in kinematics and muscle synergy. The maximum plantar pressure during walking has reduced in this patient [5,6,7,8].

This year, instead of the broken system, we continue to measure the patient in cooperation with the patients group. However, we could not have enough measurement in non-hospital environment.

B. Study on the expression for variaus mode of gait

We have proposed new methodologies to express various types of gait [9,10,11,12]. Especially, we have studied how to express the asymmetrical gait [12]. There were two types in asymmetrical gait: gait cycle preserved and gait cycle not preserved. We tried to develop an expression method which can be widely used including asymmetric gait with gait cycle not preserved.

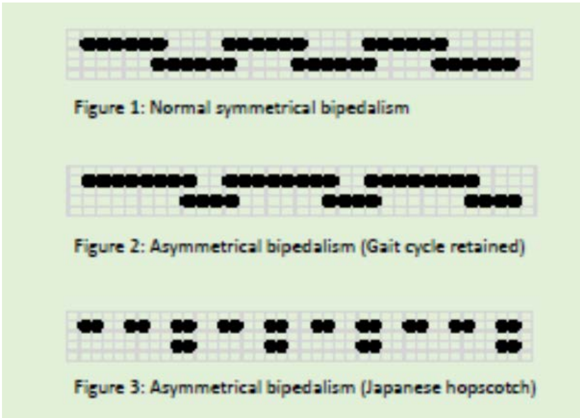

Figure 1: Normal symmetrical bipedalism

Figure 2: Asymmetrical bipedalism (Gait cycle retained)

Figure 3: Asymmetrical bipedalism (Japanese hopscotch)

Gait diagram of symmetrical gait, asymmetrical gait with gait cycle preserved, and asymmetrical gait with gait cycle not preserved.

C. Study on a comprehensive procedure for evaluating the symmetries of patients.

In addition to the symmetries mentioned above, we proposed a comprehensive procedure for evaluating the symmetries including sensory or cognitive symmetries [13]. We are going to apply this procedure in patient evaluation.

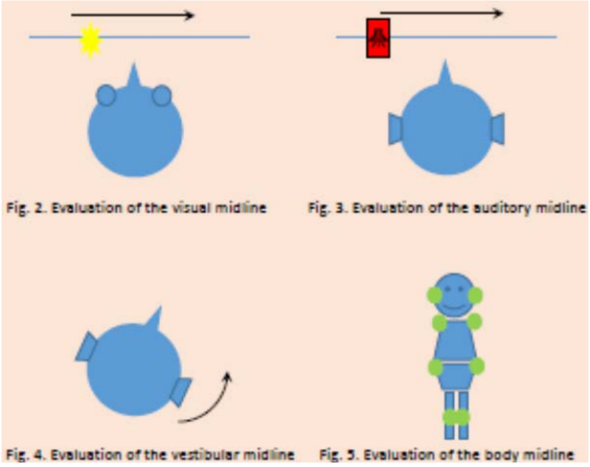

Fig. 2. Evaluation of the visual midline

Fig. 3. Evaluation of the auditory midline

Fig. 4. Evaluation of the vestibular midline

Fig. 5. Evaluation of the body midline

Evaluating patient's visual, vestibular, auditory, and musculoskeletal system.

D. Study on walking and crawling for Parkinson's disease

Using the methods mentioned in section B, we evaluated the walking and hand-knee crawling for Parkinson's disease. Testing the hand-knee crawling in addition to two feet walking, we may detect the gait disturbance of Parkinson's disease in more early stage [15].

E. Study on motor impairments for stroke patients

In stroke patients, not only lower extremities but also upper extremities are impaired. Fugl-Meyer Assessment (FMA) is widely used to measure the motor impairments of stroke. However, this assessment includes many items to carry out. Furthermore, this scale is a ordinal scale. Therefore, to evaluate the paralytic upperlimb more simply and more quantitatively, we used muscle synergy analysis for the patients.

Our preliminary result showed some unification of the synergies in patients compared to the normal subject.

IV. Future Perspective

This year was the second year of the project. As mentioned above, we have developed some methodologies to measure patients. Furthermore, we studied patient with CIP and stroke. Because of the system breakdown and the participants' environment, our achievement is not enough. Study should continue in the future.

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Annual report of research project C03-2

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***Abstract*—The author proposed a new human-human interface design [1] involving the classification of patterns in multi-channel electromyograms (EMGs) and controlled electrical stimulation on a multi-channel basis. In 2018, the following achievements were made: 1) verification of a proposed joint impedance communication method based on the functional electrical stimulation (FES); 2) proposal of a new approximated hidden Marcov model in order to realize pattern classification with high accuracy on the hardware for time-series electromyograms (EMGs); 3) implementation of novel motor point tracking method in FES during motion. The outcomes of this research are expected to support effective motor skill training effectively.**

I. Introduction

In the motor function rehabilitation, therapists must evaluate multi-muscle cooperation during motion via inspection and palpation, and must provide instruction on such cooperation by touching or tapping the skin near the relevant muscles. However, it is difficult to provide accurate evaluation and instruction using only verbal communication and palpation for large numbers of muscles and to conduct effective training based on the results of muscle condition evaluation. Against such a background, an effective method is needed to support the evaluation and communication of muscle contraction patterns and joint motions between therapists and patients in motor skill training, so we have tried to develop a new method to support rehabilitation based on a combination of functional electrical stimulation (FES) and electromyogram (EMG) [1].

II. Aim of the study

This study was conducted toward the development of a rehabilitation method based on a combination of FES and EMG pattern classification to support the evaluation and control of muscle contraction patterns for patients with hemiplegia caused by stroke or spinal cord injury. Using this approach, patterns of muscle coordination can be communicated from person to person (for example, between a therapist and a patient) during the movement of joints, allowing mutual exchanges of information on collaborative muscle contraction [1].

In 2018, a method is designed and verified to enable the joint impedance communication between person to person based on the our proposed approach [1] for learning the natural movements in motor skill training. For efficient EMG pattern classification, a novel approximated hidden Marcov model (HMM) for the classification of time-seres EMG pattern on the hardware is also proposed. A novel motor point tracking method in FES during joint motion is additionally considered. The technique can be considered potentially beneficial in areas such as rehabilitation for EMG-based motor function and training in EMG-based complex skills.

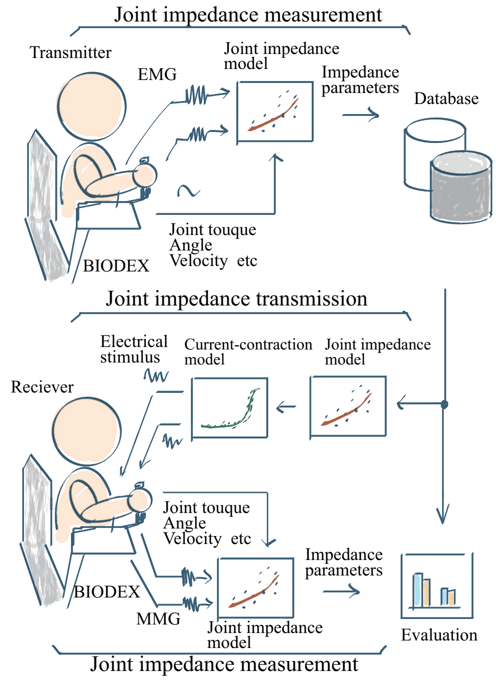


Fig. 1. Joint impedance communication

III. Research topics

A. Joint impedance communication based on usage of FES

Figure 1 shows the proposed joint impedance communication method based on usage of FES, and experimental conditions for verification of the proposed method. In a case where the subject performs single-joint motion of the wrist on a 2D plane, the dynamic properties of the hand can be approximated using a mechanical impedance model on a 2D plane as follows:

$$M\ddot{\theta}(t) + B\dot{\theta}(t) + K\theta(t) = \tau(t) \quad (1)$$

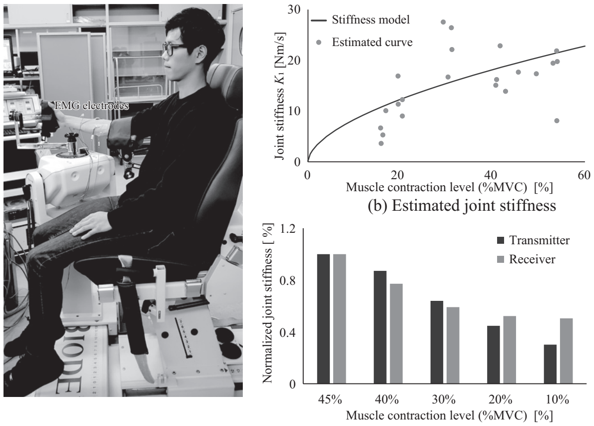
where $\theta(t)$ is the joint angle; $\tau(t)$ is the joint torque; and M, B, and K are the moment of inertia, joint viscosity and stiffness, respectively. The total muscle activities α during joint motion can be expressed using activity levels of extensors $\alpha_E(t)$ and those of flexors $\alpha_F(t)$:

$$\alpha(t) = \frac{\alpha_E(t) + \alpha_F(t)}{2} \quad (2)$$

where joint impedance parameters M, B, and K can be approximated as follows [3]:

