Seeing the Dreaming Brain
Development of a Brain-Wave-fMRI Simultaneous Measurement System

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A Third of Our Life is Spent Asleep

Humans sleep six to eight hours every day, and as it is often said, we spend a third of our lives asleep. Is sleep just a “process of resting”?

Recent studies in neuroscience have begun to reveal that this is not the case, and that the brain activity that takes place during sleep closely associated with waking activities. Through this activity, the information we have memorized or learned during the day is spontaneously reprocessed in our brain during sleep, and fixed into long-term memory. However, studies dealing with the reprocessing of the memorized and learned information during sleep have all been conducted on rats; to date, few studies are available on humans, where the cerebral cortex is significantly more developed than in rats.

Development of a System for Simultaneous Measurement of Brain Waves and Functional Magnetic Resonance Images

In 1993, NICT installed an MRI (Magnetic Resonance Imaging) unit with the aim of incorporating advanced information-processing functions of the brain into info-communication technologies, followed by studies on non-invasive measurement of human brain functions using fMRI (functional Magnetic Resonance Imaging). In 1990, the principle of fMRI was discovered by Doctor Seiji Ogawa (presently at the Ogawa Laboratories for Brain Function Research), and it is a method of precise, non-invasive measurement of the active regions of the human brain, detected by changes in blood flow (Fig. 1). However, with fMRI, it is not possible to determine directly whether the subject is excited, relaxed, or asleep. In contrast, brain waves—recordings of neural activities in the human brain taken by attaching electrodes to the head—cannot precisely determine the active region of the brain, but will clearly show the status of the subject, whether he or she is awake, asleep, and even how deeply the subject is asleep (Fig. 2). Therefore, to observe brain activity while asleep using fMRI, brain waves must also be recorded at the same time. Under normal conditions, the measurement of brain waves is simple. However, in fMRI, a localized magnetic field is inclined relative to a static magnetic field generated by a superconducting magnet that is several tens of thousands times stronger than the Earth’s magnetic field; the local field is rapidly inverted to scan the subject’s head with electromagnetic waves of around sixty to approximately one hundred and thirty Megahertz (Fig. 3). The effects of these changes on the magnetic field, and the effect of strong static magnetic fields and electromagnetic waves cause the recording of brain waves (which are on the order of several tens of micro volts) to be contaminated with noise an order of a magnitude larger than brain waves (Fig. 4), rendering it extremely difficult to perform simultaneous measurements of brain waves and fMRI.

Since 2002, the CREST Brain Function Imaging Team of NICT’s Kobe Advanced ICT Research Center has embarked on the development of a simultaneous measurement system for brain waves and fMRI, and after some attempts at modification of the hardware and software, we have succeeded in removing the effects of noise on the recorded brain waves associated with fMRI imaging, thus obtaining stable brain wave recordings. In addition to the simultaneous measurement of brain waves and fMRI, we have established work on a system for recording the eye and body motions of the subject using an infrared camera (Fig. 5). We are now conducting studies on the reprocessing of memorized and learned information during human sleep using this system.

Dreams: The Brain’s Ultimate Virtual Reality

One may acknowledge that the activities of the brain during sleep are associated with memory and learning during waking hours, but be forgiven for wondering why a research institute for communication should be interested in sleep. Human sleep can be largely divided into REM sleep, during which the eyes move rapidly, and NREM sleep, during which the eyes remain still (Fig. 2). It is during REM sleep that humans frequently dream. The duration of REM sleep depends on the person’s age, but generally for adults, about one-fourth to one-fifth of the time asleep is spent in REM activity. So if we assume that we spend a third of our lives asleep, then we can say that we spend one-twelfth to one-fifteenth of our lives in a dream, as it were. Of course, during dreams, there is no sensory input from the eyes. Thus, dreams may be regarded as the ultimate virtual reality, created spontaneously by the brain. Our brain creates a virtual reality that is indistinguishable from reality, one that even a virtual-reality laboratory equipped with the largest screen and the most sophisticated surround-sound system could not reproduce, and this is accomplished even without stimulus from the outside world. The language, image, and audio information (physical energies of light and sound) used in current communication systems can only be input through sensory

Life and Technology

Q: Is the present research for resolving the mechanism of brain functions applicable to the field of medicine?

A: Yes, it is. Non-invasive brain function measurement in the past has involved measurement of brain activities with respect to a pre-designated response (task) by presenting a subject with a visual stimulus, for example. In the case of certain disorders, such as dementia, subjects are unable to perform the given tasks. Thus, the doctor will be unable to determine whether a certain brain region is not activated because the patient cannot perform the task or because the brain region itself is not functioning. However, the brain-wave-fMRI simultaneous measurement system will permit observation of regions of the brain showing spontaneous activity such as brain waves and eye movement. In the future, it should therefore be possible for a subject simply to take a nap inside an MRI unit to enable diagnosis and prognosis of any of a variety of brain disorders.

organs such as the eyes and the ears. However, our brain creates all of these sensations—including the visual and auditory senses—and even emotion, in our dreams. We could say that every night each of us plays the role of Keanu Reeves in The Matrix. We believe that the brain-wave-fMRI simultaneous measurement system developed by our team will close in on the mechanism through which this takes place: researchers are dreamers, aren't they?

NICT's future plans to promote R&D on info-communication technologies include those approached from the standpoint of neuroscience, as in this example.

