JARQ 34(4), 271 – 277 (2000) http://ss.jircas.affrc.go.jp

Development of an Eye Camera for Measuring Eyelid and Eyeball Movements in Domestic Animals

Tetsu NEMOTO[1*], Toshiyuki SAITO[2], Etsuko KASUYA[2], Yoshifumi HONDA[3], Masato NAKAMURA[4], Toshiyo KOBAYASHI[5], Wenxi CHEN[5], Issey TAMADA[5], Ryo KUSUNOSE[6] and Makoto KAI[6]

[1,2] Department of Physiology, National Institute of Animal Industry (Tsukuba, Ibaraki, 305-0901 Japan)
[3] Department of Feeding and Environment, National Institute of Animal Industry (Tsukuba, Ibaraki, 305-0901 Japan)
[4] Laboratory of Animal Management, Hokkaido National Agricultural Experiment (Hitsujigaoka, Toyohira, Sapporo, Hokkaido, 062-8555 Japan)
[5] Department of Bioengineering, Faculty of Engineering, Soka University (Funakicho, Hachioji, Tokyo, 192-8577 Japan)
[6] Equine Research Institute, Japan Racing Association (Tokamicho, Utsunomiya, Tochigi, 320-0856 Japan)

Abstract

The analysis of the resting behavior of domestic animals must include the analysis of eyelid and eyeball movements and bodily motion. We developed an apparatus for measuring the movement of eyelids and eyeballs of domestic animals. The apparatus consists of a charge-coupled device (CCD) camera placed in the eyelid region of a head mask, and an infrared light-emitting diode as light source. Two types of apparatus have been developed: one, using a wire system and the other, using a measurable telemetry system in an unrestricted state. The weight of the device with the wire system was about 50 g and that with the telemetry system was about 880 g. The operating time of the telemetry system was 24 h or more when nickel-hydrogen was used in the power supply. By using the wire system in calf, the movements of the eyelid and eyeball could be divided into four categories: fully open eyelid movement, half-closed eyelid movement, fully closed eyelid movement and eyeball movement. The results showed that the time of half-closed eyelids and fully closed eyelids while the animal was lying down was longest from midnight to 7:00 a.m. and eyelids were half-closed or fully closed even during rumination. In the horse, the telemetry system device could be used continuously without discomfort for 24 h. Comparison of the eyelid movement and cortex brain waves, showed that the power spectrum of the cerebral cortex brain waves in an animal lying down with a half-open eyelid mainly consisted of δ waves while when the animal was standing with a fully open eyelid, α waves also appeared.

Discipline: Animal industry
Additional key words: brain waves, behavior analysis

Introduction

Active movement and resting behavior, or the waking and sleeping behavior, of domestic animals can be distinguished according to changes in bodily motion[4]. However, the analysis of the resting behavior is insufficient when used by itself for the detection of changes in bodily motion. For the purpose of our study, the resting behavior of domestic animals may include any of the following conditions, fully closed eyelid, half-closed eyelid in a state of drowsiness, fully opened eyelid, and eyeball moving with fully opened eyelid in a state of quiescence, which might occur when an animal is lying down

Present address:
[1] Department of Laboratory Sciences, School of Health Science, Faculty of Medicine, Kanazawa University (Kanazawa, Ishikawa, 920-0942 Japan).
* Corresponding author: fax +81-76-234-4369, e-mail nemotot@mhs.mp.kanazawa-u.ac.jp
Received 2 November 1999 accepted 24 December 1999.

or stretched out on its stomach. In addition, resting behavior may also be identified by a half closed-eyelid or a fully closed eyelid while an animal is ruminating. Thus, resting animal's awareness occurs at several different levels. When rest is considered to reflect the action of the parasympathetic nervous system, it was observed that the resting behavior was closely related to stress. It has also been reported that the difference in the frequency spectrum of brain waves indicates whether the eyes are open or closed because of the relationship between the activity of the eyelid and brain waves resulting from cerebral electrical activity[7,8]. Therefore, the determination of a resting animal's awareness level is a necessary part of a more complete analysis of a domestic animal, which includes eyelid and eyeball movements and the determination of certain behaviors associated with specific bodily motions. It is possible to determine the level of a resting animal's awareness from its eyelid and eyeball movements. However, there are almost no reports on methods of measuring eyelid and eyeball movements in domestic animals.