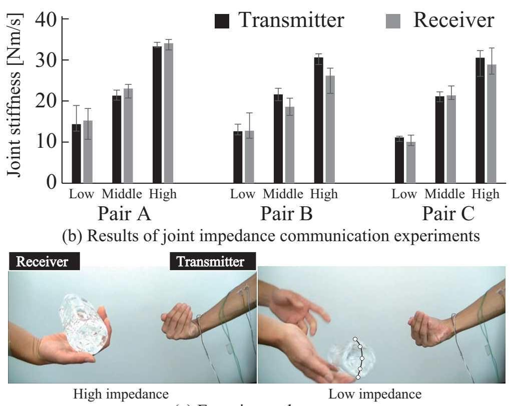
$$\begin{aligned} M(\alpha(t)) &= i, \quad B(\alpha(t)) = b_1\alpha(t)^{b_2} + b_3 \\ K(\alpha(t)) &= k_1\alpha(t)^{k_2} + k_3 \end{aligned} \quad (3)$$

$b_1, b_2, b_3, k_1, k_2, k_3$, and i are constants. These joint impedance parameters during joint motion estimated in real-time are used



(a) Experimental scene (b) Estimated joint stiffness (c) Errors of the joint stiffness communication

Fig. 2. Experimental results of joint impedance evaluation and communication



(b) Results of joint impedance communication experiments

(a) Experimental scene

Fig. 3. Results of joint impedance transmission

for decision of electrical stimulation pattern and stimulation level. Examples of the experimental scene are shown in Fig. 2. In order to estimate the relevant parameters, the hand of the subject is displaced from equilibrium by means of a small short-duration disturbance by the BIODEX. The parameters M, B and K of the subject can be estimated using the least square method from n equations for each sample. From the results (Fig. 2 (b) and (c)), it can be seen that the user's joint impedance can be expressed as Eq. (3) [3], and joint impedances can be transmitted using FES. The joint impedance comparison results show that the rough tendency of impedance parameter values can be transmitted from subject to subject, and the receiver can retain the posture when the load applied to the wrist joint [4].

B. Hardware model for time-seres biosignals discrimination

FES-based communication is impaired by unexpected stimulation of the subject's muscles if EMG patterns are misclassified by the learning machine. This study involved the investigation of a novel approximated hidden Marcov model based on a newly designed linearized Gaussian mixture model that incorporates a probability density function in time-seres data. The proposed approach enables accurate identification of EMG data with high accuracy and high speed on the hardware.

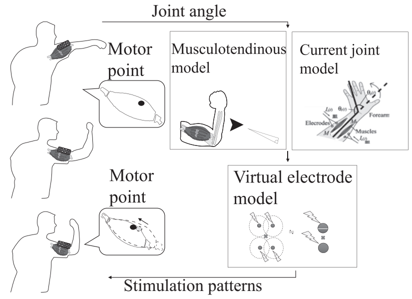


Fig. 4. Motor point tracking method during motion

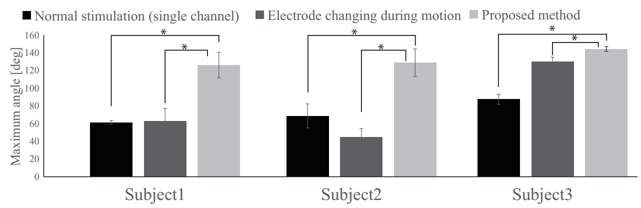


Fig. 5. Experimental results for motor point tracking

C. Motor point tracking method in FES

The study reported involved consideration of a novel motor point tracking method design for effective FES during joint motions. Figure 4 shows structure of the proposed method. In this method, the user's motor points changing is estimated by musculotendinous model and measured joint angles, and electrical stimulus are given based on the virtual electrode model according to the dynamic position changing of the motor points. With this method, the effective stimulation can be realized during dynamic joint motions and be utilized the various applications (Fig. 5).

IV. Future perspectives

This report outlines proposed methods enabling the communication of information on muscle contraction patterns and joint impedance between two subjects (such as a therapist and a patient) based on high-accuracy classification of biosignals. In future work, the author plans to investigate the effectiveness of motor skill training using the proposed method and to discuss how training may influence motorneurone function based on collaborative research.

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Annual report of research project C03-3

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Abstract—**The purpose of this study was to clarify the effect of repetitive kinesthetic illusion induced by visual stimulation therapy with conventional therapeutic exercise on the brain network function, which is defined as the functional connectivity associated with motor function, as revealed by the analysis of blood-oxygen-level-dependent signals measured on functional magnetic resonance imaging. Fifteen healthy adults and 11 patients with stroke participated in this study. The patients' upper extremities were severely paralyzed in the chronic phase after stroke. The results demonstrate that functional connectivity between the dorsal premotor cortex in the unaffected hemisphere and the ipsilateral primary motor cortex and superior parietal lobule significantly changed in the patients after intervention, accompanied by improvement of motor function. Further controlled trials are needed; however, the present results indicate that our novel approach may improve motor function in patients with severe paralysis after stroke, accompanied by functional improvement of brain networks.**

I. Introduction

In patients with severe motor paralysis after stroke, who are subjects of the present study, brain injury occurs after hemorrhage in the thalamus and putamen, and infarction in the corona radiata and internal capsule. Nerve fiber tracking performed using diffusion tensor tractography frequently demonstrates absence of the fibers in the tract descending from the primary motor (M1) and somatosensory (S1) cortices to the spinal level. Several functional magnetic resonance imaging (fMRI) studies have analyzed the correlation of the blood-oxygen-level-dependent (BOLD) signals as a measure of functional connectivity (FC) between brain sites. However, in these studies, classification of the time course of recovery from stroke and the recovery stages of sensory-motor function have not been discussed.

In the acute phase after stroke, the interhemisphere and intrahemisphere FC differ depending on the severity of stroke, and the FC becomes weak in the patients in severe condition [1]. In the patients in the subacute-to-chronic phase after stroke, the FC between M1 in each hemisphere decreases compared with that in the normal control group [2]. In a previous study, the FC between S1 and other regions indicated an asymmetrical difference, and the index of the asymmetry significantly correlated with the deficit in motor function [3].

We have conducted clinical studies in which the kinesthetic illusion induced by visual stimulation (KINVIS) is applied to patients with severe motor paralysis to induce recovery of motor function. "Severe" here is defined as a Fugl-Meyer Assessment (FMA) score less than 20 for the upper extremities (the perfect score is 66). The KINVIS is defined as a psychological phenomenon in which a person who is resting feels as if a part of his/her own body part is moving or feels the desire to move a body part, on viewing the movie of a body part that is moving. For establishing the therapeutic utility of this phenomenon, we have developed a system which is clinically useful, named KiNvis^{TM}. In the KiNvis therapy, the patient experiences KINVIS while neuromuscular electrical stimulation is applied to the muscle which is an agonist of the one whose movement is being viewed in the movie by the patient. We have previously reported that a specific brain network is activated during KINVIS [4], and M1 excitability is enhanced during this phenomenon [5,6]. Furthermore, the enhancement of M1 excitability is sustained after KiNvis therapy [7]. Frequently, while the subject is experiencing KINVIS, a spontaneous muscular contraction can be observed in the agonist muscle that is being shown in the movie [8]. We consider that these previous studies suggest that KINVIS may be associated with the drive in the nervous systems for motor output. Moreover, a previous feasibility study has shown that the motor function immediately changes in patients with stroke exhibiting severe paralysis [9]. Therefore, we speculated that repetitively applying the KiNvis therapy would produce a positive effect on motor function, with enhanced brain plasticity, in patients with stroke. The hypothesis was that the connectivity of brain regions of interest (ROIs), which are the regions associated with sensory-motor function and KINVIS, might improve and lead to changes in motor function.

II. Aim of the Group

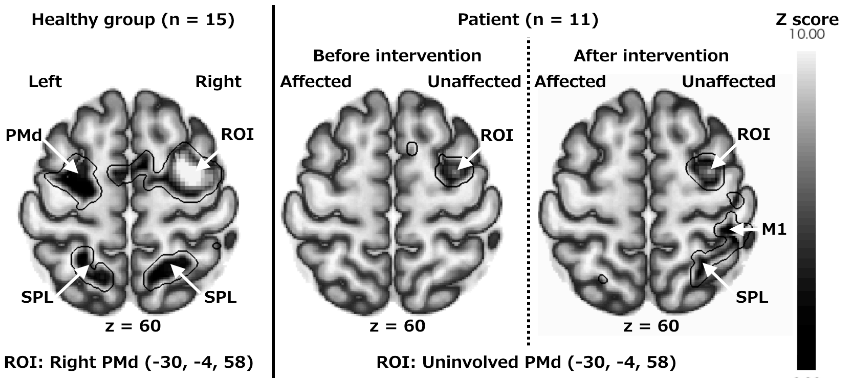
The purpose of this study was to clarify the effect of repetitive KiNvis therapy on the brain network function, which is defined as FC revealed by the analysis of BOLD signals measured on fMRI.

III. Research Topics

Eleven patients in the chronic phase after stroke (more than 6 months since stroke onset) with severe paralysis of the upper extremities were included in this study. Motor functional level of the participants was such that it was impossible to extend their fingers due to severe upper extremity paralysis. The intervention we applied in the present study was combination of KiNvis therapy and conventional therapeutic exercise for 10 days. The assessment of motor function and fMRI was performed before and after the intervention period.

