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Trend of "Brain Science and Education" Researches

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2.1 Introduction

There are still many unknown parts in the brain, and the brain is one of the important subjects in studies involving the field of future life science. In addition, brain science not only expanded the knowledge of natural science and contributed to health care and welfare, information science and robot engineering, but also expanded the range of its application to such areas as cultural sciences and social sciences including pedagogy, psychology, sociology and linguistics, resulting in greater significance of the study.

Because of the importance of brain science research, the 1990s were called the "Decade of the Brain" in the United States and researches were promoted on a large scale, and, in Europe, brain science researches have been tackled in accordance with the trend in the United States.

In our country, positive attempts to tackle brain science have been made including grants for the research of emphasized fields and the research of specific fields. Moreover, at a meeting of "the long-term view on the research and development regarding the brain" (Brain Science Committee, Life Science Committee, Council for Science and Technology Policy, Cabinet Office; May 1997), strategy goals of "knowing the brain" (elucidation of the brain function), "protecting the brain" (conquering brain disease), and "creating the brain" (development of a brain-type of computer) were set. Accordingly, some attempts were made including the inauguration of a core organization for researches of brain science, the Brain Science Institute of The Institute of Physical and Chemical Research made a start (October 1997), and a project, "elucidation of the brain function," was tackled by the Japan Science and Technology Corporation in the Core Research for Evolutional Science and Technology (CREST).

By the results to date, many findings on functional molecules and nerve circuit networks related to high-level brain function such as memory and learning have been obtained. In recent years, the technique of non-invasive brain functional imaging has rapidly progressed, and a safe technique with a higher precision was developed. On the other hand, in our country, which is reaching an aging society with a declining birthrate, it is highly expected that the findings from researches of brain science will be applied to various fields such as nursing, school education, social life, and nursing of the elderly.

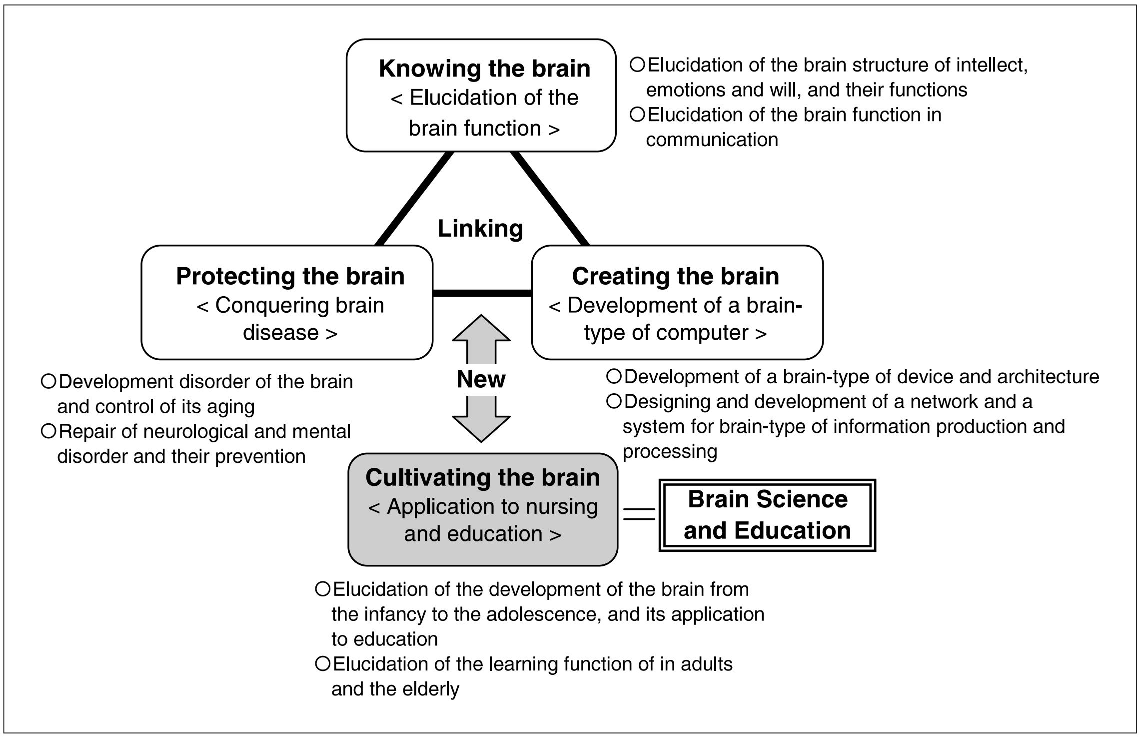
With the above as a background, a new strategic goal for brain science research, "cultivating the brain," was proposed at a meeting of "Measures for the promotion of research and development of life science" (Subdivision on R&D planning and Evaluation, Council for Science and Technology, Ministry of Education, Culture, Sports, Science and Technology; June 2002). The "cultivating the brain" is intended for elucidation of brain development from infancy to adolescence, its application to education, and elucidation of the learning function in adults and the elderly (Figure 1). In March 2002, the Ministry of Education, Culture, Sports, Science and Technology established a study meeting on researches of "brain science and education" to assess specific measures in the field.

