

Original article

The effect of hot-pack warming on the deep body temperature

— for the development of a nursing care instrument to induce sleep —

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Abstract

A hot-pack made of a dense polymer and covered with a cloth was manufactured as a warming instrument. This hot-pack can be readily warmed in a microwave oven. The present study was performed to examine the effects of warming the lower limbs using this hot-pack on the temperature and blood flow at various sites including the toe, mid-thigh, chest, and forehead. The results were as follows:

1. Hot-pack warming raised the deep body temperature.
2. Lower limb warming by the hot-pack increased the blood flow, by which the increase in temperature spread to the central part of the body.
3. The deep body temperature fell following the removal of the hot-pack, and, in addition, by sweating.

It is suggested that hot-pack warming might be useful for inducing sleep in elderly people.

Key words: hot-pack, sleep induction, warming, deep body temperature, skin surface temperature, subcutaneous temperature, blood flow

Introduction

Sleeping can be induced by the temporal rising, followed by long-term falling, of the deep body temperature (DBT) (Furukawa and Honda, 1994; Oda et al., 2001). Hot-water bathing induces sleep by raising the body temperature (Agishi et al., 2004). Therefore, taking a bath at night is desirable for the induction of sleep. However, usually nursing facilities for the elderly usually provide a bathing service in the daytime due to cost performance and staff shortages (Tsutsumi et al., 2002).

Such daytime bathing tends to induce sleep in the elderly during the daytime. This may cause an inverted sleeping rhythm, which is commonly noted in the elderly people. An instrument readily available even during the night, which can

induce bathing-like effects, would greatly contribute to the improvement of sleeping rhythms in elderly people.

We have developed a hot-pack made of dense polymer, which can be readily heated in a microwave oven. The present study was performed to examine the effects of this hot-pack on the body temperature and blood flow. The warmed hot-pack was placed on the lower limbs of the subject, and changes in the DBT were measured. In addition, changes in the skin surface (SS) and subcutaneous region (SCR) temperature, and skin blood flow (SBF) at various sites including the toe, mid-thigh, chest, and forehead were measured. Whether hot-pack warming of the lower limbs can induce sleep in elderly people was discussed.

Materials and Methods

1. Preparation of the hot-pack for warming the lower limbs

The simple, easily applicable hot-pack was prepared in the shape of a boot. The core component of the hot-pack is made of a dense polymer, and the hot-pack can be readily heated in a microwave oven. In the present study, the hot-pack making up the “foot-warming boot” was divided into several small parts so as to be easily applied to the subject’s limb. Each part was covered with cloth to promote comfort when it was put on the skin of the subject. The hot-pack was prepared as follows: a suitable amount of dense polymer (Kao) was soaked in a 125 ml of water, and the resulting soft gel material was arranged into a block of 16 x 10.5 cm. Twelve such blocks were prepared. Blocks were covered with a cloth overlaying a polyester sheet. The cloth itself was made from a weave of cotton (70%) and jute (30%). Three types of hot-pack were used for one side of the body. Accordingly, three pairs of hot-packs were prepared for both sides. Each type of hot-pack contained two blocks. Of the three types of hot-pack, one was used for the foot comprising the dorsal and plantar parts, and the other two for the ante-tibial part (Fig. 1).

2. Subjects

All four subjects were healthy males, ranging from 21 to 30 years old. All subjects were male to avoid the menstrual DBT fluctuations seen in the females. All experiments were started at 5 o'clock in the

evening to minimize the influence of the circadian rhythm. The subjects were instructed to avoid intense exercise. They were asked to sleep for more than 8 h on the day before the experiment, and fast for at least 2 h before tests. They wore a T-shirt and shorts, and were bare-footed.

3. Experimental room

The experiments were conducted in the student practice room of Ishikawa Nursing University, with a temperature of 24–26°C and humidity of 50–60 %.

4. Study periods

Experiments were performed from August 30, 2006 to September 26, 2006.