A. Changes in FC before and after KiNvis therapy

Images were acquired on a 1.5-T GE healthcare Optima MR450w MRI scanner; T1-weighted anatomical images were obtained for preprocessing. During fMRI, subjects were instructed to keep their eyes open and remain motionless in the MRI gantry. Gradient-echo echo-planar images were acquired



Voxel threshold: $p < 0.01$ (False discovery rate corrected)
Cluster threshold: $p < 0.05$ (False discovery rate corrected)
Fig. 1: FC in healthy group and patient with stroke

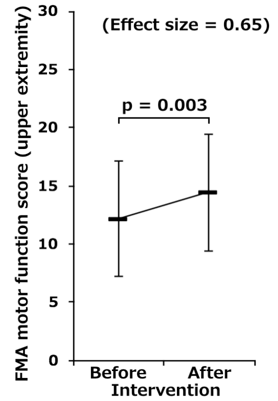


Fig. 2: Change in motor function of patients with stroke

at each session. Preprocessing and analysis of fMRI data were conducted using the CONN toolbox [10] implemented on MATLAB (MathWorks, Inc., Natick, MA, USA). The preprocessing steps included spatial realignment, slice-timing correction, spatially normalization conforming to the Montreal Neurological Institute template, smoothing using a Gaussian filter of 7-mm full width at half maximum and band-pass filtering (0.01–0.08 Hz). The lesion side of MRI data was set to the left side by flipping from right to left about the midsagittal line for patients with lesions on the right hemisphere.

A seed-based connectivity analysis was used to identify the brain regions temporally correlated with BOLD signal fluctuations in the ROIs. Twenty ROIs, which were associated with sensory-motor function and KINVIS, were defined as spherical seed regions with a radius of 6 mm. Correlation coefficients were converted to Gaussian distributed values through Fisher's z-transformation. We searched for the sites with cluster sizes greater than 20 voxels. As shown in Fig. 1, there was no cluster that was detected as being significantly correlated with the ROI of the dorsal premotor cortex (PMd) in the unaffected and affected hemispheres before the intervention in patients with severe hemiparesis after stroke. By contrast, the ipsilateral superior parietal lobule (SPL) and M1 were detected as parts of the network that was significantly correlated with PMd in the unaffected hemisphere after the intervention.

B. Changes in motor function after the intervention

The FMA score for the upper extremities significantly improved after the intervention, with medium level of effect size (Fig. 2). Additionally, the clinical score indicating spasticity improved. The level of motor functional impairment of the patients enrolled in this study was more severe than that of patients included in previous studies on the effect of conventional therapy. The present result suggests the possibility that a noninvasive physical approach, such as the multimodal stimulation developed by us, may positively affect functional recovery in a patient exhibiting severe paralysis after stroke, accompanied by fundamental functional improvement of brain networks.

IV. Future Perspective

In the present study, the effect of KiNvis therapy with therapeutic exercise on the brain function of patients with stroke was investigated using FC analysis. The results demonstrate that the improvement of motor function after our novel therapy is accompanied by changes in FC. Age-matched control trials are needed in the future to gain further insight into the mechanisms involved in this phenomenon, and to identify and confirm the brain network that should be targeted as a therapeutic approach for recovery of motor function.

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Annual Report for Research Project C03-4

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I. Abstract

The purpose of this research is to develop objective indicators of dynamic balance function from movement of center of gravity (COG) and foot pressure center (COP) based on the understanding of the balance controlling mechanisms of human body. In this study, we have shown the indices based on the positional relationships between COG and COP during step movement measured by 3D motion analysis systems and the clinical scale are closely correlated. In this year, based on the findings on relationships between COG and COP, we investigated the patterns of COG movement during walking of the patients with Parkinson's disease and ataxia, and its defining factors. In the comparison between patients groups and healthy controls the different COG control between the patients with Parkinson's disease and with ataxia. In the patients with ataxia, control of COG were performed in faster speed by moving the COP more largely than in healthy subjects. In the patients with Parkinson's disease, the range of movement of COP tends to be slightly larger, though the single walking support time is shorter, and accordingly the COG speed was lower, reflecting the senile gait typically seen in patients with Parkinson's disease. Furthermore, multiple regression analysis with COG velocity as the dependent variable and the COP-COG distance, single-leg support time and COP-COG direction as explanatory variables showed a relatively good fit, with a determination coefficient of 0.76.

II. Introduction

Previous studies have shown the importance of balance function for patients' gait and everyday activities. Thus, balance function has been one of a major rehabilitation target (1,2). Measurement of balance ability is generally performed using a clinical scale. Objective measurement for balance function could be performed with the stabilometry, which is to measure the trajectory of center of foot pressure (COP). In the posture control mechanism, the force for controlling the mass is exerted mainly through the grounded foot. It is known that movement in the center of pressure (COP) reflects the movement of the center of gravity (COG) in the static standing position. However, since the relationships between COG and COP greatly changes during body movement, the objective measurement of dynamic balance ability could be performed only with a large measurement system that can provide fixed mechanical perturbation to see the dynamic response. So far, we have shown that the positional relationship between COG and COP during step movement reflects the balance ability of the patients measured using clinical scale, which is used in the rehabilitation clinics. In addition, we have shown that the speed of COG, which is known as one of major indicators of dynamic balance function, is closely related to the positional relationship between COG and COP.

In this study, further investigation was carried out to examine the control mechanism of COG during walking, centered on the relationship with the movement of COP.

III. Group Aim

The purpose of this research is to investigate the mechanism that the COG is controlled by the COP during walking based on the understanding of control mechanism of COG by COP during step movement.

IV. Research Topics

Participants) Ten subjects with Parkinson's disease and 18 subjects with cerebellar ataxia who can walk on the treadmill without handrails, and 8 healthy subjects participated to this study.

Method) The simultaneous COG and COP measurements were performed using a three-dimensional motion analysis system (Kinematracer, KisseiComtec, Japan) combined with a force plate system (Tech Gihan, Japan). To calculate the COG, markers were bilaterally attached to 10 landmark sites on the body: the acromion processes, the hip joints (one-third the distance between the greater trochanter and the anterior superior iliac spine), the knee joints (the femur's lateral epicondyle midpoint), the lateral malleoli, and the fifth metatarsal heads. The subjects were asked to walk on the treadmill in comfortable speed. The following values, which are based on the COG-COP relationship in mediolateral axis, were calculated and averaged for each step: maximum speed of COG, the averaged COP - COG distance, COG velocity and COP velocity, the rate of COG-COP match in the directions of movement (%match COG-COP direction), the amplitude of COP, single support time (Fig1). Each indicator was calculated for each group for comparison. Steel-Dwass test was used to test the significance of difference between the groups. Furthermore, multiple regression analysis was performed to examine how the COG velocity is influenced by each factor. Stepwise method was employed to select the explanatory variables for multiple regression analysis (increase / decrease method; addition at $P < 0.10$, removal at $P \geqq 0.05$).

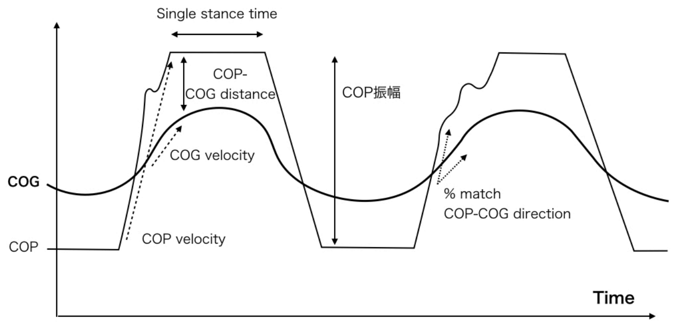

Fig. 1. Indices reflecting COG-COP relationships

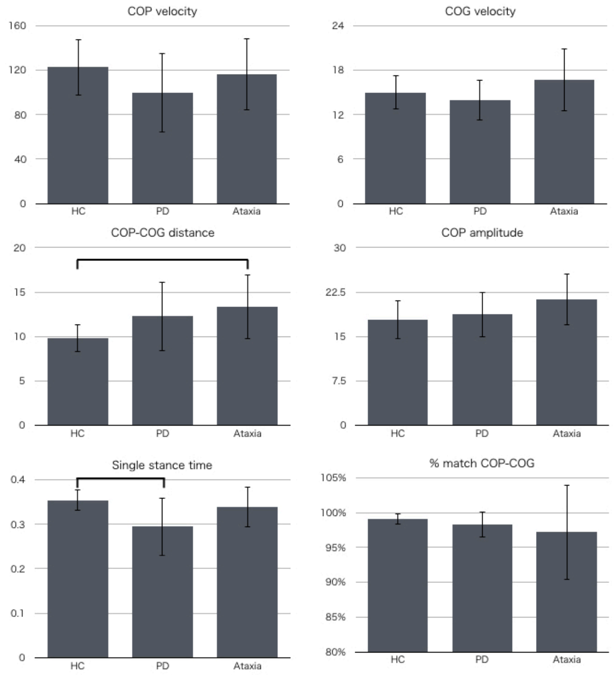

Fig. 2. Comparison of indices between healthy controls and patients groups (HC: healthy controls, PD: Parkinson's disease patients)

Results and Discussion) The COP velocity, COG velocity, COP-COG distance, COP amplitude, %match COG-COP direction and single stance time were compared between healthy control(HC) and patients groups with Parkinson's disease(PD) and cerebellar ataxia (Ataxia). Among them, the COP - COG distance was found to be significantly elevated in the Ataxia group compared to HC. In addition, the single stance time was significantly shortened in the Parkinson's disease group. Although it did not reach the significance level, the amplitude of COP showed an increasing tendency in Ataxia group. The COP and COG velocity also showed a tendency to decrease in Parkinson's disease group. Overall tendency was that the Ataxia group presented dynamic COP movement to slightly faster COG compared with healthy subjects, reflecting wide-based gait pattern typically seen in ataxic patients. On the other hand, short single stance time was observed in patients with Parkinson's disease, reflecting the senile walking pattern.

