National Institute of
Information and Communications Technology

# NICT NEWS

2019 No. 1 Vol. 473

FEATURE

## Brain-informatics for Advanced ICT in Future Society

NICT NEWS 2019 No.1 Vol.473
National Institute of Information and Communications Technology


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**Cover photo:**
Hanging on the wall on the first floor of the research building of the Center for Information and Neural Networks (CiNet) is a large, framed sign that reads "*omoroi kenkyu*" (interesting research). All of our research staff sees this sign every day as they walk to their laboratories. Dr. Toshio YANAGIDA, CiNet Center Director (in center of photo), routinely reminds his staff to work in pursuit of *omoroi kenkyu*. In addition to the sense of *interesting*, the word *omoroi* means it's exciting and involves the pursuit of solutions to the most fundamental questions. We believe our commitment to research of this nature will help us achieve extraordinary results that revolutionize society.
**Upper left photo:** 7T-MRI located in the 2nd basement of CiNet

# Happy New Year!

President of the National Institute of Information and Communications Technology
Dr. Hideyuki TOKUDA

With just two years remaining until the Tokyo 2020 Olympic and Paralympic Games, last year saw considerable effort in strengthening the cybersecurity countermeasures to combat the ever-growing threat of cyberattacks particularly to IoT devices. With respect to cutting-edge information and communication technologies (ICT) in the areas of IoT, big data, AI, and autonomous driving, we've grown increasingly aware over the past year how important it will be for machines and humans to work together to create the future of our society—that is, to improve social reliability and receptivity while strengthening data security and preserving privacy.

As Japan's sole national research institute specializing in the field of ICT, NICT has been assigned the role of resolving social issues and generating new value through the development of advanced ICT. To fulfill this role, our institute has worked hard to pursue an ambitious, wide-ranging research and development program intended to achieve the world's most advanced technologies, and to deploy and implement these technologies in society based on the collaborative/open-innovation promotion policy.

To promote ICT research and development, we've grouped our research into five research clusters: sensing fundamentals, integrated ICT, data utilization and analytics platforms, cybersecurity, and frontier research. We've made steady progress including world-record results in these areas particularly in quantum info-communications technology, ultra-large capacity transmission with a new type of optical fiber, brain-inspired ICT, multi-parameter phased array weather radar, post-quantum cryptography, and privacy-preserving technology. As part of efforts to promote collaborative/open-innovation promotion, in the National Cyber Training Center, we've initiated tactical cyber exercises (cyber colosseo) under conditions that simulate the environment expected during the Tokyo 2020 Olympic and Paralympic Games, accelerating human resource development in cybersecurity. In collaboration with the field of data utilization and analytics platforms, we've been promoting the development of highly accurate machine translation systems to improve a translation bank launched jointly in September of 2017 with the Ministry of Internal Affairs and Communications. Our efforts focused on, for example, compiling and applying translation data drawn from various spheres and improving the accuracy of translation in the medical field by working with pharmaceutical companies. We've engaged in joint research and validation projects with research institutions, businesses, universities, and local governments both in Japan and abroad and promoted activities that will allow businesses to apply our various cutting-edge technologies and activities to further their own international standardization efforts, including efforts involving the ITU, IEEE, and IETF.

To organically couple and pursue our three operational policies—collaboration, open mind/innovation, and the challenger's spirit—we plan to continue organizing NICT Open Summit and Open Challenge. As for the ideathon program launched within NICT the year before last year, we've expanded it beyond our organization. Last year, we held ideathons in Kitakyushu, Hokuriku, and Sendai. We plan to continue organizing these events throughout Japan to gather ideas from those outside NICT and to contribute to solving problems in local communities through ICT. We also continuously strengthen collaborations with overseas organizations in the U.S., Europe, and ASEAN countries. We will also continue to call for suggestions from the public about R&D themes they feel NICT should focus on in the near future and incorporate these opinions into what we do and how we do it. We will continue to build environments for data utilization so that the data and understanding gained through research at NICT will always be as open to the public as possible.

In this year, the fourth of our Fourth Medium- to Long-Term Plan, we will strive to promote R&D and maximize our achievements by concentrating every resource available to us to achieve the goals set forth in the plan. At the same time, we will strive to fulfill our social obligations as a National Research and Development Agency to make sure our R&D accurately gauges and responses to societal demands and will make efforts for further effectiveness in pursuing our mission.

Based on the comments we've received and will continue to receive from people throughout Japan, NICT will steadfastly promote cooperation between industry, academia, and government with support from various parties to move the ICT field still further forward. We appreciate your continuing support and cooperation and hope you will continue to support us in the future.

As I wrap up this New Year's message, I hope 2019 will be the best year yet for all of you.

INTERVIEW

# Creating High-Quality Communication for Communicating Heart with Neural Computation!

**Toshio YANAGIDA**
**Director General of Center for Information and Neural Networks**
After partially completing a doctoral program, He worked as a Professor at Osaka University, Distinguished Researcher at NICT, and then took his current position in 2013. He researches "Yuragi " (fl uctuation) as a basic mechanism of life. Awarded Person of Cultural Merit in 2013. Ph.D. (Engineering).

Exterior of the Center for Information and Neural Networks (CiNet) building

**The Center for Information and Neural Networks (CiNet) is a center for basic research on human brain functions founded jointly by the National Institute of Information and Communications Technology (NICT) and Osaka University. Following CiNet's establishment in 2011, construction for the research building was completed in 2013 on the Suita Campus of Osaka University. Since then, CiNet has pursued research in fields like next-generation information and communication technologies, brain-machine interface (BMI), brain function measurement, and robotics. The center is equipped with the most advanced facilities for measuring and analyzing neural functions, including a 7-tesla MRI (magnetic resonance imaging device), one of the few currently installed in Japan. Researchers have full access to all these facilities. What are CiNet's goals? In this issue, we interviewed Dr. Toshio Yanagida, CiNet Center Director, who has worked in the front lines of research efforts at the center since its founding.**

**— What does it mean to integrate brain information and communications?**

Yanagida: The advances in information and communication technologies today permit high-speed transfers of massive data volumes. But this has also led to something information fatigue, or overload. That suggests we've reached a point where the volume and speed of information transfer aren't the most pressing issues. Our center targets information and communication technologies that prioritize quality over volume.

**— What do you mean by prioritizing quality? Can you elaborate?**

Yanagida: Our brains should find the communication information pleasing. We want to make information transfer a more pleasant experience. Whenever humans transmit or receive information, the brain functions as a mediator. That's why our center focuses on the study of the brain—it lies at the core of information and communication. We hope to uncover sensations in the brain triggered by the information received and discover methods of information transfer that will be pleasing to the receiving party. The word *integration*, as it appears in the name of our center in Japanese, implies the integration of neural science and information science as well as the integration of multiple disciplines, like cognitive science, psychology, and medicine and physiology.

**— Are other countries pursuing studies like this?**

Yanagida: No. It's unprecedented. There's large-scale research on the brain and AI underway in the United States, but virtually no research seeking to integrate information and communication technologies with cognitive function.

**— How many researchers currently work at your center?**

Yanagida: Around 250 in total. Some hold concurrent positions at Osaka University. Many of our researchers are from overseas. We operate one 7-tesla MRI, three 3-tesla MRIs, and one magnetoencephalography, or MEG, machine, in addition to technical experts with extensive expertise in operating these instruments, which gives us the ability to respond the sometimes complex demands of our researchers. I'm proud to say our center is world-leading in terms of the environment we provide for brain function research.

## Rapid Progress in Brain Study with Precision Measurement Technologies

**— There's been rapid progress in brain science within the past few decades. Is it fair to say fMRI has contributed greatly to this progress?**

Yanagida: Yes. fMRI is an innovative method that lets us see in near-real-time what's going on in the human brain, without invasive electrodes. Dr. Seiji Ogawa, who's also the R&D advisor for our center, invented the fMRI. Changes in brain activity cause changes in the amount of oxygen binding to hemoglobin in the minute blood vessels in the brain, which in turn causes changes in the magnetic field in the surrounding area. fMRI detects this change in the magnetic field to measure brain activity.