Fig 1. Example of measurement with fMRI. The human brain is viewed from the right side; the region colored in yellow to red is the active region of the brain associated with eye movement.

Fig 2. Example of human sleep cycle.
Human sleep can largely be divided into REM (Rapid Eye Movement) Sleep and NREM (Non-Rapid Eye Movement) sleep. NREM sleep is further categorized according to the depth of sleep, in stages 1, 2, 3, and 4. Deep NREM sleep tends to appear in the first half of sleep, and REM sleep, shown in green, appears more often in the second half of sleep.

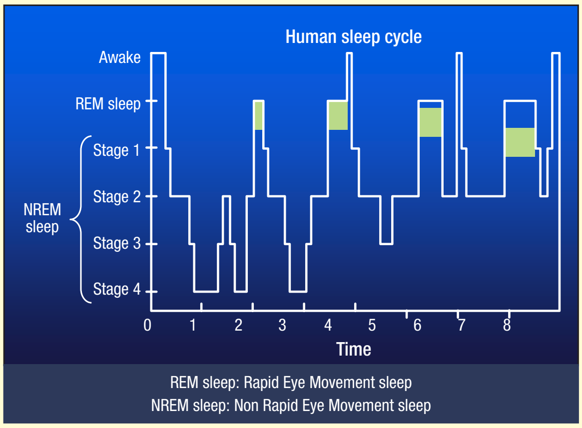


Fig 3. Schematic diagram of MRI instrument and a photograph of MRI instrument at NICT

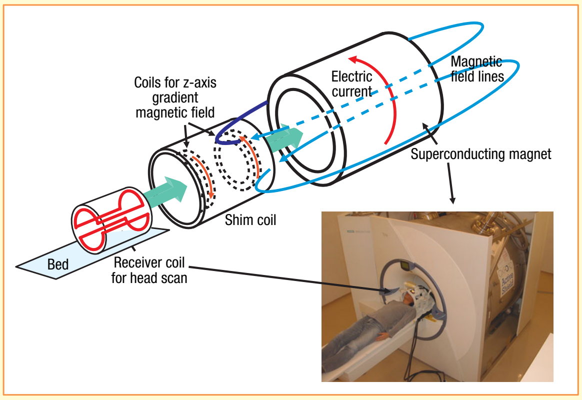


Fig 4. Brain wave and electrocardiogram recorded for a subject inside the MRI unit

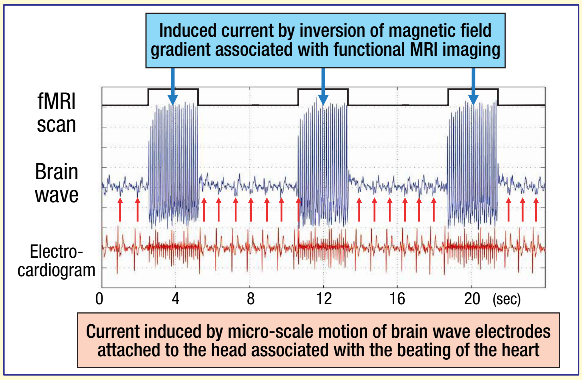
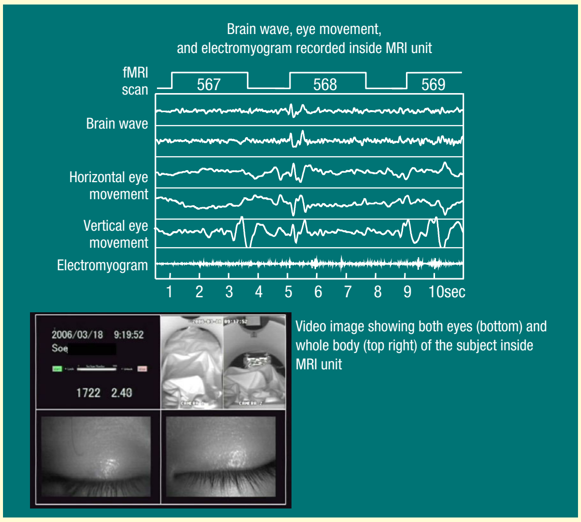


Fig 5. Brain wave, eye movement, and electromyogram of the mentalis muscle (muscle of the chin) (top) and video image of the subject asleep inside the MRI unit (bottom). The deflection in eye movement show movements during REM sleep.



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After completing his graduate course, studied at Brown University in the U.S. and the National Institute for Physiological Sciences (NIPS) of the National Institutes of Natural Sciences (NINS) in Japan; joined the Communications Research Laboratory (presently NICT) in 1993. Currently involved mainly in research and development of non-invasive brain function measurement systems such as fMRI, brain waves, and neuromagnetic imaging. Doctor of medical sciences.

This month's key concept

[fMRI (functional Magnetic Resonance Imaging)]

The "f" in fMRI stands for functional, and the "MRI" stands for magnetic resonance imaging. This is a method for visualizing neural activity within the living body (especially the brain) using magnetic resonance. In contrast to MRI, which obtains a structural image of the brain, fMRI images the neural activities of the brain with high spatial resolution using the changes in the magnetization of the blood associated with changes in blood flow. Thus this method is referred to as functional magnetic resonance imaging. By performing continuous observation while a subject is performing a task, it is possible to examine the active regions of the brain without discomfort to the subject, rendering this method an ideal tool for cognitive neuroscience studies.