Therefore, we developed an eye camera consisting of an ultra-compact CCD camera and infrared light-emitting diodes (LEDs). We installed the camera into the eyelid region of a head mask that was fitted onto domestic animals for measuring the eyeball and eyelid movements. Simultaneously, we developed a telemetry system for tracking the eyelid and eyeball movements. We used this equipment in experiments in which we tracked and measured the eyelid and eyeball movements of a calf. In addition, the experiment involved a comparison between cerebral cortex brain waves and eyelid movement. It is considered that such studies may eventually contribute to the improvement of feeding management in taking account of the welfare of the animal.

Methods

1) System construction

Fig. 1 shows that the detection part of the device for measuring eyelid and eyeball movements consists of a charge-coupled device (CCD) camera and 4 infrared light-emitting diodes mounted on a semicircular sphere made of a rubber sheet in the eyeball region on one side of the mask that is attached to the animal's head. The wire system consists of a video recorder and a TV monitor that are connected by a wire to the camera. The telemetry system device (Fig. 2) consists of an ultra-compact CCD camera and a power supply and transmitter with a transmission antenna/modulator circuit for switching video signals to VHF TV. The power supply consists of eight 1.2-volt AAA nickel-hydrogen batteries connected in series, which enable the device to conduct continuous measurement for at least 24 h. The transmitted images are received on a television screen and recorded on a video recorder.

2) Equipment specifications

The device was designed for continuous measurement of the eyelid and eyeball movements over a long period of time by using an ultra-compact and lightweight CCD camera that is attached to a head mask in domestic animals. The head mask and camera weigh 50

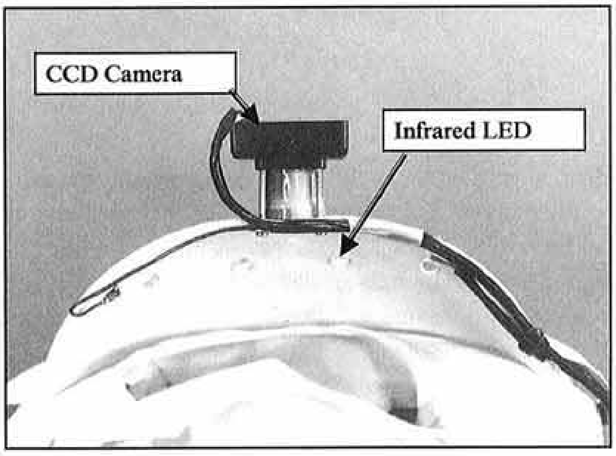

Fig. 1. Detection part of eyelid and eyeball movements in the wire system device
The apparatus consists of a charge-coupled device (CCD) camera and 4 infrared light-emitting diodes as a light source.

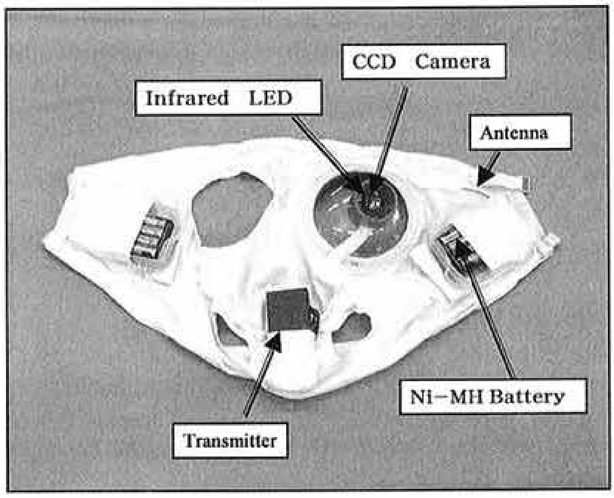

Fig. 2. Telemetry system apparatus
Charge-coupled device (CCD) camera, 4 infrared light-emitting diodes, a power supply, and transmitter with a transmission antenna/modulator circuit for switching video signals to VHF TV. The power supply consists of eight 1.2-volt AAA nickel-hydrogen batteries connected in series.