In this report, we will introduce a summary of internationally new researches of "brain science and education" as a national strategic measure, and state the future prospects.

2.2 Summary of "Brain Science and Education" researches

The researches of "brain science and education" are intended to clarify the mechanism of learning

Figure 1: Summary of brain science researches in Japan



Source: Authors' compilation based on References [1] and [2].

in order to develop and grow the innate ability in humans, and to maintain it and eliminate obstacles.

The Ministry of Education, Culture, Sports, Science and Technology set a study meeting of "brain science and education" researches in March 2002 in order to decide on a plan for the present (about 5 years) and a long-term plan for over a decade. In the study meeting, specialists from various fields such as pedagogy, educational psychology, behavioral science, biology, child neurology and brain science have continued discussions. At present, specific research plans are under discussion, and an interim report was published in July 2002. In a Research Institute of Science and Technology for Society, started by the Japan Science and Technology Corporation in fiscal 2001, "Brain Science and Education" was established as one of the research fields, and pilot studies under six titles are currently being conducted.

In Figure 2, a summary of "Brain Science and Education" researches assumed from past discussions is shown. "Education" in the relevant researches is a concept in a wide sense over a lifetime including the human fetal period.

Here we introduce the contents of the plasticity of the brain and the critical period being key words of the research subject. We also introduce a summary of the non-invasive imaging method of brain functions, which is important as a research method.