**— I see. The technologies for making brain measurements appear to be integral to progress in each of these research fields. Can you describe these research fields in greater detail?**

Yanagida: Our center defines four main areas of integrated research fields. The first is the development of technologies for establishing *heart-to-heart connections*—in other words, research on quality communication. The second is developing technologies for information networking technologies based on knowledge learned from the brain. All this research seeks to create low-energy networks based on emulation of the robust, autonomous, self-repairing, and flexible properties of the brain. The third is *communication between the heart and machine*—brain-machine interface (BMI) technologies for controlling external devices via the functions of the brain. These offer the potential for restoring functions lost or degraded by aging and for establishing more effective rehabilitation programs. The fourth involves core measurement technologies—more sophisticated fMRI devices and improving their temporal and spatial resolutions—whose purpose would be to establish measurement technologies that can make fast, accurate measurements based on the purpose of the research.

## "*Omoroi Kenkyu*"

**— How will all this research contribute to society?**

Yanagida: We don't place a special emphasis on a technology's usefulness. Overemphasizing the utility of a given research project undercuts the reasons for doing basic research in the first place. Shortsighted research goals tend to compromise the depth of the research results. A researcher should be allowed to immerse himself in whatever direction curiosity leads, without worrying about any utility of the results. That's an approach that can lead to historic breakthroughs. At that point, if something like that happens, I'm sure that someone else will pitch to make the findings useful to society.

**— So that's what you mean by "*omoroi kenkyu*."**

Yanagida: Yes. The word *omoroi* is dialect in Osaka for the word *omoshiroi*, as used in Tokyo, but it's taken on a rather different meaning. *Omoroi* refers to excitement that springs from the depths of the heart. In comparison, *omoshiroi* refers to the appeal of something that can be described pretty simply in words. *Omoshiroi* things aren't *omoroi*. It shouldn't be necessary to explain in words how a certain kind of research could be useful. The criteria for this kind of research should be that the research is fun and exciting. That's my belief.

**— So *omoroi* research on brain functions is a field in which multiple disciplines are integrated in a complex way?**

Yanagida: Yes, exactly. The brain is an extremely complex system, called the last frontier, for which the approach of even the most exhaustive anatomical study won't necessarily reveal anything. That's why we've taken the constructive approach, in which we seek to build a model of the brain having the same functions as a human brain using computers and explore the correlations between the information we input and brain function, one by one. In other words, we construct and examine.

Young researchers discussing with excitement

**— Aren't there countless numbers of neurons in the brain?**

Yanagida: Estimates of the actual number of neurons diverge, but the cerebellum alone is said to have 100 billion, and the cerebrum 15 billion. One neuron has several thousand synapses that interconnect to other neurons, so the number of synaptic couplings is estimated to on the order of 100 trillion. If these synaptic couplings are controlled by assigning binary values of 0 and 1, the number of potential combinations can be as high as 2 to the 100 trillionth power, which is far too great a scale to achieve an understanding of the whole brain. A brute force approach to computations on that scale would require fantastic amounts of electrical power. We'd never be able to build the nuclear power plants needed to supply that power.

**— How does our brain handle computations on that scale?**

Yanagida: Measurements of the brain show the baseline energy consumption of a brain is 20 W. Even when we're hard at work, it's only about 21 W. So use a mere 1 W to do our thinking. The cloud for a major American EC site uses several tens of megawatts for a single data center. The K supercomputer uses 13 MW, which corresponds to the energy consumption of thirty thousand households. That gives you an idea amazingly energy-efficient our brains are.

**— What's the mechanism of the brain?**

Yanagida: That's the key question, the question that led me to the world of brain science. The main reason computers use so much energy is that they have to remove noise. To obtain a signal, we have to apply electricity to remove noise we don't want. That produces heat. In contrast, our brain requires very little energy. Computers carry out calculations to produce a definite solution. On the other hand, our brain arrives at the optimal solution by trial and error wandering through. The solution reached may not be 100 % correct, but the brain settles for the seemingly optimal solution. Our brains are analog machines.

## Collaboration with Industries and Future Prospects

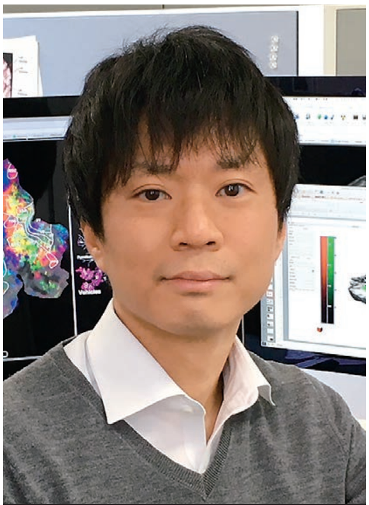
**— In what fields of brain science is industry interested?**

Yanagida: Most companies don't have the luxury of pursuing basic research, so they're quite interested in these areas. Many industries have also realized the importance of communication we find natural and pleasing. For example, more and more cars are equipped with autonomous driving systems. Different drivers will have different preferences on how a car should respond to commands—for example, where to go when told. So, systems have to be designed to adapt to each user's preferences to establish a pleasing and workable mode of communication. The hints to designing such systems lie in studies of the brain.

**— Last but not least, do you have a word on the future prospects for CiNet?**

Yanagida: From a technological prospective, we have to develop more precise methods for measuring the brain. And we have to collect a lot more data on the brain. A large-scale database will help both in research and commercial aspects. I think I've suggested in this interview that basic research shouldn't overprioritize social utility, but I do believe we need to establish a practical framework when we implement our technologies in the real world. Our researchers will continue to be given the freedom to pursue what they feel is *omoroi*, rather than a constant concern for utility considerations. Our young researchers will be the pioneers in new research frontiers, so I'd like to create an environment that they find congenial. The environment for young researchers in many ways can be pretty brutal, especially with respect to treatment, but I want to give them the support they need to make the most of their talents and to pursue their research interests with the greatest freedom. Our center is a national research institute. The plan is to have it do research that's beyond the reach of the private sector. Then, by establishing a system for collaborating with society and the private sector, we can promulgate our *omoroi* research to the world.

# Deciphering Internal Representations in the Brain



**Shinji NISHIMOTO**
**Senior Researcher, Brain Networks and Communication Laboratory, Center for Information and Neural Networks**

After getting his Ph.D. in neuroscience, he worked as a postdoctoral fellow at University of California, Berkeley. He then joined NICT in 2013. His main research interest is to understand how the brain works under naturalistic conditions. His adjunct affiliations include Guest Professor at Osaka University Graduate School of Medicine and Group Leader at ERATO IKEGAYA Brain-AI hybrid project.

**In daily life, humans take in huge volumes of information through the eyes and ears. Our brain processes this information to generate objectives and create subjective perceptual experience: for example, "It's snowing, so I should drive more carefully"; or, "This new product is so cool!" Our group pursues research with the goal of establishing mathematical foundations for artificial intelligence (AI) and the brain-machine interface (BMI) by examining how our brains function when experiencing these daily events.**

## Background of Research

The brain is a central organ that handles integrated processing of various information, from images to smells to language. We believe we can establish the foundations for a scheme that allows richer and more effective information transmission by understanding how the brain processes, expresses, and generates such various pieces of information. The 2010s saw remarkable progress in large-scale, high-precision brain activity measuring technologies, especially functional Magnetic Resonance Imaging (fMRI), as well as growing sophistication in statistical and machine learning techniques for analyzing massive volumes of recorded brain activity. This progress has made it possible to perform quantitative analyses of brain activities evoked in response to the diverse and complex experiences of daily life: for example, watching a movie or performing various cognitive tasks. These efforts have made it possible to decode perceptual content—for example, the experience of watching a movie—based on brain activity and to clarify how the entire brain functions during various types of cognitive tasks. They've generated a multitude of results invaluable not just from the academic perspective, but from the perspective of applications for society. This article will introduce a framework and examples of actual studies in this field.