Table 1. Specification of each part of the system

CCD Camera part	
Outer dimension	30×30×13 mm
Lens	16, ϕ15.7 mm
Focal distance	2.5 mm
Angle	72×57
Resolution	380 TV
Lowest subject illuminance	0.8 Lx
Power voltage	9–9.9 V
Electric power consumption	100 mA
Weight	30 g
Power supply part	
Battery	AAA Ni-MH
Voltage	1.2 V
Capacity	1,600 mAh
Weight	25 g
Transmission part	
Outer dimension	74×46×30 mm
RF output frequency	473 MHz (UHF 13CH)
Operation distance	Within 20 m
Power voltage	9–12 V
Electric power consumption	10 mA
Weight	125 g

g. The light source for illuminating the eyelids consists of four infrared light-emitting diodes (peak sensitive wavelength: 940 nm). The telemetry system device weighs 880 g and includes the head mask, transmitter, and power supply. Table 1 shows the specifications of each part in the telemetry system device.

3) Measurement of eyelid movement and cortex brain waves of a calf

In a room under temperature controlled at 20°C (illumination of 1,000 lux from 6:00 a.m. to 6:00 p.m. and 50 lux from 6:00 p.m. to 6:00 a.m.), Holstein calves were tethered with neck chains as they ate hay freely. We attached a wired eyelid and eyeball movement device to a 100 kg Holstein calf and recorded the movements for 24 h. Using the images, we measured the eyeball and eyelid movements of calves during periods when the eyes were open, half-closed, and fully closed. For behavioral analysis, we observed and recorded the animal behavior and bodily motion while it was standing and lying down. To detect the jaw movements, a breathing pickup (NEC Medical Systems Co., Ltd.) was attached around its mouth, and to detect movements while the animal was standing and lying down, a tape switch sensor (Tokyo Switch Co., Ltd.) was attached to its breast. The output signals from these two sensors were recorded on a signal data recorder (SIR-1000 Sony Co., Ltd.). The heart electric potential was detected from a stainless wire electrode on the calf's mid-dorsal line.

