Non-Invasive BMI for Mental and Physical State Regulation

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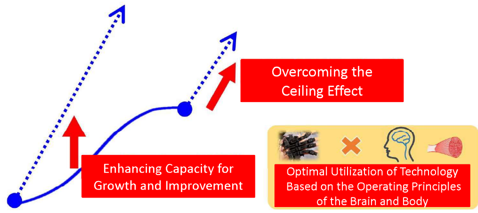
IoB Interface

Moonshot Research and Development Program Goal 1 Kanai Project

Overview

What determines the limits of our abilities? Naturally, a significant portion is determined by innate genetics. However, the factors that define the limitations we feel during daily life or advanced training have not been fully elucidated until now.

Our project has been dedicated to developing non-invasive brain function assessment technologies and training systems based on robotics and neuroscience, aiming to break through the limits of the brain, mind, and body, and realize a future society where everyone can enjoy the joy of manifesting creativity. By gaining a deeper understanding of our own brain and body, we have discovered that the abilities we once believed to be "limits" still possess room for growth, or "potential," that can be improved through the right methods.



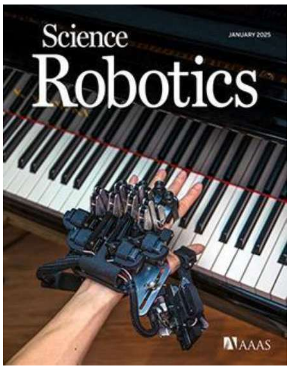
Breaking Through the Limits of Brain, Body, and Mind Through the Fusion of Science and Technology

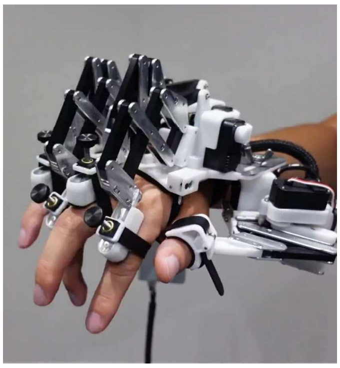
Brain Encoding Technology to Break Through Skill Limits

For experts—including pianists, athletes, and surgeons—who have practiced for many years, the "ceiling effect," where skill improvement stagnates at a certain point, becomes a major issue. Traditionally, attempts have been made to break through this by increasing practice volume, but excessive practice carries the risk of injury and failure, and its effectiveness has often been reported as insufficient. Furthermore, high-speed and complex movements are often impossible to experience firsthand, posing a challenge where skills are difficult to acquire through verbal instruction alone.

- Approximately 100 expert pianists experienced complex and high-speed finger movements—which were impossible for them to perform on their own—by wearing an exoskeleton robot capable of independently moving their fingers at high speed.
- The training involved two weeks of regular practice at home to establish a plateau in their skill level, followed by training using the exoskeleton robot.
- Training while wearing the robot enabled participants to play complex and high-speed musical pieces faster than their previous limit while maintaining accuracy.
- The effect was observed not only in the trained hand but also in the opposite hand.
- While no changes were observed in finger strength, agility, or sensory functions, plasticity (functional changes in the brain) was confirmed in the motor cortex (cerebral cortex).
- This suggests that the passive experience "wrote" the skill of high-speed, complex movements into the motor cortex of the brain.

This research presents the idea that the "ceiling effect" is not an unchangeable limit, and that this limit can be overcome with high-quality experience. Applications are anticipated not only in music but also in improving skills in sports and surgical procedures, and even in preventing injuries caused by over-practice. In the future, this technology is expected to lead to the widespread adoption of new training programs utilizing such exoskeleton robots and Virtual Reality (VR) technology, and the development of education and skill acquisition methods that transcend the constraints of human creativity and physical ability.





The results were featured on the cover of *Science Robotics* and by *The Times*, *BBC News*, and so on.