5. Methods

(1) Procedures

The subject lay quietly in the supine position for 20 min. Temperature probes were positioned near the tympanic membrane (peri-tympanic membrane region: PTM). Other temperature probes were placed on the subcutaneous region (SCR) and skin surface (SS) of each body site as described below. Probes for skin blood flow (SBF) were also put on the skin surface as outlined below. Warmed hot-packs were placed on the subject’s lower limbs, and warming was applied for 50 min. The warming was discontinued by removing the hot-packs from the limbs. The subject retained the supine position for a further 20 min after the end of warming. Throughout the experiment, the subject’s whole

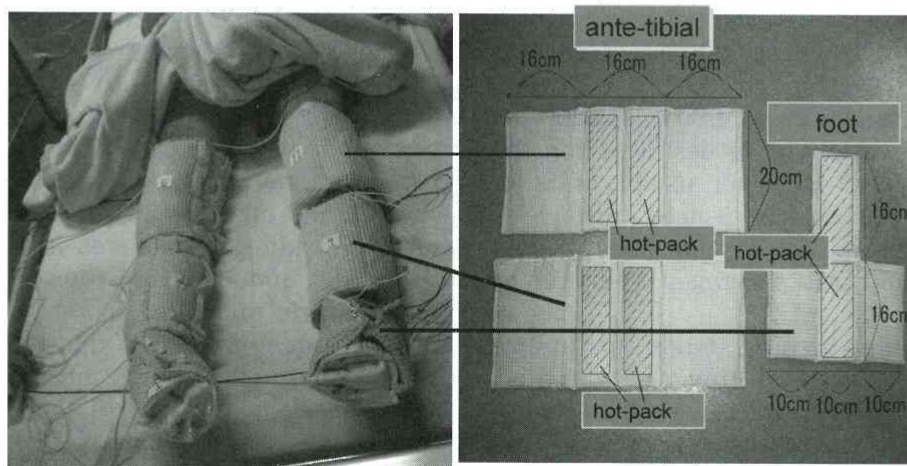


Fig. 1 Hot-packs and their positions

body was covered with a blanket. When the temperature rose to 43°C at the interface between the skin and hot-pack, a cloth was inserted between them. When the hot-pack temperature fell below 38.5°C, hot-packs were replaced with newly heated ones. As the control, the same procedures were applied to the same subjects, but hot-packs were not heated.

(2) Measurement of PTM temperature

The temperature monitor (TM-201D, By-temp) was used as a probe for the PTM. The temperature was recorded every 1 min for 90 min.

(3) Measurement of SCR temperature (2–10 mm below the skin surface)

The probe, Core-Temp (CN100B, Terumo), was used to measure the subcutaneous temperature at the left mid-thigh (medial part), left chest (2-finger breadth lateral to the left nipple), and forehead. The temperature was recorded every 1 min for 90 min.

(4) Measurement of SS temperature

A handy-type thermometer (LT-8 SERIES, Gram Corporation) was positioned at the big toe of the left foot, mid-thigh of the left leg, chest, and forehead. The temperature was recorded every 1 min for 90 min.

(5) Measurement of SBF

A laser blood flow meter (21D, Advance) was placed at the big toe of the left foot, mid-thigh of the left leg, chest, and forehead. The blood flow was measured every 1 min for 90 min.

5. Analysis

The average SS, SCR, and PTM temperatures measured for 10 min immediately before warming were used as the baselines for each subject. The differences in the temperatures from the baselines were calculated for 70 min (50 min during warming and an additional 20 min following the end of warming) in each subject. Then, the average differences were calculated for each subject. Concerning SBF, the average values were obtained for each subject during the 10 min immediately before warming, and used as the baseline. The average differences from the baselines were calculated every 10 min for 70 min, as above.

6. Ethical consideration

It was confirmed that there was no risk of low-temperature burn in this experiment. The purposes and methods of this study were fully explained to the subjects orally as well as in written form, and signed consent was obtained from all subjects who participated in this experiment.