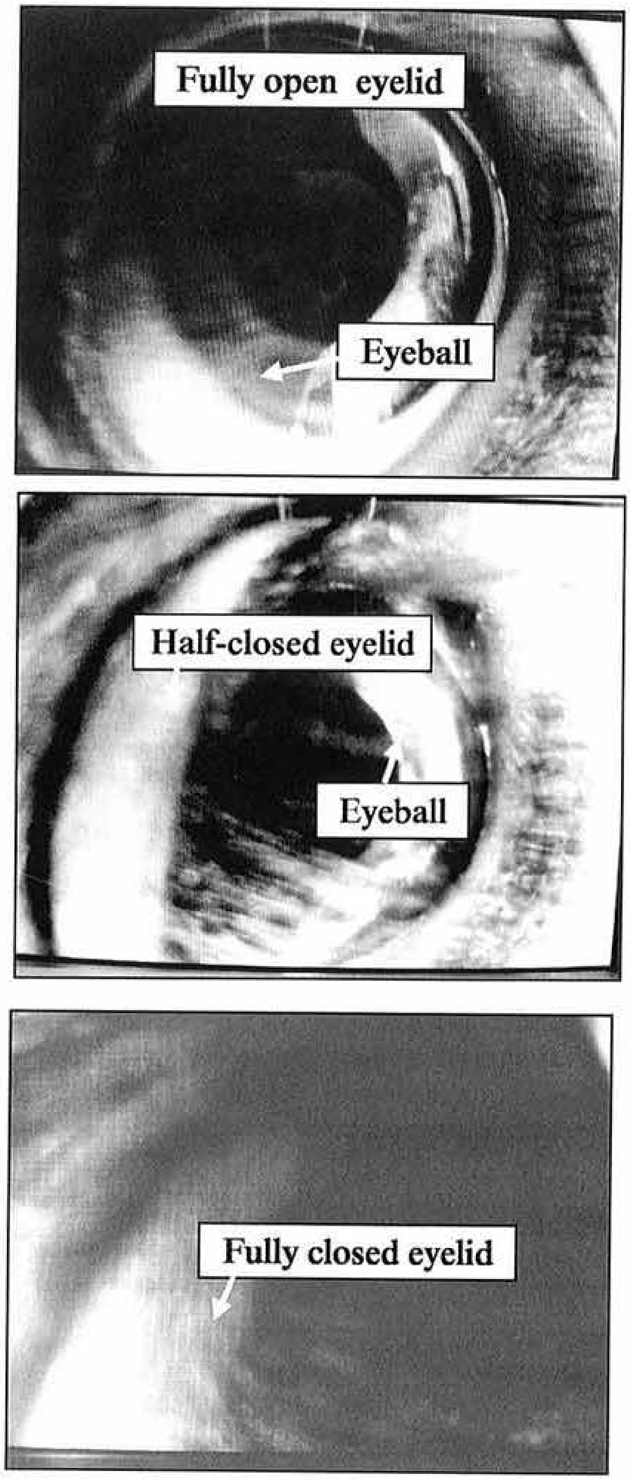

Fig. 3. Images of the eyelids and eyeballs of the calf measured with the apparatus when the eyes were open, half-closed, and fully closed

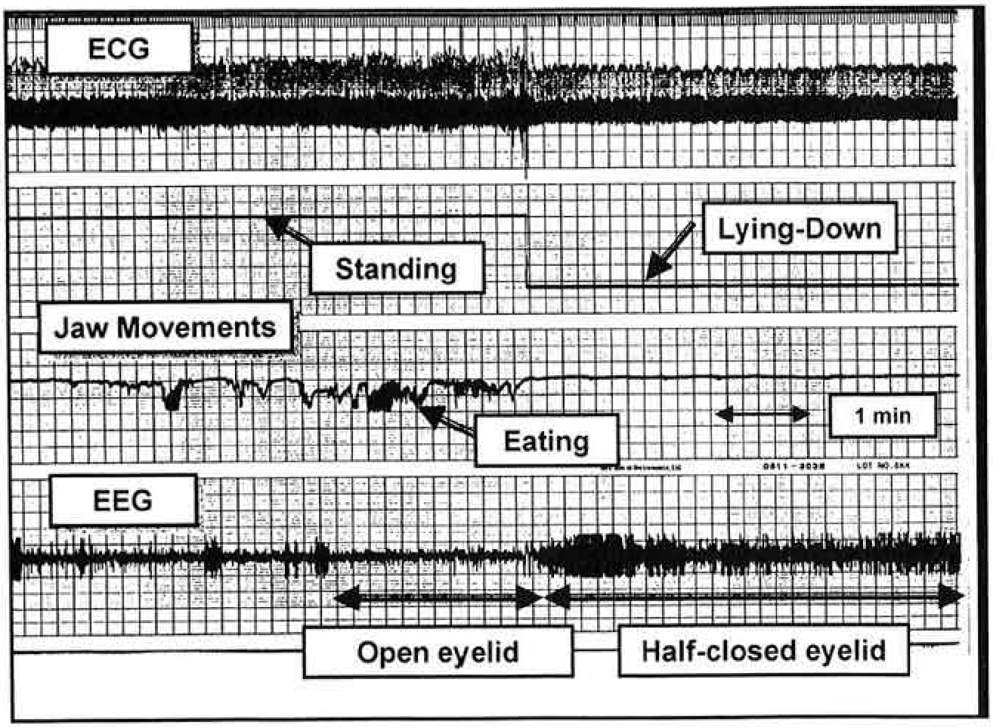

Fig. 4. Electrocardiogram, analysis of body motions, jaw movements, and electroencephalogram

From the recorded waveforms of jaw movement, we were able to discriminate among periods when the calf was still, eating, and ruminating. The on-off switch of the tape signals enabled to determine whether the calf was standing or lying down.