Furthermore, multiple regression analysis was performed with the COG velocity as a dependent variable and the above five variables as independent variables. The three significant variables were selected by stepwise method, which are COP-COG distance, single stance time, and %match COG-COP direction. Table 1 shows partial regression coefficient, standard partial regression coefficient, t value, and the P value. The coefficient of determination of this model was 0.76, which was a relatively good fit. A plot of the predicted value and the actual value is shown in fig.3.

In this study, we have investigated the relationships between COP and COG during walking and its difference between the disease groups, based on our previous efforts to clarify the COP- COG relationship during step movement. Considering that the acceleration of COG is influenced by the positional relationship between COP and COG (3), the present model which shows that the COG velocity is determined by the positional relationship between COP and COG, control accuracy of COP and time used for acceleration, would be reasonable.

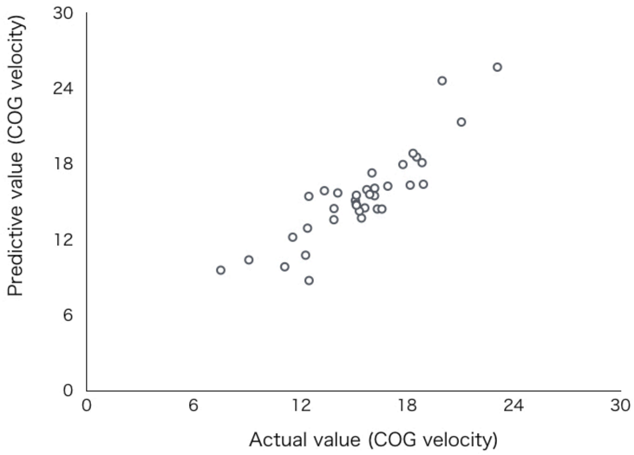

Fig. 3. Predictive value and actual value of COG velocity

Table 1 Multiple regression analysis results
RC: regression coefficient, SE: standardized error,

	RC	SE	Standardized RC	t-value	P value
(constant)	68.37	8.56	0.00	7.99	<.0001*
COP-COG distance	1.11	0.11	1.09	9.95	<.0001*
Single stance time	43.07	6.59	0.62	6.53	<.0001*
% match COP-COG direction	57.38	7.13	0.78	8.05	<.0001*

V. Future Perspective

In this study, we focused on a mechanism by which the COG acceleration is controlled by the COG - COP relationships during gait.

Further, the study of the COG - COP relationship by perturbation (prediction condition, reaction condition), muscle activity pattern and lesion pattern would be considered.

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Annual report on research project C03-5

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***Abstract*—The time window of delay detection was thought to have strong correlation with the time window of distorted sense of agency, because the feeling of being an agent of an action can be implicitly represented by comparing motor intention and proprioceptive/visual feedback information. However, our results suggested that several cognitive factors attenuate the relationship between delay detection and judgment of agency. In the case of apraxia, apraxic patients had distortion of time window for sensory-motor integration. The lesion analyses revealed that left inferior frontal gyrus and the left inferior parietal lobule on the left fronto-parietal motor network are significantly associated with the distortion of sensory-motor temporal integration. Additionally, we reveal the useful of rehabilitation using stochastic resonance for distortion of sensory-motor temporal integration.**

Sense of agency (SoA) is the subjective feeling of initiating and controlling one's own action and external events. For example, SoA may be experienced as a person's sense that they are causing something to move, or that they are generating a certain thought in their stream of consciousness. The feeling of being an agent of an action can be implicitly represented by comparing motor intention and proprioceptive/visual feedback information (i.e., sensorimotor integration). However, "judgment" of agency would be expected to be only partially distorted despite noticing the incongruence between motor intention and visual feedback information.

Limb-apraxia after stroke has been suggested to be distorted embodiment due to malfunction of multisensory integration. However, there are no studies that objectively and quantitatively understand the distorted embodiment in apraxia, and also investigated the relationship with lesions.

Mechanical and electrical noise stimulation to the body is known to improve the sensorimotor system. This improvement is related to stochastic resonance (SR), a phenomenon described as a "noise benefit" to various sensory and motor systems. However, the impact of SR on sensory-motor integration, which is important to the embodiment, has not been elucidated.

I. Objective

The Study-A aimed to experimentally reveal these relationships using a psychophysical experimental paradigm. We hypothesized that there would be a partial correlation between the time windows of visual-motor delay detection and judgment of agency, but that the effect size would be small.

In Study B, we aimed to quantitatively capture the multisensory integration in apraxia and to examine the association with the lesion.

In Study C, we investigated the effect of provision of SR on sensory-motor integration related to distorted embodiment.

II. Research

A. The relationship and difference between delay detection ability and judgment of sense of agency

We used convenience sampling to recruit 58 healthy subjects (22 males, 36 females; mean age, 21.05 years; SD, 1.09). The agency attribution task (Fig.1) and delay detection task (Fig. 2) were conducted to quantify the time window of SoA judgment for each participant .

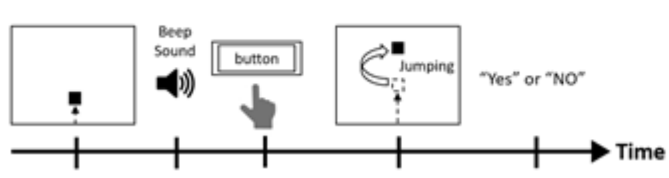

Fig.1 : The agency attribution task

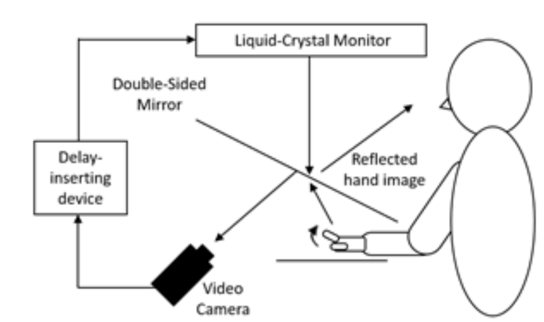

Fig.2: Delay detection task

In the agency attribution task, when participants pressed the button, the square jumped 35 mm upward at a delay. In the delay detection task, participants were asked to move their index finger just once, and to judge whether the visual feedback of finger movement was exactly synchronized with their finger movement execution after each trial. For both task, we refer to these delay conditions as: 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 msec.

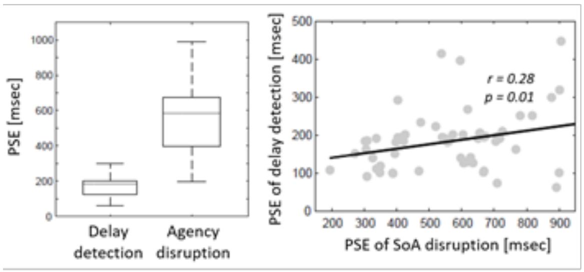

Fig.3 left: Significant difference in the point of subjective equality (PSE) between delay detection and agency attenuation ($p < .05$). Right: Significant positive correlation between PSE of delay detection and PSE of agency attenuation ($p < .05$).

The results revealed that the time window of agency attenuation was longer than that of delay detection, indicating a difference in the relationship between them. The results of the correlation analysis in the present study revealed that the PSE of delay detection was correlated with the PSE of agency attenuation, indicating that sensorimotor integration ability was closely related to the explicit SoA. The current results suggested that explicit SoA is based on sensorimotor integration, but may also be affected by cognitive processes such as thoughts, beliefs, intentions, goals, and predictability. In future studies, we intend to investigate which factors modulate explicit SoA. To the best of our knowledge, the present study is the first to reveal differences and correlations of time windows between delay detection and explicit SoA attenuation within the same subject. Although sensorimotor incongruence induces both odd sensations and SoA attenuation, their time windows were significantly different and the effect size of correlation analysis was low. These results suggested that several cognitive factors attenuate the relationship between delay detection and judgment of agency.

B. Deficits of sensory-motor integration in apraxia after stroke: Evidence from delayed visual feedback detection tasks and voxel-based lesion-symptom mapping

Three types of delayed visual feedback detection tasks were performed on apraxic patients and non-apraxic patients, and multisensory temporal integration including motor signals was evaluated. In addition, we performed voxel-based lesion-symptom mapping to investigate the relationship between apraxia and sensory-motor and multisensory integration and lesions.As a result, apraxic patients had distortion of time window for sensory-motor integration. Lesion analyses revealed that lesions such as the left inferior frontal gyrus and the left inferior parietal lobule on the left fronto-parietal motor network are significantly associated both to the apraxia and the distortion of sensory-motor temporal integration.