## Framework for Brain Information Model

In our research project, we've performed experiments that record brain activity evoked under common conditions, like watching a movie, using fMRI and other instruments, with the goal of understanding how the brain functions under the diverse and complex experiences of everyday life (Figure 1). While the results for brain activity obtained from these experiments may appear at first glance to be random noise (Figure 1, right), we see them as a kind of code used by the brain to reflect perceptual experience. From this perspective, our research is analogous to decryption: We're seeking to identify the correlation between complex perceptual experience and brain activity. We use two models in our research: The first is an encoding model, which calculates what features of perceptual experience are encoded as brain activity; the second is the decoding model, which shows what perceptual experience a certain brain activity represents. Building the encoding

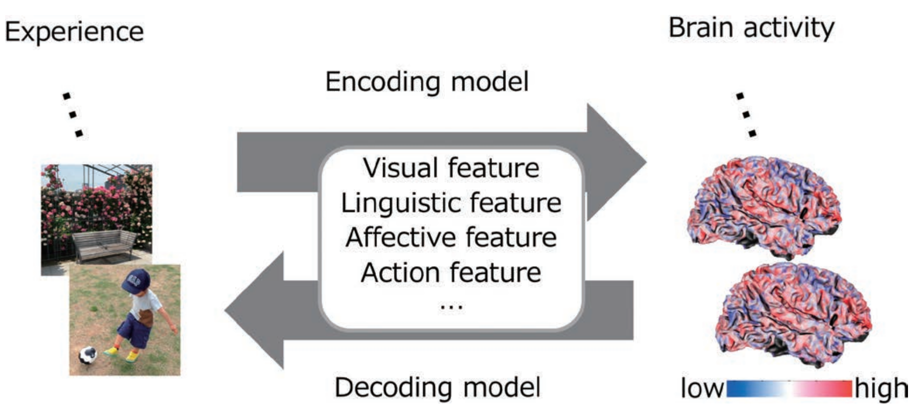



Figure 1 Concept of the encoding and decoding model of brain activity

Decoded perceptual contents (brain activity + decoding model)

| | Nouns | Verbs | Adjectives |
|---|---|---|---|
| 1 | blond hair | wear | kind |
| 2 | hair | adore | cute |
| 3 | hairstyle | don | young |
| 4 | clothes | dislike | childish |
| 5 | black hair | worry | familiar |
| 6 | wear | endear | bad |
| 7 | female | speak | scary |

Decoded perceptual contents (encoding + decoding model)

| | Nouns | Verbs | Adjectives |
|---|---|---|---|
| 1 | blond hair | wear | kind |
| 2 | female | speak | familiar |
| 3 | male | worry | cute |
| 4 | hairstyle | adore | childish |
| 5 | speech | dislike | scary |
| 6 | celibacy | talk | young |
| 7 | mother | hit | bad |

**Figure 2** An example of the decoded perceptual semantic content for audio and visual stimuli evoked by the movie on left; CENTER: an example of decoded perceptual content obtained from brain activity using the decoding model; RIGHT: an example of decoded perceptual content obtained using the encoding and decoding model of brain activity (Nishida and Nishimoto, 2018)

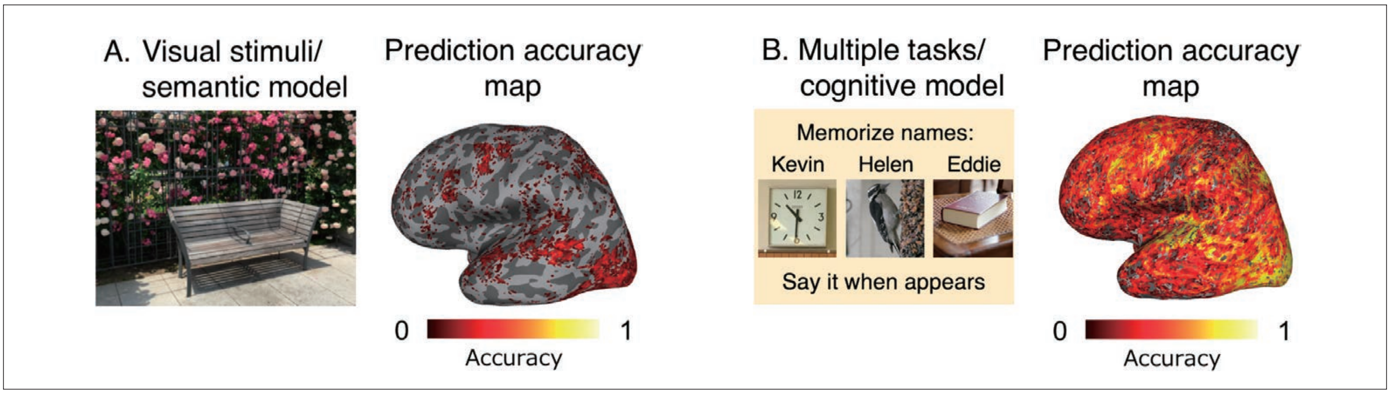



**Figure 3** Comparison of passive semantic perceptual (A) and active cognitive models (B). While the semantic perceptual model predicts activities in areas like the occipital lobe and temporal lobe, the cognitive model explains and predicts activities involving nearly the entire brain. (Nakai and Nishimoto, 2018)

model is nothing less than an attempt to build a system that behaves in the same manner as the brain—an artificial brain. We expect this research to generate insights for creating an artificial intelligence that closely resembles the human brain. The decoding model may be regarded as a system that decrypts brain activity, or the mathematical foundations for BMI capable of discerning what a person feels, thinks, or intends.

## Decoding Brain Activity

Within the above framework, we developed a technology for deducing the semantic content perceived by a test subject, represented as the degree of certainty regarding words, by examining the subject's brain activity as the subject views audiovisual content—for example, a movie (Figure 2, left and center). For several hundred pre-specified actions and visual stimulation generated by objects, the technology already exists for deducing perceptual content based on brain activity. Our decoding model is based on the concept of feature space founded on our newly-developed natural language processing technology, which allows our model to make significant deductions of perceptual content for over 10,000 words, including words for objects, actions, and impressions. This technology can be used as the foundations for quantitative evaluations that determine whether a certain image material accurately relays the intentions of its creator. Related commercial services are already being licensed to private businesses. Beyond this, we've developed a technology for deducing perceptual content from images, which would eliminate the need for additional fMRI experiments. The technology involves building a two-way encoding model and decoding model based on compiled brain activity data (Figure 2, right). The deductive technology based on the abovementioned decoding model requires fMRI experiments each time new visual and audio material is added to the perceptual content deduction database; this is extremely time- and cost-consuming. Using the encoding model (artificial intelligence model) to predict brain activity instead, we can eliminate the need for additional experiments. This system would represent a technology with remarkable potential for social applications, including applications involving identifying ideal audio or visual content. We expect significant interest for such systems.

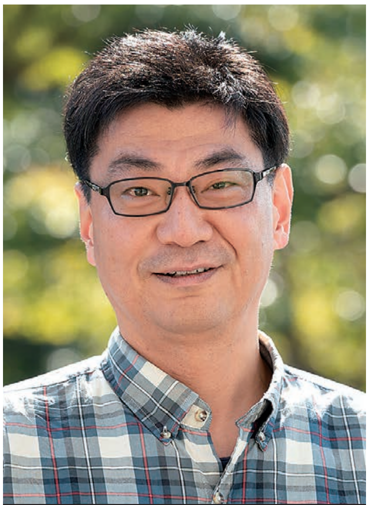
## Quantitative Understanding of Active Brain Functions

Our daily lives involve not just passive processing of visual and audio information, but active judgment and actions (decision-making and speech). In the above section, we introduced the idea of building a model of brain activities and decoding brain activities under passive conditions, like watching a movie. But a similar framework can be applied to the brain activities that occur while performing active cognitive tasks. Our group constructed a model of brain activities for over 100 types of daily tasks (involving value judgments, calculations, and so forth), employing the cognitive features of the respective activities (cognitive model). Based on this model, we've developed an encoding model applicable to activities involving nearly all areas of the cerebral cortex (Figure 3). We expect this model to contribute to an understanding of how our brains function when integrating a range of cognitive information and to provide knowledge that will have applications across a wide range of fields, including the development of AI capable of simulating such functions.