A silver ball was used as the cortical electrode for brain wave measurement and an acrylic screw was used for detecting the electrical activity in the cerebral cortex. Each of four electrodes was fixed into a position where both sides were separated by 20 cm at 10 cm from the bregma of the calf's skull. The cerebral cortex brain waves of the calf were measured and recorded with an EEG (ER2104. NEC Medical Systems Co., Ltd.).

Results

Fig. 3 shows images of the eyelid and eyeball of the calf observed by the wire system device when the eyelids were fully open, half-closed, and fully closed. If the eyelids were not fully closed but closed more than half, we categorized them as fully closed. It was also assumed that there was an eyeball movement when the eyeballs were moving while the eyelids were open. In this experiment, the evaluation of the calf's eyelid movements was divided into three stages. In addition, the calf's eyeball movement while its eyelids were open was added.

Fig. 4 shows examples of the calf's electrocardiogram, bodily motions consisting of standing and lying down, jaw movements, and electroencephalogram. The jaw movements enabled to detect rumination or eating. The periodic fluctuations of the jaw movements indicated rumination. The irregular fluctuations of the jaw movements indicated eating.

Fig. 5 shows the eyelid and eyeball movements, rumination and eating, and standing and lying down motions for a 24-hour period. The circadian variation of the biological rhythm was characterized as behavioral pattern, including eyelid and eye movements, eating and rumination behavior, and standing and lying down motions. In the daytime, the calf stood for longer periods of time and its eye movements were more frequent.

In Fig. 6, the power spectrum shows the composition of the cerebral cortex brain waves in relation to the calf's eyelid and eyeball movements in the following positions: a) fully open eyelid while standing, b) half-closed eyelid while lying down, and c) eyeball moving while eating.

Discussion

The current eye cameras have been used to measure the line of sight in humans and other primates. The main principle of the measurement by the eye camera is based on the cornea (iris) and sclera reflection method[5], which measures the eye movement using the difference