Results

1. Changes in PTM temperature

All 4 subjects showed an increase in the PTM temperature. The average differences were always higher than those of controls throughout the experiment (Fig. 2). The average temperature elevation continued after the end of the warming, with a 0.25°C elevation 10 min following the end of warming. On the other hand, the range of temperature decrease was small. All subjects continued to show an elevation of 0.1 to 0.42°C from the baselines at 20 min following the end of warming.

2. Changes in SCR temperature

All subjects showed an increase in the SCR temperature of the mid-thigh by warming of the lower limbs. The average SCR temperatures of the 4 subjects were always higher than those of controls, with a maximum value of 0.32°C at 10 min following the start of warming (Fig. 3). The temperature gradually decreased and returned to the control level 20 min after the end of warming.

Average SCR temperatures of the chest were always higher than the controls, with a maximum difference of 0.28°C (Fig. 4).

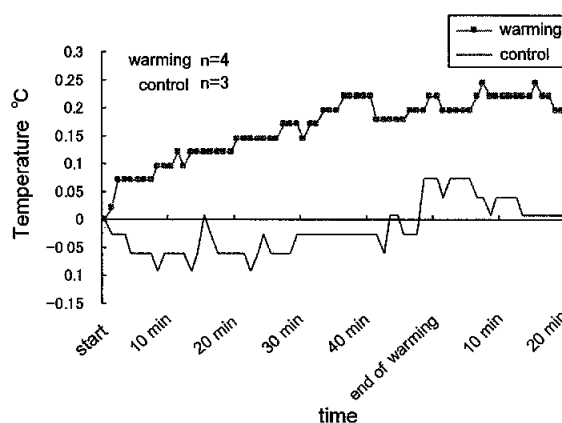


Fig. 2 Changes in PTM temperature

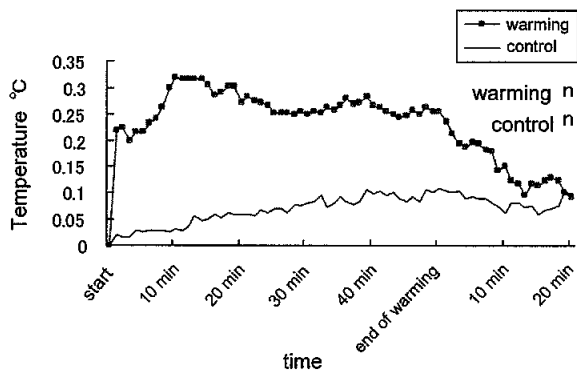


Fig. 3 Changes in SCR temperature of the mid-thigh

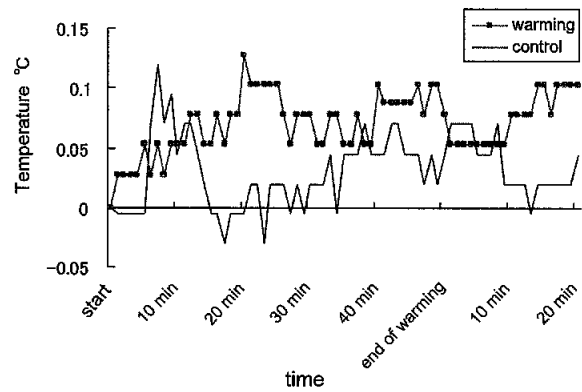


Fig. 5 Changes in SCR temperature of the forehead

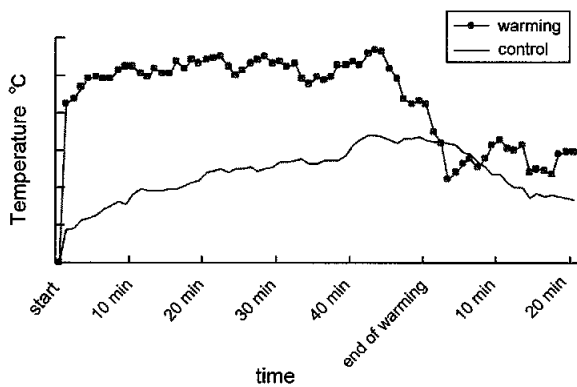


Fig. 4 Changes in SCR temperature of the chest

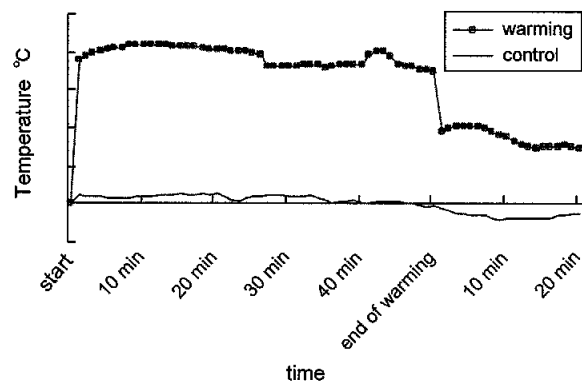


Fig. 6 Changes in SS temperature of the toe

The temperature decreased in the same manner as described above following the end of warming.

Regarding the forehead, the subjects showed various temperature fluctuations within $\pm 0.1^{\circ}\text{C}$. However, at the end of warming, all subjects showed a temperature 0.1°C higher than controls. Such a condition continued for a while thereafter (Fig. 5).

Thus, the maximum rise in temperature was 0.32°C at the mid-thigh, 0.28°C at the chest, and 0.1°C at the forehead. This showed that the nearer the site was to the warming site, the higher the SCR temperature.

3. Changes in SS temperature