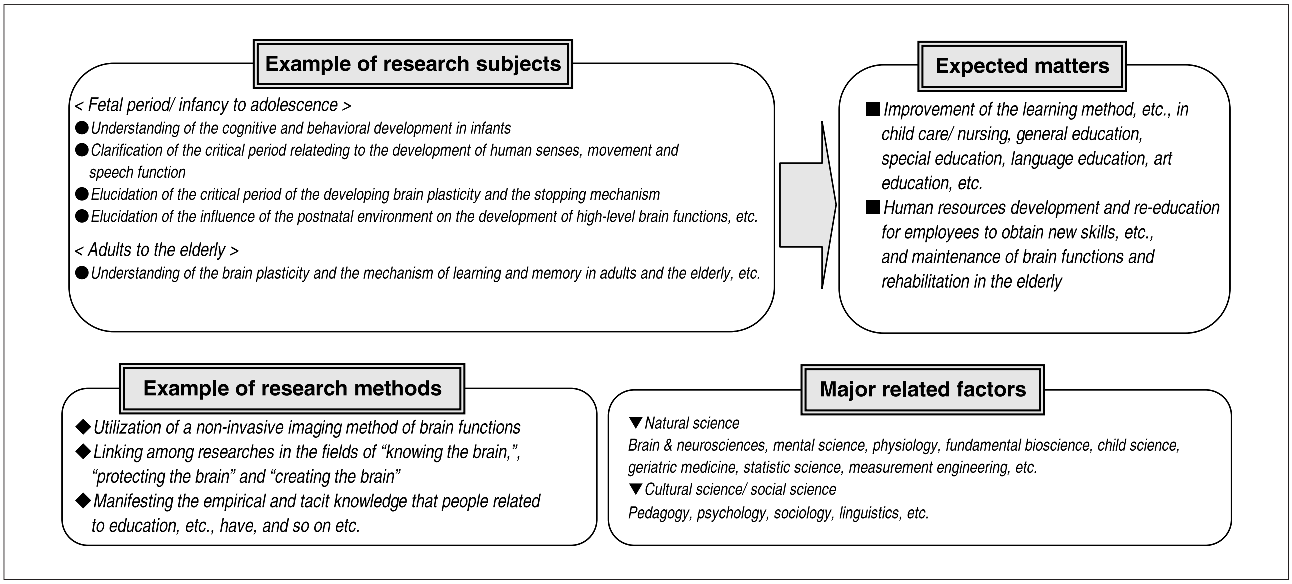
2.2.1 Plasticity of the brain (synaptic plasticity)

Plasticity refers to a variable property shown for maintaining a normal state in dealing with some environmental changes, and, in the brain, synaptic plasticity is considered to be the fundamental process for learning and memory.

The brain consists of a large number of nerve cells (neurons) and glia cells. The nerve cells are important cells for transmitting signals as a device of the nerve circuit network in the brain, and the glia cells give support to such nerve cells. In brain science, in recent years, a detailed analysis of the chemical process of signal transmission in the brain cells and the process of gene control behind it has been made.

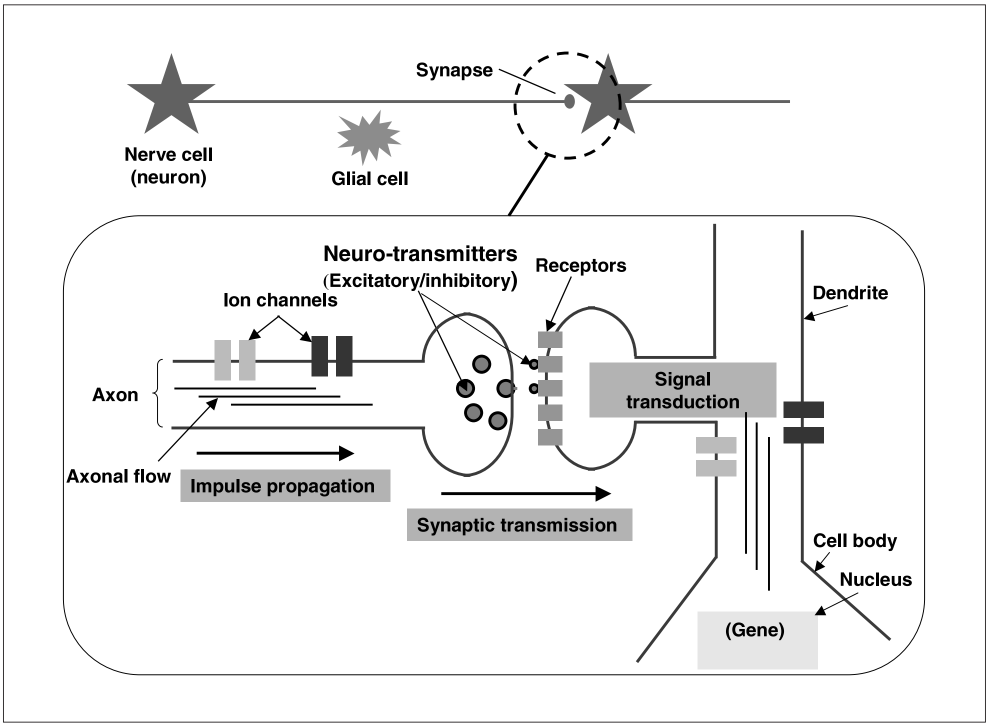
Generally, nerve cells consist of the cell body, dendrite, and axon, and nerve cells connect with each other by synapses (synapse transmission). If a signal is transmitted to the axon, neurotransmitters such as an excitatory mediator and an inhibitory mediator are formed in the synapse, and