## Future Prospects

This article describes a framework and examples of actual studies for building an encoding and decoding model of the brain. The framework is intended to strengthen understanding of how our brain functions under conditions resembling those encountered in everyday life: for example, watching movies or performing various daily tasks. The nature of our research means the gap between basic research and applications is narrow. We plan to continue to pursue a strategy that addresses all levels of research, from purely academic ones to those with an eye on practical implementations in real-world settings.

# Social Neuroscience and Prediction of Individual-level Social Behaviors



**Masahiko HARUNO**
**Research Manager, Center for Information and Neural Networks**
After completing graduate school, worked at NTT Communication Science Laboratories, ATR, UCL Institute of Neurology, University of Cambridge (Department of Engineering) and Tamagawa University Brain Science Institute. Entered NICT in 2011. Engaged in computational neuroscience, social neuroscience. Invited professor at Osaka University BFS. Doctor of Engineering.

**Dramatic advances in information communication technologies are making our world an ever-smaller place. We now live amid vast social networks that transcend the limitations of face-to-face interaction. In contrast to machines, humans are biological organisms and undertake unique social decision-making that often impose various stresses on the individuals making them. I believe a better understanding of the social aspects of the brain will make it possible to design human-friendly social networking systems and offer easy-to-use services and products based on stress predictions. In this paper, I'll introduce our research on predicting individual-level social characteristics by examining the social brain.**

## The Amygdala and Individual Differences in Social Behavior

One vital basis of social behavior is resource allocation behavior, or behavior involving decisions on how to divide resources and information between the self and others. What mechanisms of the brain are responsible for individual differences in such preferences, such as preferring to divide evenly among all or allocating more to oneself? The individual differences observed in response to such issues is known to correlate with other social behaviors, such as voting and donating. Thus, the issue is of the utmost interest and importance. The traditional view has been that choices concerning fairness in such matters result from activity in the frontal lobe, the part of the brain responsible for cognition and thinking, which suppresses the selfish tendencies of the brain's emotion/reward system. However, it may also be that the emotion/reward system itself chooses to avoid unfairness and behave fairly at a subconscious level.

To explore these two possibilities, our group performed the following experiment (Figure 1). First, individual differences in allocation preferences, or social value orientation, were assessed for each participant. A participant was asked to choose one of three ways, presented over approximately 10 seconds, to divide money between himself and an anonymous individual (Figure 1a). Choice 1 reflects a prosocial orientation, wherein the individual prefers to maximize the sum of the rewards while minimizing the differences in the rewards received by himself and the other. Choice 2 is preferred by individualistic individuals who prefer to allocate more of the reward for themselves. Choice 3 is preferred by competitive individuals who stress how much larger their reward is compared to others. We asked the 39 participants who made consistent choices at least six out of eight times (25 prosocials and 14 individualists) to participate in a functional Magnetic Resonance Imaging (fMRI) experiment to assess brain activity. In the experiment (Figure 1b), after being presented with combinations of rewards for the self and the other individual, participants had to press a button indicating the appeal of each option. This task lets us make quantitative evaluations of how the three variables—reward for self; reward for others; sense of unfairness (absolute difference in reward)—affect the decision. We looked for the brain activity triggered by each of these variables and for differences among the participants.

The results showed that brain activity in the amygdala of participants in the prosocial group correlated with perceptions of the absolute difference in reward (Figure 1c). The amygdala is an almond-shaped set of neurons located deep in our brain, known to be involved in rapid (intuitive) emergency response behaviors, such as

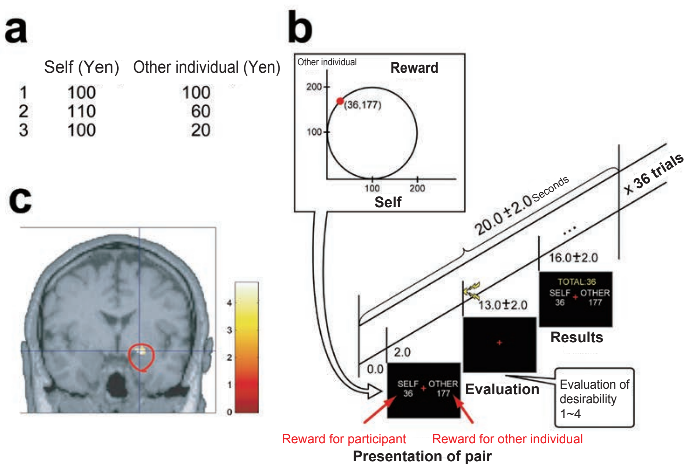



**Figure 1 Results of experiment used to identify the neural bases of social value orientation**
a) Selection task for dividing participants into groups: choices for 1. prosocial, 2. individualistic, 3. competitive
b) Task for fMRI brain activity measurements: The desirability of various reward combinations is evaluated on four levels.
c) Brain activity in the amygdala of the participants in the prosocial group correlated positively with the absolute value of the difference between the reward for self and the reward for others.

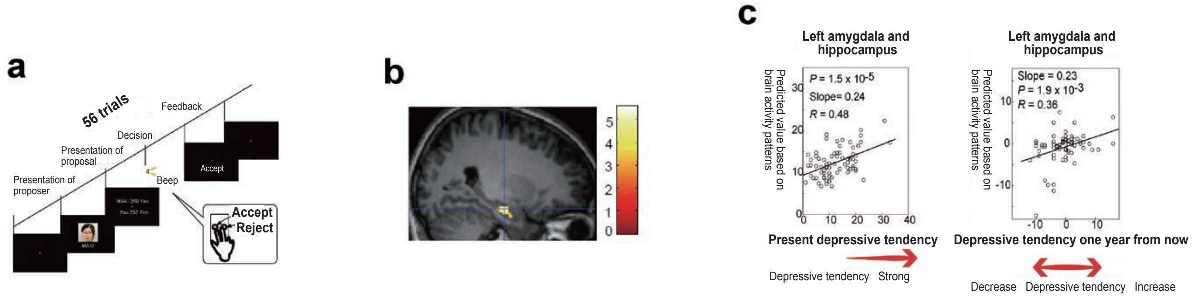



**Figure 2 Predicting present and future depressive tendencies based on brain activity patterns in the amygdala elicited by unfairness**
a) Ultimatum game for deciding whether to accept or reject the proposal for dividing the money between the participant and the proposer
b) Patterns of activity in the amygdala and hippocampus elicited by unfairness during the ultimatum game
c) Predicting the depressive tendency of each participant (represented by a circle) in the present (left) and one year in the future (right) based on amygdala/hippocampus activity patterns elicited by unfair divisions: We observe a positive correlation between actual and predicted measurement values (represented on the horizontal and vertical axes, respectively), which suggests that these predictions are possible.