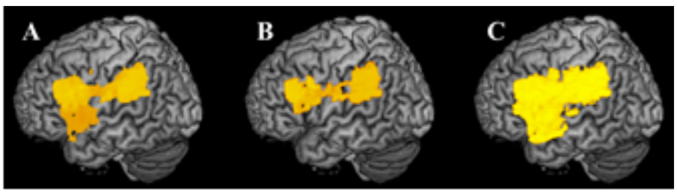

Fig. 4: Results of voxel-based lesion-symptom mapping (A) VLSM for the severity of apraxia. (B) VLSM for the delay detection threshold (DDT) for detection of delayed visual feedback during active movement. (C) VLSM for the steepness of the probability curve for detection of delayed visual feedback during active movement.

C. Stochastic resonance improves sensory-motor temporal integration

The current study investigated the influence of SR on sensory-motor temporal integration and hand motor function under delayed visual feedback in healthy young adults. The purpose of this study was to measure the usefulness of SR as a neurorehabilitation device for disorders of visuomotor temporal integration.

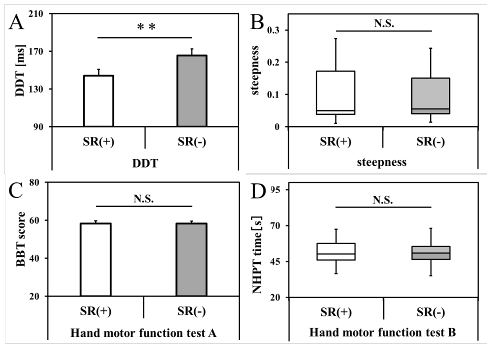

Fig. 5: DDT was significantly shortened under SR on

The delay detection threshold (DDT) under the SR on-condition was significantly shortened compared with the SR off-condition. There was no significant difference between the SR on- and off-conditions for the steepness of the delay detection probability curves, hand motor function test scores.

SR improved sensory-motor temporal integration in healthy young adults, and may therefore improve movement disorders in patients with impaired sensory-motor temporal integration.

III. Conclusion

Our series of studies showed that the time windows of the sensory-motor integration and the sense of agency were different, the apraxia after stroke had a specific failure of the sensory-motor integration, and the stochastic resonance device immediately improved sensory-motor integration.

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75. Kahori Kita, Rieko Osu, Chihiro Hosoda, Manabu Honda, Takashi Hanakawa, Jun Izawa
Neuroanatomical Basis of Individuality in Muscle Tuning Function: Neural correlates of muscle tuning
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International Conference

1. Y. Sekiguchi, D. Owaki, K. Honda, N. Hiroi, K. Fukushi, T. Nozaki, and S. Izumi
Effect of a new hip orthosis on unilateral side with various stiffness on gait in healthy control
Gait and Clinical Movement Analysis Society (GCMAS) 22th Annual Meeting
Salt Lake City, USA 2017
2. Y. Sekiguchi, T. Muraki, Dai Owaki, K. Honda, and S. Izumi
Categorizatin of Gait Pattern Based on Ankle and Hip Stiffness during gait in Patients with Hemiparesis due to Stroke
Gait and Clinical Movement Analysis Society (GCMAS) 22th Annual Meeting
Solt Lake City, USA 2017
3. D. Owaki, Y. Sekiguchi, K. Honda, N. Aizu, Y. Oouchida, A. Ishiguro, and S. Izumi
Walking Rehabilitation Using Auditory Biofeedback Prosthesis for Stroke Patients
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4. D. Owaki
Inter and intralimb coordination for adaptive bipedal walking: Tegotae-based approach
SWARM2017 Workshop on Bio-inspired control for interlimb coordination and adaptation in legged robots Kyoto, Japan 2017
5. S. Yun, W. Wen, Q. An, S. Hamasaki, H. Yamakawa, Y. Tamura, A. Yamashita, and H. Asama
Investigating the relationship between driver's sense of agency and EEG: mu-rhythm is more suppressed in higher SoA case
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6. S. Yun, W. Wen, Q. An, S. Hamasaki, H. Yamakawa, Y. Tamura, A. Yamashita, and H. Asama
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7. S. Yun, W. W, Q. An, S. Hamasaki, H. Yamakawa, Y. Tamura, A. Yamashita, and H. Asama
Investigating the relationship between driver's sense of agency and EEG: mu-rhythm is more suppressed in higher SoA case
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8. N. Yang, Q. An, H. Yamakawa, Y. Tamura, A. Yamashita, K. Takahashi, M. Kinomoto, H. Yamasaki, M. Itkonen, F.S.K. Alnajiar, S. Shimoda, H. Asama, N. Hattori, and I. Miyai
Clarification of Muscle Synergy Structure During Standing-up Motion of Healthy Young, Elderly and Post-Stroke Patients
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9. Kamada K
Super-passive mapping for language-related functions during awake craniotomy
Brain and Cognitive Science Meeting Seoul,Korea 2018
10. Kamada K
Cerebravascular surgery in posterior fossa using multi-spectrum florescence angiography
2018 China-Japan Cerebrovascular Disease Forum Tokyo 2018
11. Kamada K
Dynamics of High Frequency Oscillations between Visual Recognition and Receptive/Expressive Language Functions
50 Years of MEG Poros,Greece 2018
12. S. Imaizumi, and H. Imamizu
Intentional binding in action–effect alternations
22nd Annual Meeting of the Association for the Scientific Study of Consciousness (ASSC22)
Jagiellonian University, Krakow (Poland) 2018
13. R. Ohata, T. Asai, H. Kadota, H. Shigemasu, K. Ogawa, and H. Imamizu
Decoding self-other action attribution in the sensorimotor and the parietal cortices
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Berlin, Germany 2018
14. Morioka S, et al.
The relationship between motor imagery ability and motor function, and frequency of body use in upper limb stroke hemiplegia
12th the International Society of Physical and Rehabilitation Medicine（ISPRM） World Congress
Paris 2018
15. Hayashida K, Morioka S et al.
Effects of sharing goals with others on sense of agency and perceptual motor learning
International Society of Electrophysiology & Kinesiology Dublin 2018
16. Katayama O, Tsukamoto T, Osumi M, Kodama T, Morioka S
Neural processing mechanism of embodied disturbance caused by sensorimotor incongruence
The 17th World Congress on Pain® Boston 2018
17. R. Chiba (Invited)
Embodied-Brain Systems and Understandings of Postural Control with modeling
The 1st Korea-China-Japan International Symposium on Disability Overcome Seoul, korea 2018
18. Kubota S, Sidikejiang W, Kudo M, Inoue K, Umeda T, Takada M, Seki K
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19. Oouchida Yutaka, Ortiz-Catalan Max, Sudo Tamami, Inamura Tetsunari, Ohki Yukari, and Izumi Shin-ichi
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40th International Conference of the IEEE Engineering in Medicine and Biology Society

Hawaii, USA 2018

20. S. Yun, W. Wen, Q. An, S. Hamasaki, H. Yamakawa, Y. Tamura, A. Yamashita, and H. Asama
    Investigating the Relationship Between Assisted Driver's SoA and EEG
    International Conference on NeuroRehabilitation Pisa, Italy 2018
21. Kamada K
    Passive Mapping and Monitoring ICG-VG / ECoG for Neurosurgery
    Lecture for Neurosurgery:Neurosurgery, Ground Round, Stanford University Morning conference
    Stanford,USA 2018
22. Kamada K
    Lecture for Neurosurgical Residents: Neurosurgery with Academia
    Neurosurgery. Ground Round, Stanford University Stanford,USA 2018
23. Kamada K
    Rehabilitation with recoveriX and its positive effects oh fMRI in stroke patients
    2018 BCI Meeting Asilomar, USA 2018
24. Kamada K
    Clinical needs for quantitative evaluation of "Consciousness"
    2018 BCI Meeting Asilomar, USA 2018
25. Kamada K
    Passive Mapping and Monitoring using ECoG for Neurosurgery
    2018 BCI Meeting Asilomar, USA 2018
26. Kamada K
    Rehabilitation with recoveriX and fMRI evaluation for acute stroke patients
    2nd recoveriX & mindBEAGLE conderence 2018 London 2018
27. Kamada K
    Treatment and Rehabilitation with recoveriX for acute stroke patients
    BCI Workshop, BCI for stroke rehabilitation Honolulu, USA 2018
28. Kamada K
    Characterization and Decoding with Intracranial Recording
    EMBC Preconference BCI workshop Honolulu, USA 2018
29. Kamada K
    Rehabilitation with recoveriX and its positive effects oh fMRI in acute stroke patients
    EMBC Preconference BCI Workshop Honolulu, USA 2018
30. Kamada K
    ECoG-based Passive Functional Brain Mapping
    EMBC 2018 Honolulu, USA 2018
31. Kamada K
    Basic and advanced functional Brain Mapping/Monitoring for tumor surgery
    SNSA CONGRESS 2018 Sun City, South Africa 2018
32. Kamada K
    Clinical Impact of Real-time Monitoring for Deep-seated Brain Pathology
    SNSA CONGRESS 2018 Sun City, South Africa 2018
33. Kamada K
    Multi-spectrum Indocyanin Green Videography for CNS Vascular Pathology
    WFNS FOUNDATION & ACNS MYANMAR SEMINAR YANGON
    Yangon,Myanmar 2018
34. Kamada K
    Real-time Passive Language Mapping for Awake Craniotomy
    WFNS FOUNDATION & ACNS MYANMAR SEMINAR YANGON
    Yangon,Myanmar 2018
35. Kamada K
    Basics and Characteristics of Microscope for Vascular Disease
    WFNS FOUNDATION & ACNS MYANMAR SEMINAR YANGON
    Yangon,Myanmar 2018
36. Kamada K
    Non-invasive and invasive Brain-Computer Interfaces for medical application and research projects
    IEEE SMC2018 Miyazaki,Japan 2018
37. Kamada K
    Passive Mapping and Monitoring using ECoG for Neurosurgery
    2018 BCI meeting Asilomar, USA 2018
38. Kamada K
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39. Kamada K
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    BCI Workshop BCI for stroke rehabilitation Honolulu, USA 2018
40. F Kaneko, K Shindo, M Yoneta, M Okawada, K Akaboshi, M Liu
    Comparison of functional brain connectivity before and after complex approach of KiNvis and BMI to patients with severely impaired chronic stroke. -A primary analysis of the resting state functional MRI-