Figure 2: Summary of "Brain Science and Education" researches



Source: Authors' compilation based on References [1] and [2].

Figure 3: Information transmission in the synapse



Source: Material prepared by Dr. Masao Ito, director of the Brain Science Institute, The Institute of Physical and Chemical Research.

the signal is transmitted to receptors on the dendrite of the signal transmitting side (Figure 3). A complicated chemical reaction is caused by this, and the signal is further transmitted to cells to work on the next nerve cell or an outside area such as muscle. In recent years, researches on the mechanism of signal transmission have progressed considerably, and it is known that more than 100 kinds of molecules such as ion channels, receptors and mediators are involved in the process.

The continuous change in the efficiency of synapse transmission and the shape depending on the activity is called synapse plasticity; this is considered to be the most fundamental process in the memory and learning of the brain, and its research has advanced significantly in the world. As for synapse plasticity, approximately 10 types of it have been detected from around the 1970s when it was discovered to date.

In proceeding with research of "Brain Science and Education," it is important to elucidate the plasticity of the brain and the mechanism of learning and memory, with further development of researches in the relevant field desired.

2.2.2 Critical period or sensitive period of the brain

In high-level functions of the brain such as learning and memory, it is known that there is a critical period or sensitive period (the time when a phenomenon or reaction is decided to occur or not). The range of the time is almost proportionate to the life span of each biological species, and the period with a short peak is often called the critical period, and the period with a long peak to some degree the sensitive period. For example, the critical period (sensitive period) of the plasticity in the visual system may be expressed by day units in mice and rats, and by week units in cats, and it is around two years in humans. The sensitive period is known to vary depending on the type of various senses and stimulations.

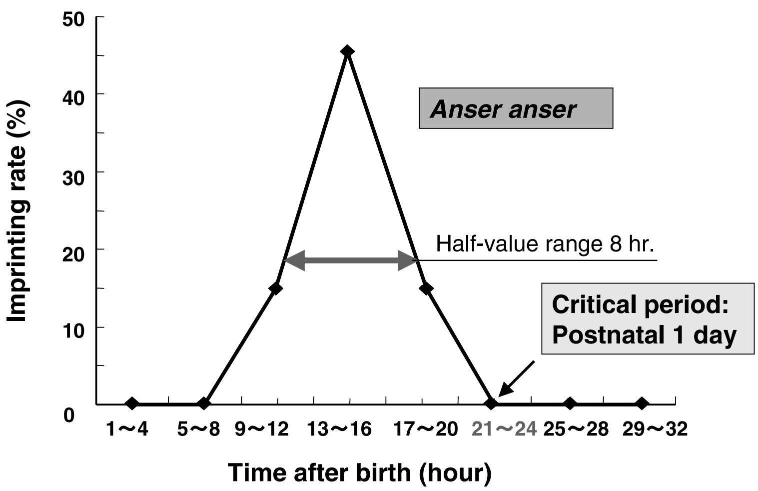
For example, with regard to the critical period of one form of learning, the imprinting phenomenon, many findings have been obtained up to now. The imprinting phenomenon is a special learning function that occurs in the short time after an animal's birth. To give a well-known example, a chick recognizes as its mother the first thing it sees after birth, and behaves by following this first seen thing. In an experiment using *Anser anser*, the possible duration of the imprinting phenomenon is very short, and there was a peak at around 15 hours after birth (Figure 4).