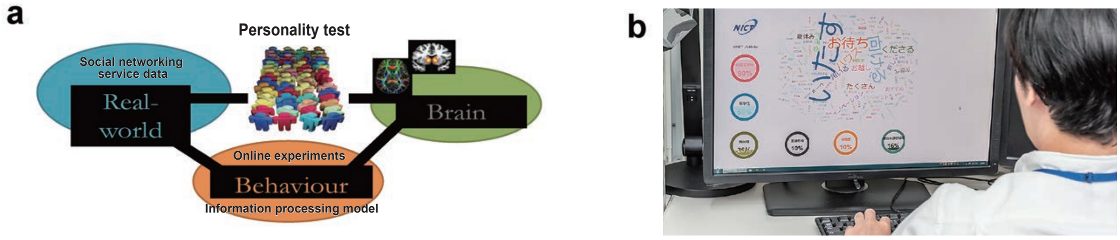



**Figure 3 Study based on big data on social brain and behavior**
a) Construction of brain information processing model reflecting real-world social behavior based on large-scale behavioral data, personality test data, social networking service (SNS) data collected using an online experiment system, and brain information data.
b) Construction of a system for predicting individual-level social characteristics based on SNS data (example of application on official NICT-issued ID)

choosing to flee from snakes, or reading another individual's facial expressions. In contrast to the prevailing belief that the frontal lobes are the basis for advanced social behavior, our study suggests that, the amygdala, a brain structure also found in fish and mice, is involved in seemingly advanced decision-making processes, including perceptions of unfairness and actions to avoid unfair allocation.

## Predicting Present and Future Depressive Tendencies Based on Amygdala Activity Patterns Elicited by Inequity

Several cohort studies (i.e., studies that track the behavior of and responses to questionnaires from participants over an extended timeframe) point to a link between clinical depression and economic inequity. This observation led us to formulate a theory that amygdala activity patterns elicited by unfair allocation will allow predictions of present and future depressive tendencies. To investigate this theory, we used an experimental task, called the ultimatum game, in which a proposal for dividing a given sum is first presented by a certain individual: for example, 269 yen for the individual presenting the proposal (proposer) and 232 yen to the individual responding to the proposal (responder) (Figure 2a). The responder decides whether to accept or reject the offer. If the responder accepts, the money is divided as proposed; if the responder rejects the proposal, both parties get 0 yen. One would think the optimal strategy for maximizing the reward received by the responder would be to accept any proposal presented; interestingly enough, the results show individuals tend to reject any offer in which their share is less than 20 % of the total amount. We found that the perception of unfairness with a proposal elicited activity in the amygdala, a result consistent with our earlier results (Figure 2b). The participants were asked to take a depressive tendency test, called the Beck Depression Inventory-II (BDI-II), a total of two times: the first at the same time as the fMRI experiment, and the second, one year after the experiment. Using AI techniques, we tried to predict the depressive tendencies at the time of the fMRI experiment and one year later based on the brain activity patterns in the amygdala elicited by the sense of unfairness in each participant (Figure 2c). The results showed a positive correlation between the actual and predicted values of depressive tendencies for both times: at the time of the experiment (left) and one year later (right). This suggests depressive tendencies can indeed be predicted based on brain activity patterns in the amygdala elicited by perceptions of unfairness. This finding points to a strong link between perceived unfairness and the mental state of the individual in question, an important scenario in which the amygdala plays a key role.

## Big Data on Real-World Behavior and the Prediction

An assessment on the distribution of individual differences in social behavior requires the collection and analysis of big data that accounts for age, sex, place of residence, and other details. Our research group is undertaking a project to construct a brain information processing model by first building an online data collection system to collect and analyze massive volumes of data from behavior and personality tests for approximately 10,000 Japanese individuals, as well as SNS and brain activity and structural data for a part of the same individuals (Figure 3a). Our data have started to show significant differences between the sexes in terms of social behavior, including, for instance, preferences in avoiding situations of unfair allocation described above. Such gender-dependent differences may significantly affect the designs of future social systems and human resource strategies. The data also indicate that predictions of various individual-level social behaviors can be made by applying AI technology to SNS data and personality test data (Figure 3b). We are also beginning to understand that certain social behaviors require different types of data for predictions; for example, some can be predicted more precisely based on SNS data, while others, such as future depressive tendencies, can only be accurately predicted using brain activity data.

## Future Prospects

The accumulation of big data on social behavior has rapidly reshaped our understanding of how individual differences in social behavior correlate with age, sex, and place of residence. There are high expectations that this will allow us to identify the information processing mechanisms in the brain responsible for these differences. The results may make it possible to predict various individual-level social behavior and characteristics based on brain activity and SNS data to an extent well beyond the bounds of existing methodologies. However, in establishing highly precise prediction methods and seeking to identify how these methods can be applied to various problems in future research and development efforts, we must also keep in mind the socially acceptable limits of such applications.

# Non-Invasive Modulation of Human Brain Activity and Its Applications

## Identifying new functions for alpha oscillations

**Kaoru AMANO**
Senior Researcher, Brain Networks and Communication Laboratory, Center for Information and Neural Networks

He then joined CiNet as a senior researcher (PI) in 2013. Since 2013, he is also a visiting associate professor in the Graduate School of Frontier Biosciences, Osaka University. His primary research interests are in the neural mechanism underlying visual perception, multi-sensory perception, and temporal perception.

**Even after two phenomena are found to be correlated, determining their causal relationship isn't always a simple matter. Which is the cause and which the effect? We encounter similar problems in seeking to correlate perceptions and/or behavior with brain activity: for example, determining what area of the brain is activated when viewing a certain image. Discerning whether the brain activity is responsible for generating (i.e., that the relationship is causal) or incidental (i.e., that the relationship is not causal) to the perception and/or behavior in question is often difficult. To determine the causal relationship, if one exists, we've developed a method that allows non-invasive modulation of human brain activity to examine changes in perception and behavior accompanying changes in brain activity.**

### What are Alpha Oscillations?

Alpha oscillations are electrical oscillations generated by the brain (brain waves) within the 8–13 Hz frequency range (approximately 10 oscillations per second). Since these dominate when we close our eyes or relax, these oscillations were originally thought to have no active function. However, recent studies indicate they may be involved in visual perception. More specifically, they are closely associated with functions such as focusing attention on visual targets. Even so, previous studies were only able to show a correlation between visual perception and alpha oscillations. No conclusive study to date has been able to clearly demonstrate that alpha oscillations do give rise to visual perception.

### Inter-Individual Variations in Illusory Jitter Frequency Reflect Inter-Individual Variations in Alpha Oscillation Frequency

In this study, we performed an experiment focusing on a phenomenon known as illusory jitter (Figure 1), in which the movement of equiluminant red and green objects against a black background creates the illusion that the green figure oscillates at approximately 10 times per seconds (10 Hz). The illusion arises because while both the red-green and red-black borders are actually moving at the same speed, the former is perceived to move more slowly than the latter. The green bar is perceived as falling behind relative to the red square, but since this isn't actually the case, our brain attempts to correct for the lag. The cyclic correction process is believed to be perceived as jitter. Our study has revealed that the inter-individual variations in illusory jitter frequency experienced by a person directly reflects the inter-individual variations in alpha oscillation frequency. In other words, we discovered that individuals with higher and lower alpha oscillation frequencies, respectively, perceived faster and slower illusory jitter (Figure 2, left). In addition, there are