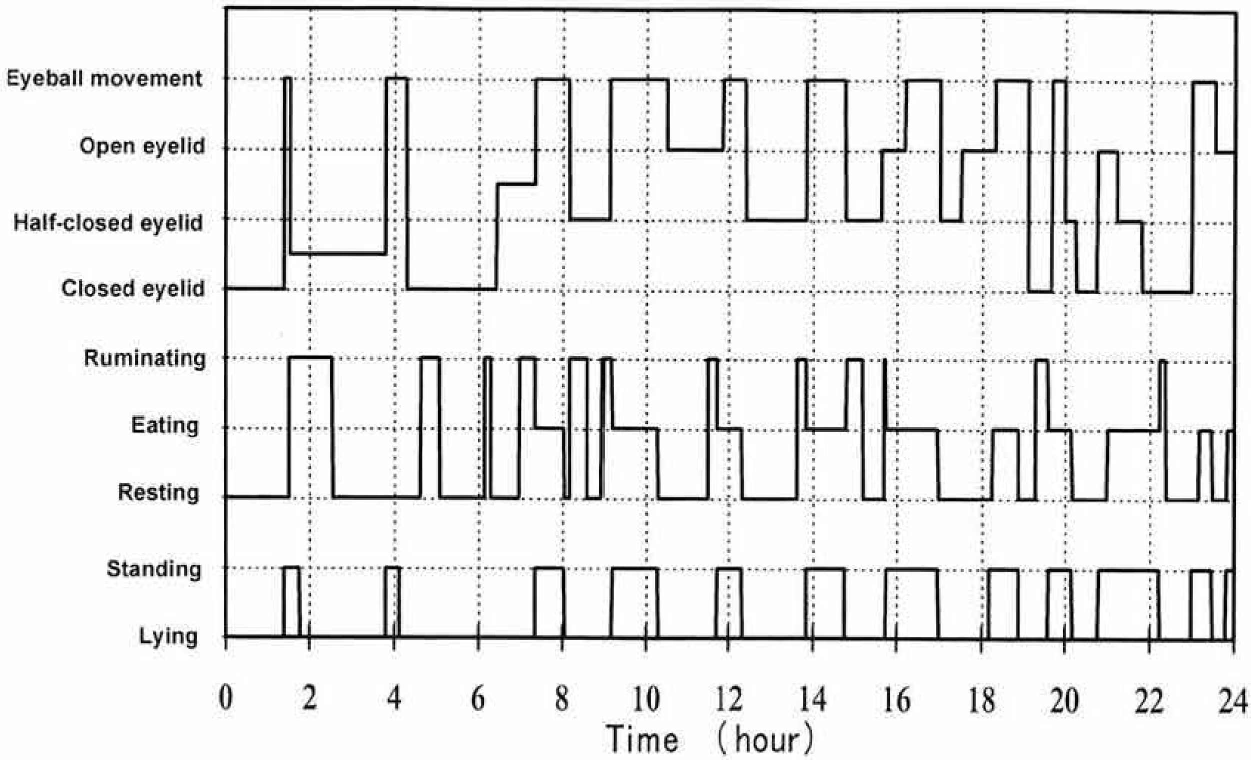

Fig. 5. Eyelid and eyeball movements, rumination and eating behavior, standing and lying down behavior of calf during a 24 h period

Eyelid and eyeball movements were divided into four categories:
fully open eyelid movement, half-closed eyelid movement, fully closed eyelid movement and eyeball movement.

in the reflectivity of the light of the sclera (white of the eye) and the corneal reflex method. When an image analysis method[1-3] is applied, it has been reported that the motion of the eyeball and changes in the pupil may be measured by image processing. For the measurement of a blink, permanent magnet is fixed in the upper eyelid, and the method for detecting the movement of the upper eyelid in the Hall element of glasses was reported[6]. However, this equipment has limitations because of the problems associated with attachment. When working with animals, simplicity of attachment is essential. Other important factors are safety and durability. Because of all of these considerations, it is most appropriate to use an image processing method employing CCD cameras as eye cameras for domestic animals.

In the current studies, we developed a device that held infrared LEDs and an ultra-compact CCD camera in a rubber sheet with a hemispheric shape placed in the eye region of a head mask. By using a hemispheric rubber sheet or transparent acrylic sheet in the eye region of the head mask and attaching an ultra-compact CCD camera to the sheet, we developed a method that allowed long periods of measurement. This device may include either a wire system or a telemetry system for sending the detected images. The difference in the systems enables researchers to use one system in the laboratory and another in the field.

The power supply is a particular problem with the telemetry system. The terminal voltage for the transmitter and CCD camera is 9–10 V, and the power consumption is about 110 mA. With the power supply of eight AAA nickel-hydrogen batteries (1.2 V) connected in series, the power is 9.6 V (1,600 mAh). The device has double power supply units (9.6 V, 1,600 mAh × 2) connected in parallel. The two units provide a continuous measurement time of 29 h, and the batteries only have to be replaced once a day for 24 h of measurement.

We have also developed two application methods, one for a calf and the other for a horse. Because the mask and camera weigh only 50 g, we consider that the wired system could be used on a calf over long periods of time. However, with the telemetry system, the total weight of the device is about 880 g and includes 16 batteries, each one weighing 26 g, and the transmitter. Even with this weight, the horse showed no sign of discomfort when the telemetry system was attached for 24 h. But, this telemetry system of 880 g is a burden for measurements in calves. Therefore, we did not use the telemetry system in the calf experiment. Instead, we used an equipment that measures for 12 h and weighs 405 g,