All subjects showed an increased temperature of the big toe by warming the lower limbs. The maximum elevation was 10°C , the minimum was 1.8°C , and the maximum average change in the 4 subjects was 4.2°C . The temperature fell by 1.6°C within 1 min after the discontinuation of warming (Fig. 6).

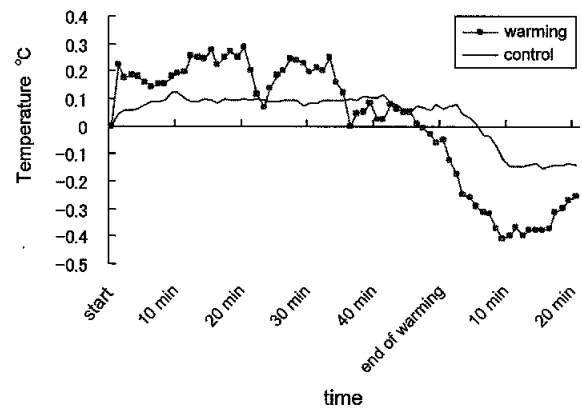


Fig. 7 Changes in SS temperature of the mid-thigh

At the mid-thigh, the average temperature of the 4 subjects reached a maximum 20 min after the commencing the warming, and remained higher than the control until 40 min after beginning of warming. However, the temperature gradually dropped to lower than the control at the end of warming (Fig. 7). This lower temperature condition continued for a while thereafter.

Regarding the chest, the subjects showed

an increase in temperature. However, at the end of warming, only one subject maintained the elevated temperature, while the other three showed a fall in temperature. The average temperature reduction was larger than in control (Fig. 8).

Concerning the forehead, the average temperature rose until 20 min after the beginning of warming, and fell below the baseline thereafter. The control cases showed no distinct changes of temperature (Fig. 9).

4. Changes in SBF

By warming, the average SBF of the big toe was higher than the control (80% higher at maximum) throughout the experimental period (Fig. 10). Similarly, the warming of the lower limbs increased the SBF at the mid-thigh by ca. 60% over the baseline (Fig. 11).

For the chest, the average SBF was little changed between the start and end of warming, with only a 6% increase at 20 min fol-

lowing the end of warming (Fig. 12). Three subjects showed a decrease in the blood flow of the forehead. The average value of the 4 subjects was 25% lower than the baseline at the end of warming (Fig. 13). This average value was also lower than that of control subjects.

The nearer to the warming point, the higher the blood flow rate was. That is, the blood flow rate became higher at the big toe, mid-thigh, chest, and forehead in this order (Fig. 14) by warming of the lower limbs.