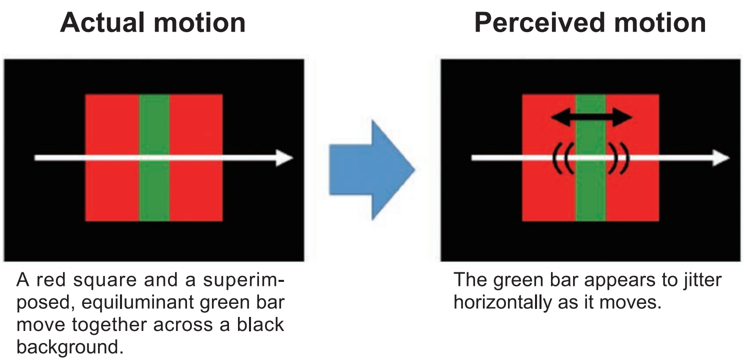



Figure 1 Illusory jitter

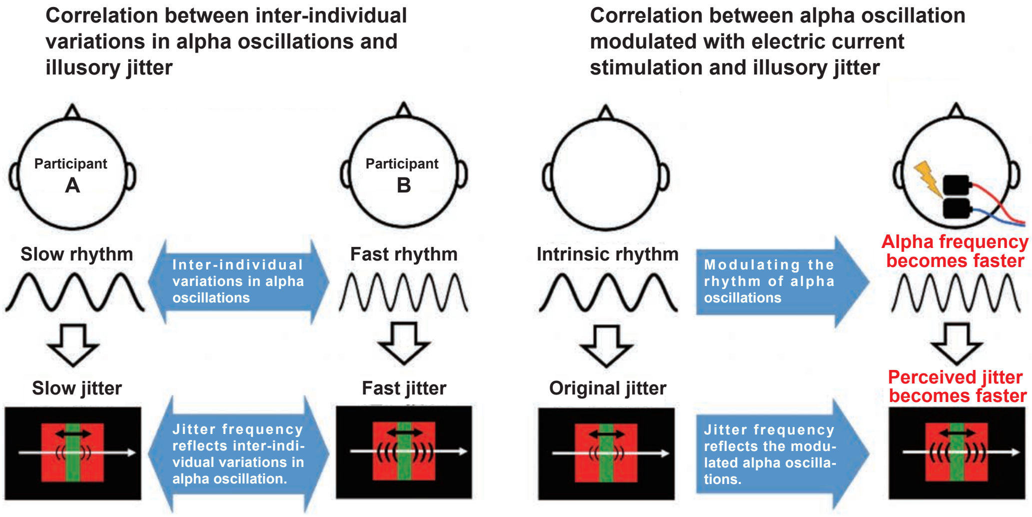



**Figure 2** Relationship between illusory jitter and inter-individual difference in or manipulation of alpha oscillations

slight within-individual variations in alpha oscillation frequency, which we found also affects how illusory jitter is perceived.

## Fluctuations in Perceived Illusory Jitter Frequency with Fluctuating Alpha Oscillation Frequency

We've developed a technology that artificially modulates the alpha oscillation frequency by applying weak electric stimulation, harmless to humans, to the back of a participant's head (transcranial direct current stimulation). This led to the world's first successful observation of manipulated fluctuations in this frequency. With conventional methods involving AC stimulation of the brain, it's difficult to observe brain activity as stimulation being applied due to noise from electric stimulation, which makes brain function measurement methods like electroencephalography (EEG) and magnetoencephalography (MEG) not applicable. The key feature of the present study is that variations in alpha oscillation can be observed free of artifact from electric stimulation, using unique waveforms (amplitude modulation) differing from those employed by conventional methods. When the alpha oscillation frequency is made artificially higher or lower using this technology, the illusory jitter frequency perceived by the participant fluctuates in sync (Figure 2, right). The finding that perception reflects the changes induced in the brain waves proves alpha oscillations do indeed contribute to the perception of illusory jitter.

## Determining the Timing of Integration of Visual Information with Alpha Oscillation Frequency

Our study suggests alpha oscillations contribute causally to visual information processing. Figure 3 presents the functions we assume for alpha oscillations. Pathways associated with visual information processing include the dorsal visual pathway, which mainly performs processing related to object motion and depth, and the ventral visual pathway, which mainly performs processing for object shape and color. The results of brain activity measured during subjective perception of illusory jitter reveal that the inferior parietal lobe (IPL), part of the dorsal visual pathway, and the inferior temporal gyrus (IT), part of the ventral visual pathway, coordinate their activities within the alpha oscillation band. In the case of illusory jitter, the lag in the position of the green bar calculated by the dorsal pathway using motion information is corrected based on the correct positional information (position of the center of the red square) calculated by the ventral pathway, in timing with the rhythm of the alpha oscillation. The experiment suggests is the possibility that alpha oscillations act as a type of pacemaker, by determining the timing of information communication among different visual pathways.

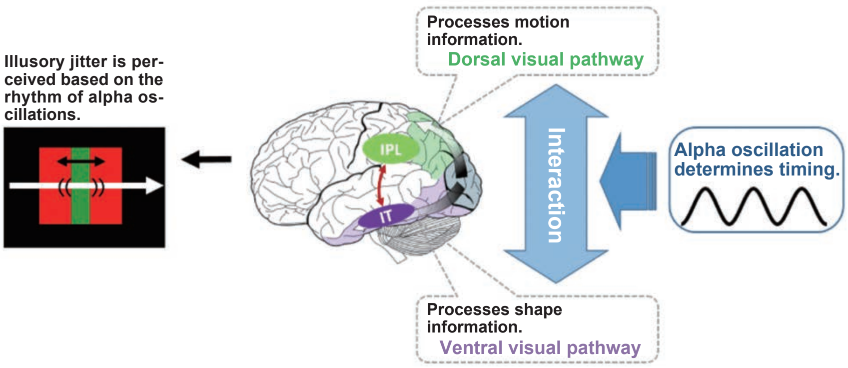


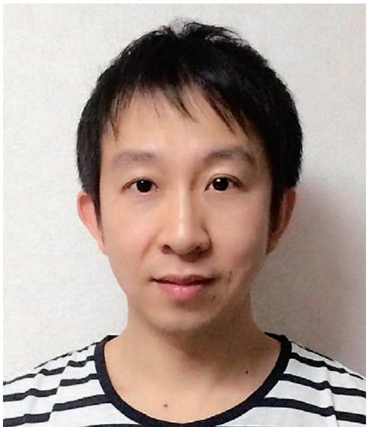

**Figure 3** Integration of information across visual pathways based on the rhythm of alpha oscillations

## Future Prospects

This study validated a causal relationship wherein alpha oscillations are cause and the illusory jitters are effect. Other cognitive functions may also be associated with alpha oscillations, including other visual functions, hearing, and memory. In the future, we hope to apply the alpha oscillation modulation technology developed in this study to resolve the in-depth correlation between such cognitive functions and alpha oscillations. For example, it may be possible to adjust the alpha oscillation frequency to compensate for deteriorating cognitive function or to improve short-term memory in the elderly. We also plan to examine in detail the correlation between alpha oscillations and the cognitive functions required to perform daily tasks, like deskwork, with the goal of finding ways to enhance performance in everyday work.

# Improvement in English Listening Skill by Neurofeedback Training

**Yasushi NARUSE**
Director, Neural Information Engineering Laboratory, Center for Information and Neural Networks (CiNet)
After completing the doctoral course at a graduate school, in 2007, entered NICT to work on the research and development of Brain ICT. Ph. D. (Science).



**Ming Chang**
Researcher, Neural Information Engineering Laboratory, Center for Information and Neural Networks (CiNet)
After completing the doctoral course at a graduate school, in 2016, entered NICT to work on the research of neurofeedback training. Ph. D. (Information Science).

When people hear the word "encephalogram," they picture a doctor at a hospital examining a patient with some sort of brain problem. Recent advances in brain wave measurement (encephalography; EEG) technologies have made it possible to evaluate brain waves in everyday situations, even outside the hospital. NICT has been active in EEG research, particularly research on instruments that realized users could simply wear on their head (Figure 1). Such devices would allow use of EEG not just to diagnose disease, but for healthcare at home. These technologies may also find applications outside medicine, including education and marketing. Here we'll introduce an example of an application involving education. The example involves neurofeedback training based on encephalograms for the purpose of improving English listening skills.

