Japan Academy Prize to:

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for "Understanding of Brain Functions by Computational Neuroscience and Development of Brain Machine Interface"

Outline of the work:

Based on his critical examination of the traditional equilibrium-point-control hypothesis, Dr. Mitsuo Kawato proposed a new theory of cerebellar internal models—MOSAIC Theory, as a bidirectional theory of vision. He influenced the international neuroscience research field from the viewpoint of elucidating brain functions based on information processing and computational theory. In 2009, he succeeded in decoding brain information while recording brain activities from outside the head. Based on these studies, he developed a novel brain information technology, called the brain machine interface (BMI), so that people can control robots or home electrical devices just by their own thoughts. Furthermore, in 2011, he developed the "decoded neurofeedback (DecNef)" method with which people could induce desirable information in their brains without special physical training. DecNef is an innovative causal tool for human neuroscience that can lead to new therapies for psychiatric and neurological diseases, including depression and central chronic pain.

(1) Proposal of a cerebellar internal model theory and its experimental examination

An equilibrium-point-control hypothesis (or virtual-trajectory-control hypothesis) was a standard model for a neural mechanism for motor control. This hypothesis assumed that the brain sends just a mechanical equilibrium point to downstream neural and muscle systems, and that corresponding movements spontaneously and mechanically emerge. Dr. Kawato measured mechanical stiffness of human arms during movements, which he found rather small, and thus demonstrated the necessity of new internal models within the brain (*Science*, 1996) departing from the above hypothesis. He has developed a new theory regarding how internal models are acquired in the cerebellum, as a computational extension of the Marr-Ito-Albus theory of cerebellar functions. In his theory, the cerebellar cortex acquires internal models while executing movements several times based on the synaptic plasticity of Purkinje cells of the cerebellum, and while being guided by error signals carried by climbing fiber inputs. This motor learning allows animals to execute desired movements more precisely as more experience accumulates. Later, mathematical analysis of the neural activities of monkey Purkinje cells supported the cerebellar internal model theory (*Nature*, 1993). Furthermore, this theory was supported by a functional MRI study of the human cerebellum while human subjects were learning to use new tools (*Nature*, 2000). By a series of theoretical and experimental studies, the internal model theory became a standard and major theory of motor control mechanisms. The MOSAIC Theory, further developed for explaining higher cognitive functions, including communications, led to the development of a bidirectional theory of vision. These computational neuroscience achievements by Dr. Kawato have profoundly influenced the neuroscience field.

(2) Implementation of learning algorithms on humanoid robots

The internal model theory was implemented on a humanoid robot with 30 degrees of freedom in the JST-ERATO Kawato Dynamic Brain Project. The robot learned more than 20 different tasks based on cerebellar internal model theory by watching and reinforcement learning. The demonstration attracted worldwide attention and created a new field of neurorobotics.

In 2008, with a new BMI system based on a regular internet connection, a humanoid robot in Kyoto successfully walked according to neuron firing recorded in the cerebral cortex of a walking monkey on the US east coast. This marks a fusion of neuroscience and network robotics.

(3) Development of brain machine interface (BMI)

In BMI, the brain activities of a user are measured in real time, and the decoded information allows the user to control machines and computers. In 2009, brain information was decoded, while the brain activity was recorded simultaneously by near-infrared spectroscopy (NIRS) and electroencephalograph (EEG) from outside the head. In collaboration with Honda and Shimadzu, Dr. Kawato demonstrated non-invasive BMI so that people can control robots or home electrical devices just by their own thoughts (natural thinking of movements or mental motor imagery). The revolutionary aspect of this BMI is to combine NIRS with high spatial resolution and EEG with high temporal resolution to attain a high accuracy in decoding.

(4) New pathways to novel therapies for psychiatric disorders

In 2011, Dr. Kawato developed the “decoded neurofeedback (DecNef)” method, with which people can induce desirable information in their brains without special physical training or conscious understanding of induced brain information. The method of fMRI voxel decoding (artificial intelligence technology) is used to estimate how close the brain activity patterns of a patient are to the desired pattern. This closeness measure is fed back online to the patient as a reward. The patient can learn to achieve specific patterns of brain activities in a prescribed brain area without conscious understanding (*Science*, 2011). DecNef is an innovative causal tool for human neuroscience that could lead to new therapies for psychiatric and neurological diseases, including depression and central chronic pain.

List of Main Publications

1. Yamashita A, Yahata N, Itahashi T, Lisi G, Yamada T, Ichikawa N, Takamura M, Yoshihara Y, Kunimatsu A, Okada N, Yamagata H, Matsuo K, Hashimoto R, Okada G, Sakai Y, Morimoto J, Narumoto J, Shimada Y, Kasai K, Kato N, Takahashi H, Okamoto Y, Tanaka SC, Kawato M, Yamashita O, and Imamizu H: Harmonization of resting-state functional MRI data across multiple imaging sites via the separation of site differences into sampling bias and measurement bias. *PLoS Biology*, **17**, e3000042 (2019).
2. Yamashita M, Yoshihara Y, Hashimoto R, Yahata N, Ichikawa N, Sakai Y, Yamada T, Matsukawa N, Okada G, Tanaka SC, Kasai K, Kato N, Okamoto Y, Seymour B, Takahashi H, Kawato M, and Imamizu H: A prediction model of working memory across health and psychiatric disease using whole-brain functional connectivity. *eLife*, **7**, e38844 (2018).
3. Taschereau-Dumouchel V, Cortese A, Chiba T, Knotts JD, Kawato M, and Lau H: Towards an unconscious neural-reinforcement intervention for common fears. *Proceedings of the National Academy of Sciences, USA*, **115**, 3470–3475 (2018).
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10. Shibata K, Watanabe T, Sasaki Y, and Kawato M: Perceptual learning incepted by decoded fMRI neurofeedback without stimulus presentation. *Science*, **334**, 1413–1415 (2011).
11. Haruno M and Kawato M: Activity in the superior temporal sulcus highlights learning competence in an interaction game. *Journal of Neuroscience*, **29**, 4542–4547 (2009).
12. Kawato M: From "Understanding the Brain by Creating the Brain" towards manipulative neuroscience. *Philosophical Transactions of the Royal Society B*, **363**, 2201–2214 (2008).
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14. Kawato M: Brain controlled robots. *HFSP Journal*, **2**, 136–142 (2008).
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