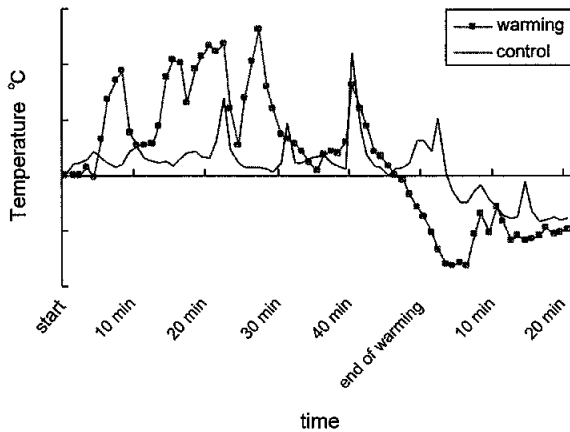


Fig. 8 Changes in SS temperature of the chest

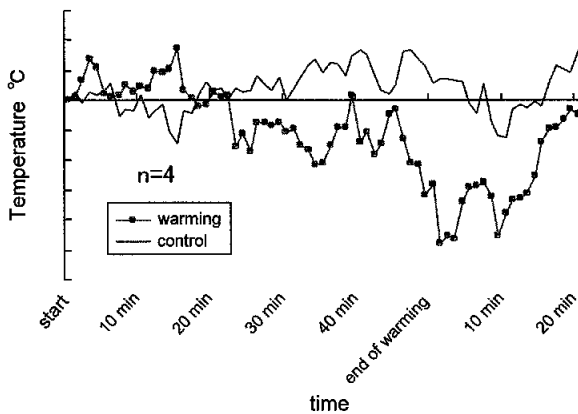


Fig. 9 Changes in SS temperature of the forehead

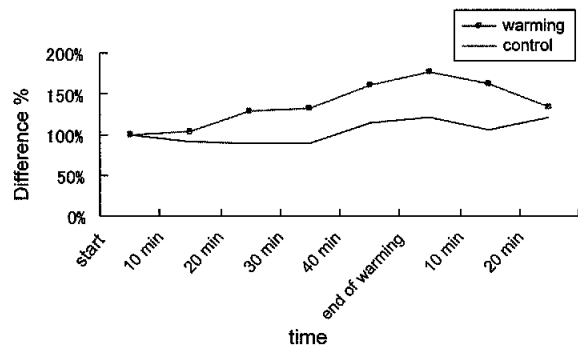


Fig. 10 Changes in SBF of the toe

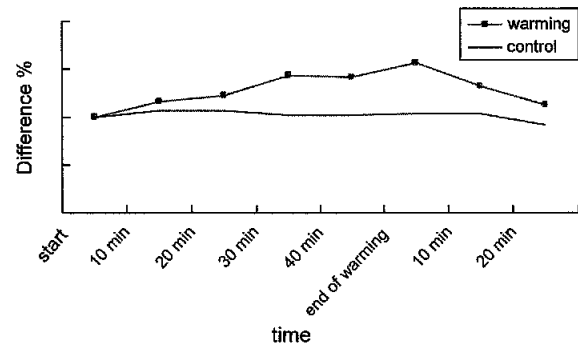


Fig. 11 Changes in SBF of the mid-thigh

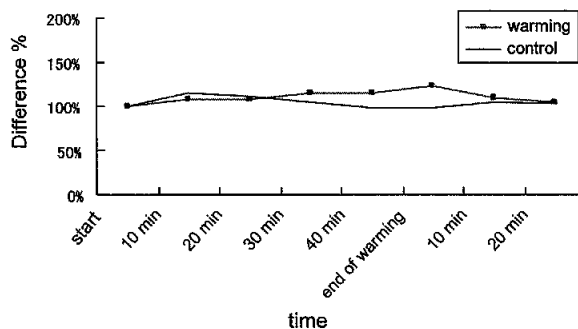


Fig. 12 Changes in SBF of the chest

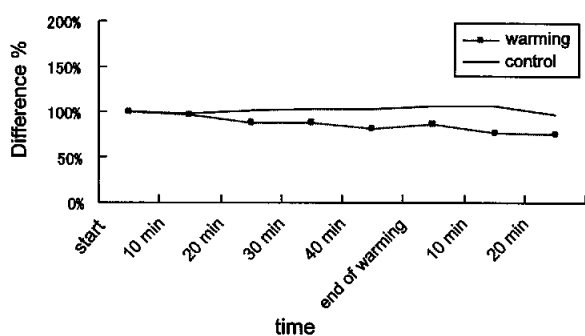


Fig. 13 Changes in SBF of the forehead

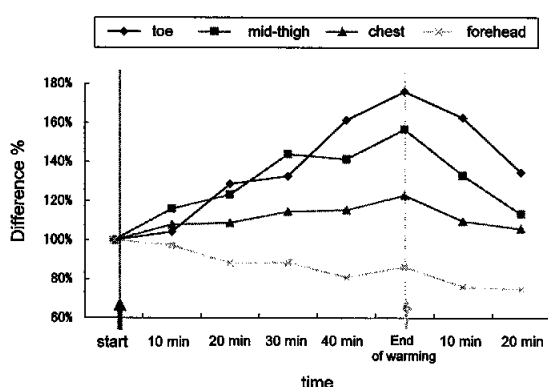


Fig. 14 Average blood flow rate in each place

5. Others

All four subjects claimed that they felt too hot, with sweating over the whole body, during warming of the lower limbs. Sweating continued even after hot-pack removal. All subjects stated that the hot-pack had a soft touch to the skin.

Discussion

1. Changes in DBT

The present study was performed to explore to what extent hot-pack warming of the lower limbs has an effect on DBT elevation. The DBT was measured in the PTM in the present study. The thermometer was of the non-contact type. Therefore, the temperature was somewhat lower than that measured in the rectum. However, the temperatures of both the PTM and rectum showed a good correlation (Nishiyama and Hanaoka, 1996). It is generally recognized that the SCR temperature of the forehead reflects the DBT (Iwasaki and Nomura, 2005; Harioka et al., 1993). Accordingly the subcutaneous temperature at the forehead was also measured in the present

study.

The temperature in the PTM was raised by 0.25°C. Similarly the SCR temperature at the forehead was raised by 0.13°C. These values are smaller than those obtained at the mid-thigh (0.32°C), and chest (0.28°C). These results are consistent with previous reports that the DBT cannot be markedly changed in response to external effects (Goudsouzian et al., 1973).