Although the imprinting phenomenon itself is a genetic process incorporated in the gene, the process is considered to be completed through information of the first seen moving object, that is, an epigenetic process not incorporated in the gene such as a visual stimulation from the environment. This indicates that the influence of the postnatal environment is one of the important factors in the development of brain functions.

The sensitive period in language acquisition is often used as an example in humans. Within 1 year after birth, it became known that there is a sensitive period of distinguishing consonants such as the distinction of L and R. The sensitive period in language acquisition is said to generally exist at 10–15 years of age. If the relationship between the sensitive period of learning and the influence of the environment is clarified, it may lead to the drawing out of humans' abilities to the maximum.

The relationship between the sensitive period of high-level brain functions in humans and the environment has barely been elucidated. It is one of the goals of "Brain Science and Education" researches to proceed with fundamental re-

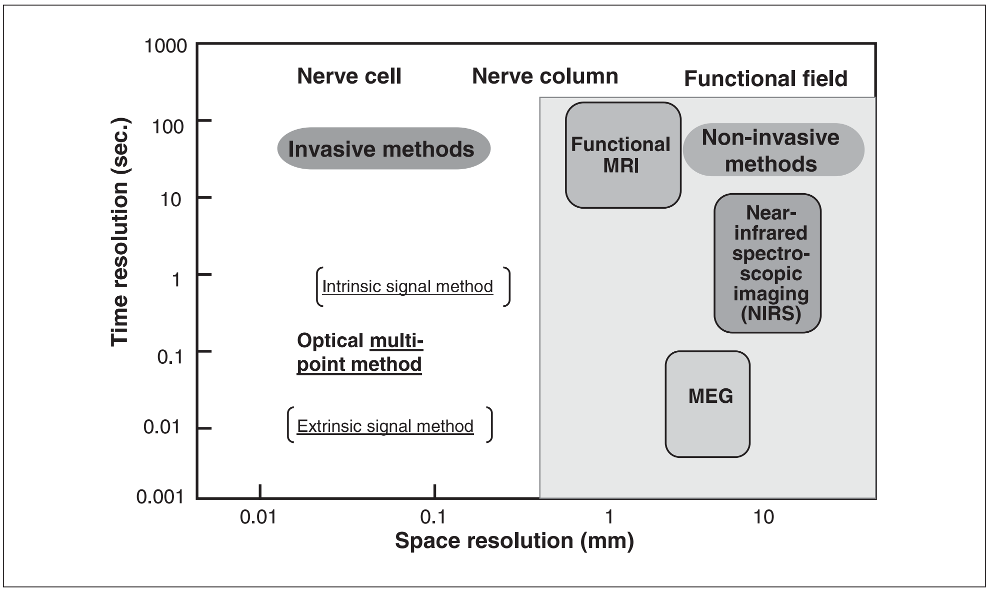
Figure 4: Critical period of imprinting phenomenon



Note: In Figure 4, chicks with complete imprinting are plotted. In the research, all the chicks did not have complete imprinting, and the total in the plot does not reach 100%.

Source: Material prepared by Dr. Hideaki Koizumi, senior chief scientist of the Advanced Research Laboratory & Central Research Laboratory, Hitachi, Ltd.

Figure 5: Comparison of imaging methods of high-level brain functions



Note: The values are approximate aims, and show a conceptual comparison of the measuring methods.

Source: Authors' compilation based on material given by Dr. Hideaki Koizumi, senior chief scientist of the Advanced Research Laboratory & Central Research Laboratory, Hitachi, Ltd.

searches and apply the results to education, etc., in the future. At that time, the problem with education is that it requires time for feedback, and it would be necessary to proceed with a large-scale longitudinal research and a statistical analysis, as well as the subsequent follow-up investigation, based on a systematic plan.