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42. Fuminari Kaneko, Keiichiro Shindo, Megumi Okawada, Masaki Yoneta, Kazuto Akaboshi, Meigen Liu
Convergent approach including cognitive and physiological Stimulation for sensory-motor functional improvement in chronic stroke: A case report
ISPRM 2018　　Paris, France　2018
43. Kamada K
Characterization and Decoding with Intracranial Recording
EMBC Preconference BCI workshop　　Honolulu, USA　2018
44. Kamada K
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Yangon,Myanmar　2018
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Basics and Characteristics of Microscope for Vascular Disease
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51. Kamada K
Non-invasive and invasive Brain-Computer Interfaces for medical application and research projects
IEEE SMC2018　　Miyazaki,Japan　2018
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Society for Neuroscience - Neuroscience 2018　　San diego, USA　2018
55. Fuminari Kaneko, Keiichiro Shindo, Megumi Okawada, Masaki Yoneta, Kazuto Akaboshi, Meigen Liu
Convergent approach including cognitive and physiological Stimulation for sensory-motor functional improvement in chronic stroke: A case report
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Paris, France　2018
56. N. Miyata, Y. Yoneoka, Y. Maeda
Modeling the range of motion and the degree of posture discomfort of the thumb joints
the 20th Congress of the International Ergonomics Association Florence, Italy　2018
57. N. Miyata, R. Takahashi, M. Takemura, K. Fujita, Y. Maeda,
Observation of Grasping Style Adaptation due to Artificially-Limited Joint Range of Motion of the Thumb
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Nagoya, JAPAN　2017
58. R. Takahashi, N. Miyata, Y. Maeda, and K. Fujita
Grasps under Artificially-limited Thumb's Joint Range of Motion –Posture Analysis with ROM Boundary and Muscle Loads–
29th 2018 International Symposium on Micro-NanoMechatronics and Human Science
Nagoya, JAPAN　2018
59. K. Shima, K. Shimatani, G. Sato, M. Sakata, P. Giannoni and P. Morasso

A Fundamental Study on How Holding a Helium-filled Balloon Affects Stability in Human Standing
2017 IEEE 15th International Conference on Rehabilitation Robotics
London, UK　2017

60. T. Mukaeda and K. Shima
A Novel Hidden Markov Model-Based Pattern Discrimination Method with the Anomaly Detection for EMG Signals
39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society
Jeju Island, Korea　2017
61. A. Takai, D. Rivela, G. Lisi, T. Noda, R. Teramae, H. Imamizu, and J. Morimoto
Investigation on the neural correlates of haptic training
2018 IEEE International Conference on Systems, Man, and Cybernetics (SMC2018)
Miyazaki, Japan　2018
62. T. Asai and H. Imamizu
Normal aging in resting-state functional brain networks
The 2nd International Symposium on Embodied-Brain Systems Science (EmBoss 2018)
Senri Life Science Center, Shinsenrihigashimachi, Toyonaka-city, Osaka, Japan　2018
63. T. Hamamoto, H. Imamizu, and T. Asai
Resting and Meditating states in Functional Brain Connectivity
The 2nd International Symposium on Embodied-Brain Systems Science (EmBoss 2018)
Senri Life Science Center, Shinsenrihigashimachi,Toyonaka-city, Osaka, Japan　2018
64. M. Tanaka, T. Asai, H. Imamizu, and R. Ohata
Biased Sense of Agency Changes Feedback Control
The 2nd International Symposium on Embodied-Brain Systems Science (EmBoss 2018)
Senri Life Science Center, Shinsenrihigashimachi, Toyonaka-city, Osaka, Japan　2018
65. K. Hiromitsu, T. Asai, S. Imaizumi, M. Tanaka, H. Kadota, and H. Imamizu
Right Inferior Parietal Lobe Mediates the Relation Between the Prediction Error and the Sense of Agency—tDCS and TMS Study—
The 2nd International Symposium on Embodied-Brain Systems Science (EmBoss 2018)
Senri Life Science Center, Shinsenrihigashimachi, Toyonaka-city, Osaka, Japan　2018
66. R. Ohata, W. Wen, A. Yamashita, H. Asama, and H. Imamizu
Dissociative processes for detecting change in control
The 2nd International Symposium on Embodied-Brain Systems Science (EmBoss 2018)
Senri Life Science Center, Shinsenrihigashimachi, Toyonaka-city, Osaka, Japan　2018
67. H. Imamizu
Brain networks building up sense of agency
The 2nd International Symposium on Embodied-Brain Systems Science (EmBoss 2018)
Senri Life Science Center, Shinsenrihigashimachi, Toyonaka-city Osaka, Japan　2018
68. K. Tsunetomo, S. Shirafuji, and J. Ota
Analysis of rockers during the stance phase of gait for feature extraction
IEEE Int. Symp. Micromechatronics and Human Science (MHS2018)
Nagoya, Japan　2018
69. Qi An, Hiroki Kogami, Ningjia Yang, Hiroshi Yamakawa, Yusuke Tamura, Hiroshi Yamasaki, Matti Itkonen, Fady Shibata-Alnajjar, Shingo Shimoda, Noriaki Hattori, Makoto Kinomoto, Kouji Takahashi, Takanori Fujii, Hironori Otomune, Ichiro Miyai, Atsushi Yamashi
Rehabilitation Intervention of Physical Therapists Improves Muscle Synergy during Standing-up Motion of Stroke Patients
2nd International Symposium on Embodied-Brain Systems Science (EmboSS2018)
Osaka, Japan　2018
70. Ningjia Yang, Qi An, Hiroshi Yamakawa, Yusuke Tamura, Kouji Takahashi, Makoto Kinomoto, Hiroshi Yamasaki, Matti Itkonen, Fady Shibata-Alnajjar, Shingo Shimoda, Noriaki Hattori, Takanori Fujii, Hironori Otomune, Ichiro Miyai, Atsushi Yamashita, and Hajime
Clarification of Altered Muscle Synergies during Sit-to-stand Motion in Stroke Patients
2nd International Symposium on Embodied-Brain Systems Science (EmboSS2018)
Osaka, Japan　2018
71. Hiroki Kogami, Qi An, Ningjia Yang, Hiroshi Yamakawa, Yusuke Tamura, Hiroshi Yamasaki, Matti Itkonen, Fady Shibata-Alnajjar, Shingo Shimoda, Noriaki Hattori, Makoto Kinomoto, Kouji Takahashi, Takanori Fujii, Hironori Otomune, Ichiro Miyai, Atsushi Yamashi
Effect of Physical Therapy on Joint Angle of Hemiplegic Patients during Standing-up Motion
2nd International Symposium on Embodied-Brain Systems Science (EmboSS2018)
Osaka, Japan　2018
72. S. Hamasaki, A. Yamashita and H. Asama
A Three-Dimensional Evaluation of Body Representation Change of Human Upper Limb Focused on Sense of Ownership and Sense of Agency
Micro & Nano Scale Systems to Robotics & Mechatronics Systems 2018
Nagoya, Japan　2018
73. S. Hamasaki, A. Yamashita and Y. Tamura
Investigation of the Influence of Sense of Ownership and Agency on Three-Dimensional Change of Body Representation of Upper Limb
2nd International Symposium on Embodied-Brain Systems Science 2018
Osaka, Japan　2018
74. Sonmin Yun, Wen Wen, Qi An, Shunsuke Hamasaki, Hiroshi Yamakawa, Yusuke Tamura, Atsushi Yamashita and Hajime Asama