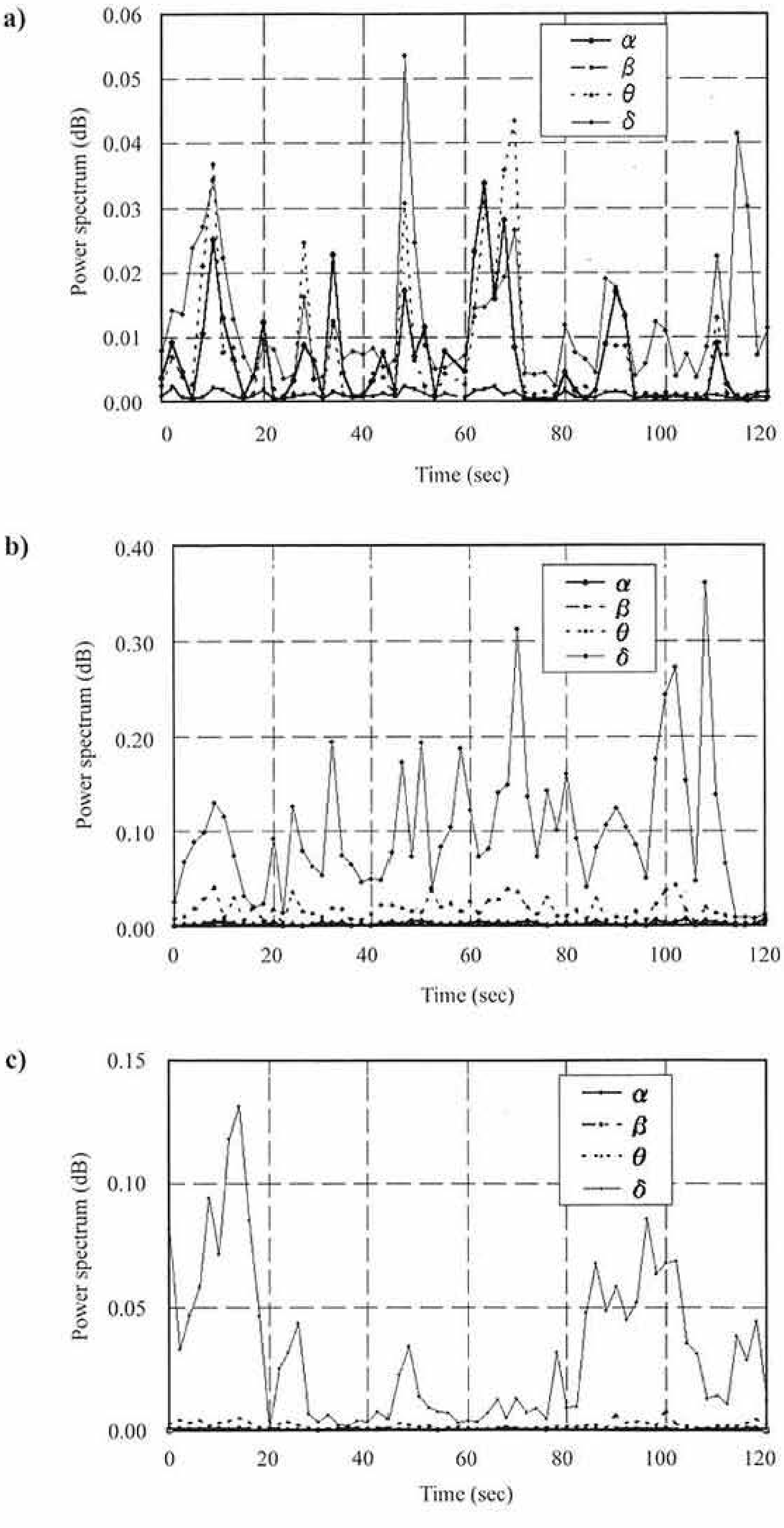

Fig. 6. Power spectrum composition of cerebral cortex brain waves for eyelid and eyeball movements of the calf

a): Fully open eyelid in standing position.

b): Half-closed eyelid in lying down position.

c): Eyeball movement while the animal is eating.

which reduces the number of batteries to eight and is considered to be adequate when applied to the calf.

The power source for the telemetry system had two units connected in parallel that consisted of eight AAA batteries connected in series. Since the discharge of electricity occurred due to the difference in voltage between the units, leading to a degradation of the discharge, we inserted diodes between the units. We also built a fuse into the circuit to prevent overheating when the intensity of the current was too high.

It is necessary to use as few batteries for the power supply as possible for preventing battery problems. By increasing the capacity of each battery, the number of batteries can be decreased. When eight "A" nickel-hydrogen batteries (9.6 V, 5,000 mAh, and 160 g × 8) were used in the telemetry system, the continuous measuring time was about 45 h. However, the cloth head mask is not strong enough for attaching eight "A" nickel-hydrogen batteries. In addition, such a weight (160 g × 8) is too heavy for domestic animals. Consequently, it is obvious that AAA batteries are preferable as a power source because of their capacity and lighter weight.