2.2.3 Measuring method of high-level brain functions

The rapid progress of non-invasive measuring techniques for high-level brain functions such as human thinking and memory in recent years brought about a significant opportunity in proceeding with researches of "Brain Science and Education." Generally, non-invasive measuring in brain researches refers to methods not involving surgical invasion such as craniotomy. Some clinical methods playing important roles such as positron emission tomography (PET), single photon emission computed tomography (SPECT) are included in non-invasive measuring, but as radioactivity is used in these, there is a limitation in applying them to healthy people because of the association with radiation exposure.

At present, safe and useful non-invasive imaging methods to measure high-level human brain functions are functional magnetic resonance imaging (fMRI), magneto-encephalography (MEG), and near-infrared spectroscopic imaging (NIRS; photo-topography), etc. In Figure 5, various imaging methods of high-level brain functions including invasive methods are shown, with the relationship between the space resolution and time resolution.

For three non-invasive imaging methods, a comparison among them in terms of the approximate space resolution and time resolution, the degree of freedom in subjects, and the usage of measurement is shown in Table 1.

Of the non-invasive imaging methods, the best in the space resolution is functional MRI, and the best in the time resolution is MEG. However, the degree of freedom in subjects is low for both, and the type of subjects and their conditions are limited. In NIRS, there is room to be improved in the space resolution, but it has the following characteristics: (1) the subject is not enclosed in a narrow space, (2) the subject can move, and (3) there is no noise. Therefore, it provides a measurement of the brain activities in newborns and infants in a natural environment.

However, in order to grasp high-level brain functions at a higher precision, many technological problems in the present non-invasive imaging methods still remain to be solved. The measurement of brain functions is a technically difficult method in the first place and infants are included in the major subjects in the research of "Brain Science and Education," therefore, a

Table 1: Comparison of non-invasive imaging methods of high-level brain functions

	Functional MRI	MEG	NIRS
Space resolution	1 mm (particularly good)	Several mm	10 mm
Time resolution	Several dozens of sec.	Several msec. (particularly good)	Several sec.
Degree of freedom in subjects	Small	Small	Large (particularly good)
Principle	By reflecting the difference of magnetism in blood hemoglobin associated with nerve activity to the magnetic resonance signal, the change of local brain blood flow responding to the stimulation is analyzed.	A weak magnetic field induced at the surface of the head with the nerve activity measured using a high-sensitivity magnetic sensor (SQUID fluxmeter). From the MEG obtained, localization of a power source in the brain is presumed.	By measuring the absorption rate of near-infrared radiation that changes depending on the concentration, the change of local brain blood flow responding to the stimulation is analyzed.
Example of main usage	Visual and auditory induction reaction, and high-level brain functions such as language cognition and memory.	Clinically, it is considered to be useful in presuming a signal source in epilepsy or abnormal slow wave. In addition, it is also useful in presuming spontaneous MEG during sleep, a magnetic field induced by stimulations such as electricity, magnetism, light, and sound, and the signal source.	It is said to be useful for monitoring of the brain blood flow in an operation or in epilepsy, and measurement of brain functions in infants was attempted.

Source: Authors' compilation based on material prepared by Dr. Hideaki Koizumi, senior chief scientist of the Advanced Research Laboratory & Central Research Laboratory, Hitachi, Ltd., and Reference [4]

particularly safe measuring method is required. The development of measuring technology is a field that has not attracted people's attention very much in Japan to date, but it is one of the most important factors in proceeding with "Brain Science and Education" research, and, as such, should be dealt with positively in the future.

2.3 International trends in "Brain Science and Education" researches

In 1999, the Center of Educational Research and Innovation (CERI) of the Organization for Economic Cooperation and Development (OECD) started a project named "Learning Sciences and Brain Research: Potential Implications for Education Policies and Practices." This is an international research program being promoted in 30 industrially advanced member nations. From fiscal 2002, the second term was started, and the application of brain researches in the field of education will be studied by forming three research networks (lifelong study, calculation study, and reading and writing study) (Table 2). In the project, our country will play the role of an adjuster in the field of "Brain development and lifelong study," centering in the Brain Science Institute, The Institute of Physical and Chemical Research.