Technology for Estimating Brain State

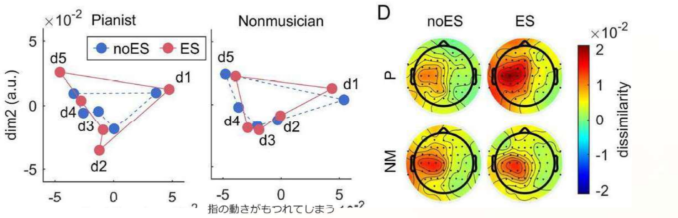
Brain condition varies from day to day. Using a headphone-type EEG device developed by the Ushiba SPM group, we continuously measured the preparatory brain waves of junior pianists in our Piano Academy over a long period of one year.

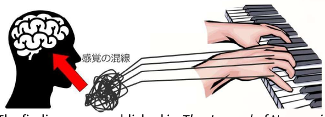
By extracting and analyzing a component known as 1/f fluctuation (or 1/f noise) from the EEG signals, we successfully predicted the day-to-day differences in their performance. This suggests the possibility of estimating a person's subconscious state of wellness or decline using non-invasive brain function measurement combined with data science technology.

Academy student with international competition awards

Technology for Conditioning Brain State

Feeling that one's "body is out of condition" is a critical problem for professionals whose careers rely on physical movement, such as athletes, musicians, and surgeons. In particular, when executing delicate movements, fumbled finger movements leading to failure can sometimes compromise the quality of medical care, culture, or industry. Behind this issue, we discovered a mechanism where force and tactile information sent from each finger is not correctly routed to the respective "finger rooms" within the brain. Furthermore, we found that applying imperceptible, weak electrical stimulation to the peripheral nerves is an effective brain conditioning technique to prevent information from different fingers from becoming confused or crosstalking in the brain.





(Left) Mechanism of sensory crosstalk in the brain, causing tangled finger movements. (Upper) Discovery in experts: Peripheral electrical stimulation increases the distance between the brain's "finger rooms."

The findings were published in *The Journal of Neuroscience*.

Future Prospects

The ability to predict a person's condition from their brain state suggests the possibility of achieving "Peaking"—the regulation of the brain's state using BMI technology. We have developed a prototype system for this purpose. Moving forward, we aim to verify its effectiveness and realize a world where it is possible to optimize one's brain state.

Furthermore, it has become clear that what we once believed to be the limits of our body and mind can be broken through by science and technology. We are working on expanding one such means—the exoskeleton robot—to the entire body, to enable breakthroughs in the limits of more advanced and complex skills, and to realize technology that can transfer tacit knowledge cultivated over many years to others, and ensure its continuous inheritance across generations.

Just as sports science and National Training Centers exist for athletes, we will also strive to establish the science and training centers for performing artists, aiming for the sustainable development of culture.

Shinichi Furuya

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Research Director, Tokyo Research, Sony Computer Science Laboratories, Inc.; Representative Director, NeuroPiano (General Incorporated Association); Visiting Professor, Hanover University of Music, Drama and Media; Part-time Lecturer at Tokyo University of the Arts, Kyoto City University of Arts, and Toho Gakuen School of Music; Specially Appointed Professor, Tokyo College of Music. After studying at the Faculty of Engineering Science and the Graduate School of Human Sciences, Osaka University, obtained a Ph.D. in Medicine from the Graduate School of Medicine. Previously held positions at the Department of Neuroscience, University of Minnesota; the Institute for Music Physiology and Musicians' Medicine, Hanover University of Music, Drama and Media; and the Faculty of Science and Technology, Sophia University, before assuming current roles. Major research awards include the DFG (German Research Foundation) Heisenberg Fellowship, the Klein Vogelbach Prize, the Alexander von Humboldt Foundation Postdoctoral Fellowship, the MEXT (Ministry of Education, Culture, Sports, Science and Technology) Leading Initiative for Excellent Young Researchers, and the Japan Society for the Promotion of Science (JSPS) Prize, among others. Major performance activities include performing at the Ernest Bloch Music Festival (USA) and winning an award at the KOBE International Music Competition, etc. Major publications and translations include The Science of the Pianist's Brain and What Every Pianist Should Know About the Body.

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Internet of Brains

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