Using the wire system device for eyelid and eyeball movement experiments in calves, we divided the eyelid movement into three categories: fully open eyelid, half-closed eyelid, and fully closed eyelid. In addition, eyeball movement was added to the analysis. When the position of the eyelids was intermediate between half-open and fully closed, we classified the position as fully closed. However, the time during which the eyelid of the calf was completely closed was about 4 min in total in 24 h. Results of the measurement experiment showed that the time during which the calf's eyelids were half-closed or fully closed while lying down was longest from midnight to 7:00 a.m. Furthermore, the eyelids were half-closed or fully closed even during rumination. During the daytime, the calf's eyelids were fully open and the eyeball movement was very active for long periods of time. Moreover, the behavior relating to the calf's position fluctuated most from the position of standing and lying down between midnight and 8:00 a.m. Most of this time was spent in the lying down position. These findings nearly matched earlier results under identical conditions[4]. Based on our observations, it appears that the weight of the equipment did not affect appreciably the calf.

The relationship between eyelid movement and brain waves of the cerebral cortex showed that brain waves clearly differed depending on whether the eyelids were open or half-closed. It should be emphasized that the amplitude of brain waves with half-closed eyelids was smaller than that of brain waves with open eyelids. This fluctuation of amplitude was in agreement with the results hitherto reported. The fluctuations of the brain wave amplitude were closely related to the open eyelid and half-closed eyelid positions. The power spectrum component of the brain waves with open eyelids and in the standing position revealed α waves with a similar value to that of the δ and θ waves. In addition, values of the β waves were low. The power spectrum with half-closed eyelids in the lying down position consisted of δ and θ waves. The power spectrum in the eyeball movement while the animal was eating showed the largest amount of δ waves. Then, we considered that the calf's resting position should be analyzed in relation to the eyelid and eyeball movements and body motion fluctuations.

The above-mentioned results show that this device can be employed over long periods for continuous measurement of eyeball and eyelid movements. Moreover, we consider that the measurement of the eyelid and eyeball movements can contribute to the examination of domestic animals in resting positions. Especially, the behavior of domestic animals can be conveniently and efficiently analyzed by using this equipment even in the tropical zone.

We consider that the wire system device and the telemetry system device can contribute significantly to biological measurements for the analysis of motion.

References

1) Ishikawa, N. et al. (1998): Potential diagnostic system for Alzheimer's disease-development of a long time pupil area measurement system using pupil iris area compensating method. *Jpn. J. Med. Bio. Eng.*, **12**(9), 189–199 [In Japanese with English summary].
2) Matsuda, K. & Nagami, T. (1997): All-purpose measurement system of the eye positions. Proc. 12th Symp. Bio. Physiol. Eng., 173–176 [In Japanese with English summary].
3) Matsusima, J., Kumagai, M. & Harada, C. (1988): A new recording of eye movements with charge couple device (CCD) image-sensor. *Equilibrium Res.*, **47**(2), 169–173 [In Japanese with English summary].
4) Nemoto, T., Saito, M. & Nakamura, M. (1998): Relation between the physical and biorhythm of calves. Proc. 13th Symp. Boil. Physiol. Eng., 549–552 [In Japanese with English summary].
5) Reulen, J. P. H. & Bakker, L. (1982): The measurement of eye movement using double magnetic induction. *Inst. Electr. Electron. Eng. Trans. Bio Med. Eng.*, **29**, 740–744.
6) Togawa, T. (1986): Biomedical measurement and sensor, Corona Publishing Co., Ltd., Tokyo, Japan, 299 [In Japanese].
7) Toida, N. et al. (1982): Textbook of Modern Physiology, 15, Igakushoin Ltd., Tokyo, Japan, 491–584 [In Japanese].
8) Torii, H. & Kawamura, H. (1987): Physiology of biological rhythm. Handbook of Physiological Sciences, 13, Igakushoin Ltd., Tokyo, Japan, 172–190 [In Japanese].