As stated above, the field of "Brain Science and Education" researches internationally attracted considerable attention in recent years, and attempts to deal with this have been started.

In the United States, researches of brain science are being promoted on a large scale centering in the National Institutes of Health (NIH). The researches of brain science are being conducted over several institutes, and, particularly, the National Institute of Biomedical Imaging and Bioengineering (NIBIB) established in December 2000 is intended for the development of imaging technology, and noted in the aspect of measuring technology of brain functions. As for child science, researches are being conducted centering in the National Institute of Child Health and Human Development (NICHD).

Based on a workshop held in December 2001,

Table 2: Research project "Harmony of brain researches and education science" by CERI of OECD

1st term (1999 – 2002)

The following three international forums were held.

- Learning science and brain research on infancy (June 2000, New York, USA)
- Learning science and brain research on adolescence (Feb. 2001, Granada, Spain)
- Learning science and brain research on adulthood (Apr. 2001, Wako, Saitama Pref., Japan)

2nd term (2002 – 2005)

Experimental researches by the following three international research networks were conducted.

- Brain development and lifelong study (Adjusting organization: Brain Science Institute, The Institute of Physical and Chemical Research)
- Brain development and arithmetic thinking (Adjusting organization: Oxford University, UK)
- Brain development and the abilities of reading and writing (Adjusting organization: The Sackler Institutes for Developmental Psychobiology, USA)

Source: Material prepared by Dr. Masao Ito, director of the Brain Science Institute, The Institute of Physical and Chemical Research

the National Science Foundation (NSF) and the Department of Commerce (DOC) compiled a report titled "Converging Technologies for Improving Human Performance." Here, they advocate the necessity of promoting multidisciplinary research and development that converges nanotechnology, biotechnology, information technology (IT) and cognitive science, as well as future strategies. Of the fields presented here, some are involved in "Brain Science and Education" researches, and the U.S. trend after this has attracted the attention.

2.4 Conclusion

The researches of "Brain Science and Education" involve a new field just started internationally. Bridging across and fusing many different fields make this field, and the linking of the respective fields is important. Particularly, it is essential for specialists in nursing and education and researchers of brain science and medicine, who have hardly contacted each other before, to hold discussions.

To advance the research, it is necessary to conduct it in liaison with researches in the fields of "knowing the brain," "protecting the brain" and "creating the brain." If the development of measurement techniques for brain functions is added to such liaison, it may lead to a breakthrough in "Brain Science and Education," and it would be necessary for us to take measures to develop a new technique to enable non-invasive kinetic imaging of high-level brain functions in a natural environment, as well as a new technological development to provide a simple and easy measurement of the internal brain such as the hippocampus that plays an important role in memory.

The problem of education has a significant social influence and requires considerable time to verify hypotheses. Therefore, in applying the results of fundamental researches such as the relationship between the sensitive period and learning to education, it would be necessary to draw a conclusion after conducting a large-scale longitudinal research based on a systematic program, and statistical analyses based on that.

The research of "Brain Science and Education" is a socially important problem, and, at the same time, it requires more ethical consideration and social understanding and cooperation compared to other fields.

Acknowledgements

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References

[1] Brain Science Committee, Life Science Committee, Council for Science and Technology Policy, Cabinet Office; "Long-term concept of research and development regarding the brain", May 1997 (in Japanese)

[2] Subdivision on R&D planning and Evaluation, Council for Science and Technology, Ministry of Education, Culture, Sports, Science and Technology; "Policies for the promotion of research and development of life science", June 2002

[3] "Assessment of 'Brain Science and Education' Researches (interim report)" (study meeting of "Brain Science and Education" researches, Ministry of Education, Culture, Sports, Science and Technology; July 2002) (in Japanese)

[4] Kamiya Akira, Imachi Kou, Ueno Shougou; "Medical Bioengineering", Baifukan, 2000 (in Japanese)

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