## Background of Research

Because the Japanese language doesn't distinguish between the sounds for "r" and "l," many Japanese have difficulty perceiving the difference between the pronunciations for "right" and "light." The two words often end up being perceived as the same word. Strangely enough, however, we know that while a Japanese listener may not consciously distinguish between these two words, the words "light" and "right" trigger differences in brain activity patterns that can be observed when an individual is made to listen to repeated utterances of the word "light," with the occasional "right" mixed in randomly: for example, "light, light, ***right***, light, light, light, ***right***…" While the listener may be incapable of distinguishing the two words consciously and declare what he or she is hearing is the word "light" being repeated, at a subconscious level, the listener's brain detects and reacts to the difference in sounds. This brain activity is referred to as mismatch negativity (MMN). Research shows MMN grows stronger as an individual becomes better at distinguishing the two sounds. To date, researchers have used this property of MMN primarily to evaluate the results of auditory training intended to help listeners get better at distinguishing sounds; these evaluations consider whether the MMN is amplified. We've turned this idea on its head: If we can develop a program that trains participants to amplify MMN, we believe the individual will in time learn to distinguish the two sounds. This approach is called neurofeedback training.

## Neurofeedback Training

For the training, we developed a system

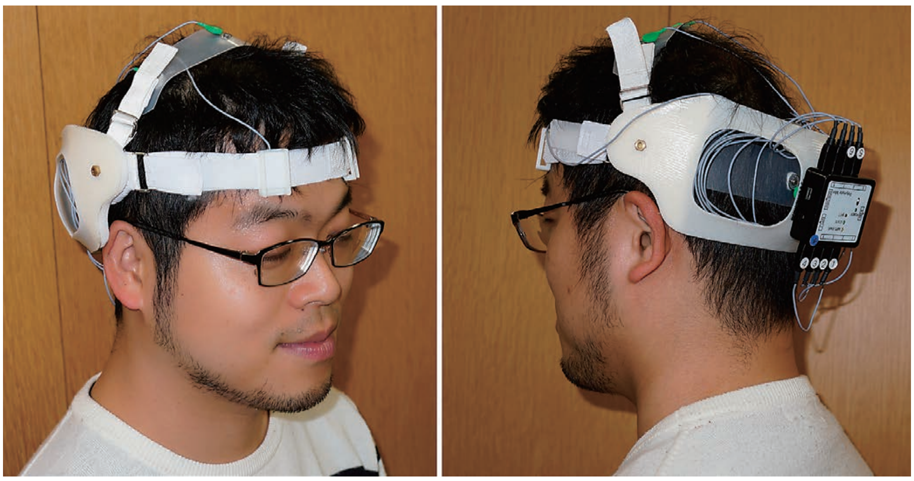


Figure 1 Wearable electroencephalograph (EEG) developed by NICT

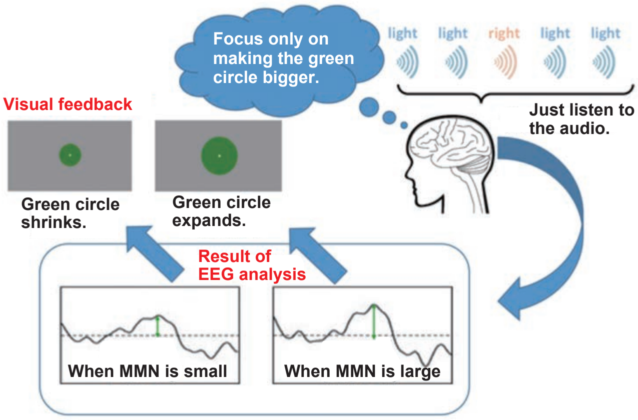



Figure 2 Schematic diagram of neurofeedback training; MMN stands for mismatch negativity

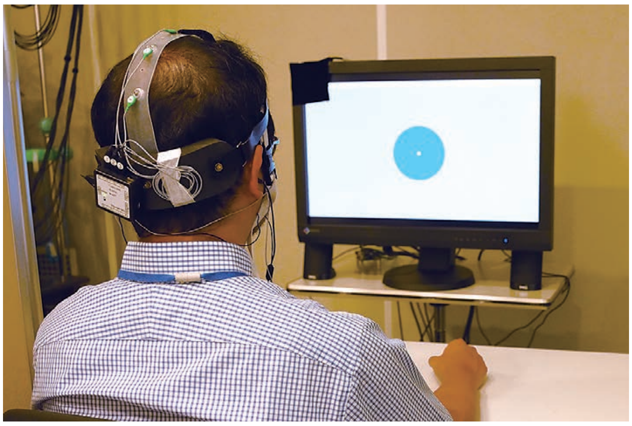


Figure 3 Individual participating in the neurofeedback training

for taking encephalograms of a participant as he or she listened to a series made up of two words (e.g., "light, light, ***right***, light, light, light, ***right***…"). We analyzed the amplitude of the MMN in real-time, then visualized the amplitude of the measured MMN as a green circle whose size changes with amplitude (Figure 2). We asked our participants to listen to the audio of this series of words and simultaneously focus their attention on making the green circle shown on screen larger. The participants appeared to have no idea how to enlarge the circle at first, but through trial-and-error eventually learned how. In other words, they learned how to amplify their MMN. Our brains are capable of learning a multitude of tasks; we now know that the brain can learn how to control its activity based on real-time visualization of its own activity. Figure 3 is a scene from an actual neurofeedback training session.

## Efficacy of Neurofeedback Training

One group of participants, called the neurofeedback training group, underwent neurofeedback training for approximately one hour every day for five days. The results of cognitive testing (involving asking participants to distinguish "right" and "light" in a listening test) demonstrated the effectiveness of this training; those in this group improved with each passing day. The participants began by giving correct answers at a rate of roughly 60 %. By the end of the experiment, this figure had improved to about 90 % (black circles in Figure 4).

The study also involved a control group of participants who did not undergo neurofeedback training. As with the neurofeedback training group, this group was also asked to listen to the same series of words through earphones while wearing an EEG device. The screen before them displayed the green circle changing its size, but in this case the change was based on MMN data obtained for participants in the neurofeedback training group. This meant the participants in the control group could not enlarge the green circle, no matter how hard they tried, since the feedback provided to them was not based on their own data. As with the neurofeedback training group, participants in the control group attended sessions lasting approximately one hour every day for five days, but their cognitive testing results showed no improvement (white dots in Figure 4). While participants in both groups listened to English words under the same conditions, only test results for those in the neurofeedback group improved. The results suggest another key factor in improving the ability to distinguish English words beyond listening is obtaining neurofeedback on MMN amplification.

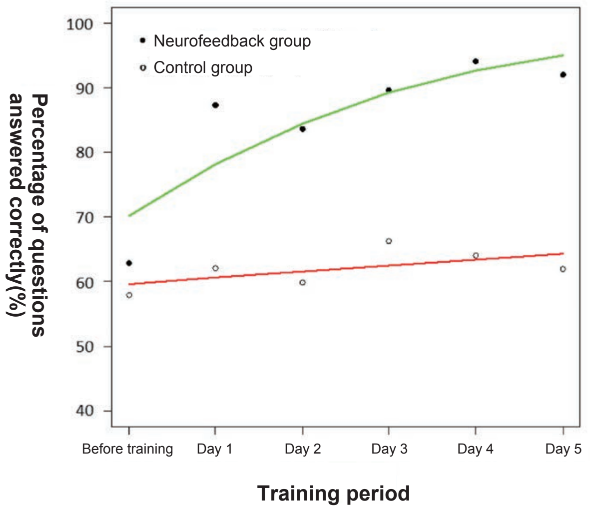



Figure 4 Comparison of results of cognitive testing for neurofeedback group and control group

## Future Prospects

We believe this technology will help improve the English listening skills of the Japanese, who tend to do poorly in the area. We are currently pursuing research and development for practical implementations. Academic studies can be performed in the controlled environment of a laboratory; practical implementations must assume that the users will undergo the neurofeedback training sessions in everyday environments, with various extraneous noise sources superimposed on the encephalograms. We are also seeking to develop a simpler EEG device. By jointly tackling such issues one by one with various private businesses, our team is striving to produce a practical EEG model suitable for real-world use.