Investigating the Relationship between Assisted Driver's Sense of Agency and EEG Alpha Power
The 2nd International Symposium on Embodied-Brain Systems Science (EmboSS2018)
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75. Kei Aoyagi, Wen Wen, Qi An, Shunsuke Hamasaki, Hiroshi Yamakawa, Yusuke Tamura, Atsushi Yamashita and Hajime Asama
Improvement of Sense of Agency via Visual Intervention in Virtual Reality
The 2nd International Symposium on Embodied-Brain Systems Science (EmboSS2018)
Osaka, Japan 2018
76. K. Mochizuki, K.Nakajima, M. Inase, A. Murata
Neuronal correlates of sensory suppression for self-attributable afferent inputs in primate primary somatosensory cortex.
The 2nd international symposium on Embodied-Brain system science
Osaka, Japan 2018
77. A. Murata, K. Maeda, H. Ishida, K.Nakajima, M. Inase
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The 2nd international symposium on Embodied-Brain system science
Osaka, Japan 2018
78. Sanada T, Mitsuhashi T,Takeuchi F,Kamada K
Complex functional brain network identified by "passive" electrical mapping in a case with intractable epilepsy.
EmboSS 2018 Osaka 2018
79. Tanaka, H.
Directional tuning and reference frames in human pointing
3rd International Mobile Brain/Body Imaging Conference
Berlin, Germany 2018
80. Hirokazu Tanaka and Makoto Miyakoshi
Two extensions of trial reproducibility maximization for EEG data analysis
3rd International Mobile Brain/Body Imaging Conference Berlin, Germany 2018
81. Tanaka H, Ishikawa T, & Kakei, S
Neural evidence of the cerebellum as a state predictor
Neuroscience 2018 Kobe, Japan 2018
82. Hirokazu Tanaka, Makoto Miyakoshi, and Eishi Asano
A Multivariate Method Detecting Traveling Waves from ECoG data
The 2nd International Symposium on Embodied-Brain Systems Science (Emboss 2018)
Osaka, Japan 2018
83. Hirokazu Tanaka, Takahiro Ishikawa, and Shinji Kakei
Neural Evidence of the Cerebellum as a State Predictor
The 2nd International Symposium on Embodied-Brain Systems Science (Emboss 2018)
Osaka, Japan 2018
84. A. Fukui, H. Osaki, Y. Ueta and M. Miyata
Layer-specific impairment of somatosensory processing in the primary sensory cortex after motor cortex infarction
2nd International Symposium on Embodied-Brain Systems Science
Osaka, Japan 2018
85. H. Osaki, M. Kawashima, M. Yasuda and M. Miyata
Nociceptive neurons in the primary somatosensory cortex: area and layer specific distribution
2nd International Symposium on Embodied-Brain Systems Science
Osaka, Japan 2018
86. K. Kaminishi, R. Chiba, K. Takakusaki, and J. Ota
Musculoskeletal simulations to investigate influences of muscle weakness and sensory noise to postural control stiffness
29th 2018 International Symposium on Micro-NanoMechatronics and Human Science
Nagoya, Japan 2018
87. K. Kaminishi, P. Jiang, R. Chiba, K. Takakusaki, and J. Ota
Musculoskeletal simulation for determining influences of the magnitude of sensory noise and stiffness on the selection of hip or ankle movement strategies
40th International Engineering in Medicine and Biology Conference Hawaii, USA 2018
88. K. Kaminishi, R. Chiba, K. Takakusaki, and J. Ota
Musculoskeletal simulation to investigate influences of the magnitude of sensory noise and stiffness on the selection of an ankle/hip strategy
2nd International Symposium on Embodied-Brain Systems Science (EmboSS 2018)
Osaka, Japan 2018
89. Yusuke Sekiguchi, Takayuki Muraki, Hiroaki Ishikawa, Keita Honda, Haruki Yaguchi, Nobuyuki Yamamoto, and Shin-Ichi Izumi
Abdominal muscle elasticity in patients with hemiparesis due to stroke, Gait and Clinical Movement Analysis Society
23th Annual Meeting, Indianapolis, USA 2018
90. Honda K, Sekiguchi Y, Owaki D, Izumi
Effects of a plantarflexion assisst orthosis on compensatory strategy during gait in patients with hemiparesis,
Gait and Clinical Movement Analysis Society (GCMAS) 23th Annual Meeting
Indianapolis, USA, 2018
91. Takakusaki K
Autonomic and cognitive impairment based on basal ganglia dysfunction
International symposium on autonomic function Nagoya, JPN 2017
92. Takakusaki K, Takahashi M, Miyagishi S, Kaminishi K, Chiba R, Ota J.

Postural control that precedes to the forelimb reaching in the cat.
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93. Takakusaki K, Takahashi M, Miyagishi S, Chiba R. Drew T.
Postural control that precedes to the forelimb reaching in the cat.
Society for Neuroscience 2017 Washington DC, USA. 2017
94. T. Fumuro, M. Matsuhashi, T. Hitomi, R. Matsumoto, R. Takahashi and A. Ikeda
Visuospatial processing load enhance the brain activity associated with motor preparation
31st International Congress of Clinical Neurophysiology
Washington DC, USA 2018
95. M. Togo, R. Matsumoto, A. Shimotake, T. Kobayashi, T. Kikuchi, K. Yoshida, T. Kunieda, S. Miyamoto, R. Takahashi and A. Ikeda
Role of the premotor and precentral negative motor area in praxis: a direct electrical stimulation study with behavioral analysis
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Washington DC/USA 2018
96. Neshige S, Kobayashi K, Matsuhashi M, Shimotake A, Hitomi T, Kikuchi T, Yoshida K, Kunieda T, Matsumoto R, Takahashi R, Miyamoto S, Maruyama H, Ikeda A.
Rational cortical mapping algorithm for epilepsy surgery: non-stimuli, multi-intrinsic brain activities without cortical stimulation
12th Asian & Oceanian Epilepsy Congress
Bali, Indonesia 2018

Member List

Steering Committee (X00): Comprehensive research management for understanding the plasticity mechanism of body representations in brain

Principal Investigator	Jun Ota (Professor, The University of Tokyo)
Funded Co-investigator	Eiichi Naito (Research Manager, NICT)
Funded Co-investigator	Shin-ichi Izumi (Professor, Tohoku University)
Funded Co-investigator	Toshiyuki Kondo (Professor, Tokyo University of Agriculture and Technology)
Co-investigator	Hiroshi Imamizu (Professor, The University of Tokyo)
Co-investigator	Kazuhiko Seki (Director, NCNP)
Co-investigator	Kaoru Takakusaki (Professor, Asahikawa Medical University)
Co-investigator	Hajime Asama (Professor, The University of Tokyo)
Co-investigator	Nobuhiko Haga (Professor, The University of Tokyo)
Co-investigator	Akira Murata (Associate Professor, Kinki University)
Co-investigator	Tetsunari Inamura (Associate Professor, NII)
Co-investigator	Takashi Hanakawa (Director, NCNP)
Research Collaborator	Yoshiaki Iwamura (Emeritus Professor, Toho University / Part-time Professor, Ueno Gakuen University)
Advisory Board Member	Yoshikazu Shinoda (Emeritus Professor, Tokyo Medical and Dental University)
Advisory Board Member	Eiichi Saito (Professor, Fujita Health University)
Advisory Board Member	Koji Ito (Emeritus Professor, Tokyo Institute of Technology / Guest Researcher, Tokyo Metropolitan Institute of Medical Science)
Advisory Board Member	Paolo Dario (Professor, Scuola Superiore Sant'Anna)

Research Project A01-1: Neural mechanisms inducing plasticity on body representations

Principal Investigator	Hiroshi Imamizu (Professor, The University of Tokyo)
Funded Co-investigator	Akira Murata (Associate Professor, Kinki University)
Funded Co-investigator	Yukari Ohki (Professor, Kyorin University)
Funded Co-investigator	Takaki Maeda (Assistant Professor, Keio University)
Co-investigator	Satoshi Shibuya (Assistant Professor, Kyorin University)
Co-investigator	Kenji Ogawa (Associate Professor, Hokkaido University)
Co-investigator	Tomohisa Asai (Researcher, NTT Communication Science Laboratories)
Co-investigator	Tsukasa Okimura (Assistant Professor, Keio University)
Co-investigator	Yuichi Yamashita (Section Chief, NCNP)
Co-investigator	Hiriaki Shigemasu (Associate Professor, Kochi University of Technology)
Co-investigator	Hiroshi Kadota (Associate Professor, Kochi University of Technology)
Co-investigator	Masahiro Yamashita (Researcher, ATR)
Co-investigator	Kei Mochizuki (Researcher, Kinki University)
Co-investigator	Cai Chang (Researcher, ATR)
Co-investigator	Ryu Ohata (Researcher, The University of Tokyo)

Research Project A02-1: Neural adaptative mechanism for physical changes

Principal Investigator	Kazuhiko Seki (Director, NCNP)
Funded Co-investigator	Eiichi Naito (Research Manager, NICT)
Funded Co-investigator	Shinji Kakei (Project Leader, Tokyo Metropolitan Institute of Medical Science)
Co-investigator	Ken-ichi Inoue (Assistant Professor, Kyoto University)
Co-investigator	Naomichi Ogihara (Professor, Keio University)
Co-investigator	Tatsuya Umeda (Section Chief, NCNP)
Co-investigator	Tomomichi Oya (Section Chief, NCNP)
Co-investigator	Masaya Hirashima (Senior Researcher, NICT)
Co-investigator	Tsuyoshi Ikegami (Researcher, NICT)
Co-investigator	Satoshi Hirose (Researcher, NICT)

Co-investigator	Naohiro Takemura (Researcher, NICT)
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Co-investigator	Lee Zonho (Senior Researcher, Tokyo Metropolitan Institute of Medical Science)
Co-investigator	Takahiro Ishikawa (Researcher, Tokyo Metropolitan Institute of Medical Science)
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Research Project A02-2: Adaptive embodied-brain function due to alteration of the postural- locomotor synergies

Principal Investigator	Kaoru Takakusaki (Professor, Asahikawa Medical University)
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Co-investigator	Hiroshi Funakoshi (Professor, Asahikawa Medical University)
Co-investigator	Yuriko Sugiuchi (Associate Professor, Tokyo Medical and Dental University)
Co-investigator	Yasuo Higurashi (Researcher, Kinki University)
Co-investigator	Tetsuo Ota (Professor, Asahikawa Medical University)
Co-investigator	Kazuhiro Obara (Assistant Professor, Asahikawa Medical University)
Co-investigator	Mirai Takahashi (Assistant Professor, Asahikawa Medical University)
Co-investigator	Seiji Matsumoto (Lecturer, Asahikawa Medical University)