# Successful Data Transmission of 1.2 Pb/s Using 4-Core, 3-Mode Optical Fiber Measuring 0.16 mm in Diameter

## Establishing basic technologies for the next-generation optical communication infrastructure

Research around the world is seeking to develop novel optical fiber technologies capable of overcoming the current limits on the transmission capacity of optical fibers widely used today in optical communication (single-core, single-mode fiber having outer diameter 0.125 mm) and capable of handling ever-growing volumes of communication traffic and large-scale optical transmission. These novel optical fibers fall into two classes: The first is multi-core fiber with multiple paths (cores) through the fiber. The second is multi-mode fiber, which features a single core capable of handling multiple transmission modes. Successful experiments involving long-haul high-capacity transmission using multi-core fibers have been reported. However, these achievements required optical fibers with large diameters, which are less resistant to mechanical stresses, such as bending and pulling, more susceptible to fiber breakage during manufacturing and installation, and harder to connect.

Joint efforts involving Hokkaido University, the MQ Photonics Research Centre at Macquarie University in Australia, the NICT Network System Research Institute, and Fujikura Ltd. have resulted in a transmission system based on a 4-core, 3-mode optical fiber with a diameter of 0.16 mm (Figure). Experiments with this fiber resulted in the successful transmission of 1.2 petabits/second. In this experiment, lightwaves were multiplexed and demultiplexed to and from the fiber with a specially designed coupler. High-density, multi-level modulation of 256 QAM was used 368 wavelengths in order to achieve this transmission capacity.

The outer diameter of this optical fiber is close to that of conventional optical fibers, an achievement that facilitates both cable production and installation as well as allow the use of existing facilities for installation and rapid real-world deployment. This optical fiber features extremely high density information transmission capacity compared to conventional fiber and supports spatial channels in multiples of four, making it highly compatible with data center I/O methods. Hence, it has strong potential for applications in high-density optical interconnections both inside and outside data centers.

"We plan to continue research and development efforts to establish the basic technologies for the next-generation optical communication infrastructure that can smoothly accommodate the traffic which will no doubt continue to increase into the future, such as big data and 5G network services," said Research Managers Dr. Yoshinari Awaji and Dr. Hideaki Furukawa of the Photonic Network System Laboratory of NICT Network System Research Institute. "We hope this transmission system will find data center applications and, later, to metropolitan area network applications by improving the transmission distance, and so we wish to further promote industry-academia-government collaboration."

The results of this work received great acclaim at the 44th European Conference on Optical Communication (ECOC2018, held on Sept. 23–27, 2018) and was adopted and presented as a Postdeadline Paper on September 27, local time.

Reference

Ruben S. Luís, Georg Rademacher, Benjamin J. Puttnam, Tobias A. Eriksson, Hideaki Furukawa, Andrew Ross-Adams, Simon Gross, Michael Withford, Nicolas Riesen, Yusuke Sasaki, Kunimasa Saitoh, Kazuhiko Aikawa, Yoshinari Awaji, and Naoya Wada, "1.2 Pb/s Transmission Over a 160 µm Cladding, 4-Core, 3-Mode Fiber, Using 368 C+L band PDM-256-QAM Channels," in Proc. 44th European Conference on Optical Communication (ECOC), September 2018, paper Th3B.3.

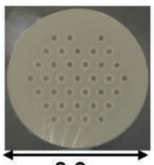
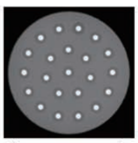
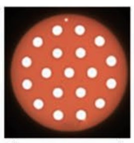
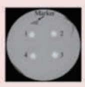
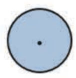
| | Representative research achievements | | | Present result | Standard optical fiber |
|---|---|---|---|---|---|
| | March 2015 | October 2015 | October 2017 | September 2018 | |
| Transmission throughput (bps) | | 2.15 Pb/s | 10.16 Pb/s | 1.2 Pb/s | 0.15 Pb/s at maximum |
| Core, mode | 36core, 3mode | 22core, 1mode | 19core, 6mode | 4core, 3mode | 1core, 1mode |
| Cladding diameter |  0.3mm |  0.26mm |  0.267mm |  0.16mm |  0.125mm |
| Coating diameter | | | | 0.25mm | 0.235～0.265mm |

Figure　Comparison between our 4-core, 3-mode optical fiber and other optical fibers

■Related press release

• **Successful Transmission of 1.2 Pb/s Over a 4-core 3-mode Optical Fiber with a Cladding Diameter of 0.16 mm**
(released on November 21, 2018 https://www.nict.go.jp/en/press/2018/11/21-1.html)

# Measuring Information Transmission Pathways in the Human Brain

Hiromasa TAKEMURA

Researcher (Tenure-Track). Ph.D.
Brain Function Analysis and Imaging Laboratory
Center for Information and Neural Networks (CiNet)

During my PhD studies, I focused on the psychological study of the human visual system. But even back then, I was eager to pursue other research themes once I'd earned my degree. After earning my degree, I was fortunate to have the opportunity to pursue research at Stanford University in the United States, which had been my dream all along. At Stanford, I had a chance to work on a project measuring information transmission pathways in the human brain using MRI.

Advances in both computing hardware and information transmission technologies, including the optical fiber used to connect remote locations, are important factors for improving information and communication technologies. The human brain is analogous to information and communication technologies. The gray matter of the brain consists of the cell bodies of neurons. It's where we observe brain activity. Thus, it functions as the computational hardware of the brain. Technologies like fMRI and MEG are ways to measure brain activity in the gray matter; they're core technologies at CiNet for information and communication research related to the brain. In contrast, white matter consists of bundles of fibers that connect remote parts of the brain. They're analogous to optical fiber cables. The key to understanding our brain's efficient approach to information processing may lie in the white matter.


My research is distinct from other research underway at CiNet in that I focus specifically on white matter. Most of the studies of white matter in the past have involved dissecting and sketching the post-mortem brain. In recent years, a measurement method using an MRI known as diffusion magnetic resonance imaging (dMRI) has emerged. The method enables us to acquire information on the brain's white matter as it exists in a living brain as digital data and make quantitative analyses. The research I've pursued to date includes the following: (1) developing a method for analyzing dMRI data; (2) rediscovering fiber bundles whose existence was confirmed in classical post-mortem brain studies but which have been overlooked in modern studies; and (3) performing quantitative evaluations of white matter bundles and analyzing their individual differences. Based on the findings of these studies and advancement of dMRI measurement technologies, I hope to elucidate how white matter contributes to information processing in the brain and establish the foundations for using and applying dMRI in diverse research fields.

## Biography

1985 Born in Tokyo
2007 Graduated from Department of Life and Cognitive Sciences, College of Arts and Sciences, The University of Tokyo
2012 Completed Doctoral Course at the Graduate Course of Arts and Sciences at the University of Tokyo; became research associate at Stanford University
2015 Granted JSPS Research Fellowship for Young Scientists (SPD); joined NICT as Special Researcher
2018 Currently holds the same position

## Awards, etc.

2011 Ikushi Prize from the Japan Society for the Promotion of Science
2017 Magna Cum Laude Merit Award from the International Society for Magnetic Resonance in Medicine

## Q&As

Q: What did you like the most about being a researcher?

A: Research is sometimes a tough business. However, I really like the moment I feel the intellectual thrill when some experimental findings connect to each other.

Q: What do you think is your worst personal failure to date?

A: During my college years, I was on a table tennis team with an impressive tradition. I lost a match that ended up dropping my team to a lower league. That, in my memory, remains a distinct experience in personal defeat.

Q: What are you currently into outside of your research?

A: I'm tracking the growth process of my first son, who's two years old. At first his speech involved just fragments of just one or two words, but he's gradually learned to form longer word strings and even sentences. The process is fascinating.

In this column "NICT's Challengers" you will find a profile of NICT staff tackling a variety of things.

NICT NEWS 2019 No.1 Vol. 473
Published by **Public Relations Department, National Institute of Information and Communications Technology**
Issue date: Jan. 2019 (bimonthly)
4-2-1 Nukui-Kitamachi, Koganei, Tokyo
184-8795, Japan
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ISSN 2187-4050 (Online)