Research Project A03-1: Visualization of Brain Functional Dynamism by hybrid functional analysis with real-time feedback

Principal Investigator	Kyosuke Kamada (Professor, Asahikawa Medical University)
Co-investigator	Fumiya Takeuchi (Associate Professor, Asahikawa Medical University)
Co-investigator	Shusei Fukuyama (Assistant Researcher, Asahikawa Medical University)

Research Project A03-2: Neural Basis for the Reference Frame and the Functional Synergies in Controlling Eye-head Coordination

Principal Investigator	Yuriko Sugiuchi (Associate Professor, Tokyo Medical and Dental University)
Co-investigator	Shinji Kakei (Project Leader, Tokyo Metropolitan Institute of Medical Science)

Research Project A03-3: Development of assistive technologies for rehabilitation by visualizing neural representation of muscle synergies using electroencephalography

Principal Investigator	Natsue Yoshimura (Associate Professor, Tokyo Institute of Technology)
Co-investigator	Hiroyuki Kambara (Assistant Professor, Tokyo Institute of Technology)
Co-investigator	Yosuke Ogata (Assistant Professor, Tokyo Institute of Technology)
Co-investigator	Okito Yamashita (Department Head, Neural Information Analysis Laboratories, ATR)

Research Project A03-4: Neural basis of human body representation: a direct electrocorticographic recording and stimulation study

Principal Investigator	Riki Matsumoto (Professor, Kobe University)
Co-investigator	Akio Ikeda (Professor, Kyoto University)
Co-investigator	Takeharu Kunieda (Professor, Ehime University)
Co-investigator	Kazumichi Yoshida (Senior Lecturer, Kyoto University)
Co-investigator	Masao Matsuhashi (Associate Professor, Kyoto University)
Co-investigator	Akihiro Shimotake (Assistant Professor, Kyoto University)

Research Project A03-5: Understanding the interaction between tactile and nociceptive information in the somatosensory cortex and controlling of nociception

Principal Investigator	Hironobu Osaki (Assistant Professor, Tokyo Women's Medical University)
Co-investigator	Mariko Miyata (Professor, Tokyo Women's Medical University)
Co-investigator	Yoshifumi Ueta (Assistant Professor, Tokyo Women's Medical University)
Co-investigator	Goichi Miyoshi (Assistant Professor, Tokyo Women's Medical University)

Research Project A03-6: Body representation changes underlying motor recovery after internal capsular stroke in macaques

Principal Investigator	Noriyuki Higo (Chief Scientist, AIST)
Co-investigator	Yumi Murata (Researcher, AIST)
Co-investigator	Toru Yamada (Researcher, AIST)
Co-investigator	Jun Izawa (Associate Professor, University of Tsukuba)

Research Project B01-1: Modeling of slow dynamics on body representations in brain

Principal Investigator	Hajime Asama (Professor, The University of Tokyo)
Funded Co-investigator	Toshiyuki Kondo (Professor, Tokyo University of Agriculture and Technology)
Funded Co-investigator	Hirokazu Tanaka (Associate Professor, JAIST)
Funded Co-investigator	Shiro Yano (Assistant Professor, Tokyo University of Agriculture and Technology)
Funded Co-investigator	Jun Izawa (Associate Professor, University of Tsukuba)
Co-investigator	Atsushi Yamashita (Associate Professor, The University of Tokyo)
Co-investigator	Masafumi Yano (Emeritus Professor, Tohoku University)
Co-investigator	Qi An (Research Assistant Professor, The University of Tokyo)
Co-investigator	Wen Wen (Researcher, The University of Tokyo)

Research Project B02-1: Modeling of motor control that alters body representations in brain

Principal Investigator	Jun Ota (Professor, The University of Tokyo)
Funded Co-investigator	Shinya Aoi (Lecturer, Kyoto University)
Funded Co-investigator	Ryosuke Chiba (Associate Professor, Asahikawa Medical University)
Co-investigator	Taiki Ogata (Associate Professor, Tokyo Institute of Technology)
Co-investigator	Dai Yanagihara (Associate Professor, The University of Tokyo)
Co-investigator	Kazuo Tsuchiya (Emeritus Professor, Kyoto University)
Co-investigator	Toshio Aoyagi (Professor, Kyoto University)
Co-investigator	Soichiro Fujiki (Assistant Professor, The University of Tokyo)
Co-investigator	Shohei Shirafuji (Researcher, The University of Tokyo)
Co-investigator	Yu Yong (Professor, Kagoshima University)

Research Project B03-1: Elucidation of the synergy reformation mechanism for neural function recovery

Principal Investigator	Tetsuro Funato (Associate Professor, The University of Electro-Communications)

Research Project B03-2: Transformation of body representations in embodiment process of active artificial limb

Principal Investigator	Yasuhisa Hasegawa (Professor, Nagoya University)

Research Project B03-3: Emergence of Fast/Slow Dynamics of Body Image in Muscular Skeletal Humanoid Robot

Principal Investigator	Koh Hosoda (Professor, Osaka University)
Co-investigator	Ichiro Tsuda (Professor, Hokkaido University)
Co-investigator	Hideo Kubo (Professor, Hokkaido University)
Co-investigator	Shuhei Ikemoto (Assistant Professor, Osaka University)

Research Project B03-4: Investigation of adaptation process of the upper limb by artificially-disabled healthy participants

Principal Investigator	Natsuki Miyata (Senior Researcher, AIST)
Co-investigator	Koji Fujita (Assistant Professor, Tokyo Medical and Dental University)
Co-investigator	Yusuke Maeda (Associate Professor, Yokohama National University)

Research Project C01-1: Neurorehabilitation based upon brain plasticity on body representations

Principal Investigator	Shin-ichi Izumi (Professor, Tohoku University)
Funded Co-investigator	Tetsunari Inamura (Associate Professor, NII)
Co-investigator	Naofumi Tanaka (Associate Professor, Tohoku University)
Co-investigator	Yutaka Ouchida (Associate Professor, Osaka Kyoiku University)
Co-investigator	Kazumichi Matsumiya (Professor, Tohoku University)

Co-investigator	Hiroaki Abe (Lecturer, Kohnan Hospital)
Co-investigator	Yusuke Sekiguchi (Lecturer, Tohoku University)
Co-investigator	Masahiko Ayaki (Associate Professor, Keio University)
Co-investigator	Fuminari Kaneko (Associate Professor, Sapporo Medical University)

Research Project C02-1: Rehabilitation for postural/movement impairments using sensory intervention

Principal Investigator	Nobuhiko Haga (Professor, The University of Tokyo)
Funded Co-investigator	Takashi Hanakawa (Director, NCNP)
Funded Co-investigator	Hiroshi Yokoi (Professor, The University of Electro-Communications)
Funded Co-investigator	Dai Owaki (Assistant Professor, Tohoku University)
Co-investigator	Arito Yozu (Associate Professor, Ibaraki Prefectural University of Health Sciences)
Co-investigator	Arito Yozu (Associate Professor, The University of Tokyo)
Co-investigator	Masao Sugi (Associate Professor, The University of Electro-Communications)
Co-investigator	Kahori Kita (Assistant Professor, Chiba University)
Co-investigator	Shin-ichi Furuya (Associate Professor, Sophia University)
Co-investigator	Kazumasa Uehara (JSPS PD, NCNP)

Research Project C03-1: The relationship between body consciousness and motor control aspects of body representation in the brain

Principal Investigator	Arito Yozu (Associate Professor, Ibaraki Prefectural University of Health Sciences)
Co-investigator	Masashi Hamada (Assistant Professor, The University of Tokyo)

Research Project C03-2: Motor Skill Training/Analysis of brain plasticity Through Muscle Contraction Pattern-Based Direct Rehabilitation

Principal Investigator	Keisuke Shima (Associate Professor, Yokohama National University)
Co-investigator	Koji Shimatani (Professor, Prefectural University of Hiroshima)
Co-investigator	Hideki Nakano (Assistant Professor, Kyoto Tachibana University)
Co-investigator	Atsushi Tasaka (Associate Professor, Osaka Health Science University)

Research Project C03-3: Study on kinesthetic illusion induced by visual stimulation under the mixed reality and brain functional connectivity

Principal Investigator	Fuminari Kaneko (Associate Professor, Keio University)
Co-investigator	Yoshiyuki Asai (Professor, Yamaguchi University)
Co-investigator	Eriko Shibata (Researcher, Sapporo Medical University)

Research Project C03-4: Development of comprehensive measurement system of balance function to monitor the effect of rehabilitative interventions

Principal Investigator	Masahiko Mukaino (Lecturer, Fujita Health University)
Co-investigator	Fumihiro Matsuda (Assistant Professor, Fujita Health University)

Research Project C03-4: Effect of "Hybrid-Neurorehabilitation to improve Sense of Agency" for patients with stroke hemiplegia

Principal Investigator	Shu Morioka (Professor, Kio University)
Co-investigator	Sotaro Shimada (Professor, Meiji University)
Co-investigator	Michihiro Osumi (Assistant Professor, Kio University)