Although the range of elevation was small, hot-pack warming exhibited a distinct effect on the elevation of the DBT. This is supported by the comments of subjects that they felt hot during hot-pack warming of the lower limbs.

It is known that there is a temporal elevation, subsequently followed by a fall in body temperature, before sleep induction (Furukawa and Honda, 1994; Oda et al., 2001). In the present study, the temperatures in the PTM and forehead did not fall until 20 min following the end of warming. Hashiguchi (2002) reported that the rectal temperature did not fall until 27 min following the end of bathing or hot water showering. The DBT falls by natural heat loss accelerated by the increase in blood flow caused by a preceding elevation of the body temperature (Michikami et al., 1999). It is said that the raising of the PTR by 0.20°C induces a fall in the DBT due to the regulatory mechanism of the body including sweating. In some subjects, the temperature of the PTM was raised by 0.25°C at 10 min following the end of warming. The subjects underwent sweating. The skin temperature fell at all sites examined after the end of warming. It is suggested that the central temperature regulation mechanism might also contribute to the lowering of the DBT after hot-pack removal from the lower limbs.

2. Changes in temperature at SCR and SS, and changes of SBF

The average SCR temperature of the 4 subjects rose at the mid-thigh, chest and forehead by warming the lower limbs. The average SBF of the 4 subjects increased at the toe, mid-thigh and forehead by warming the lower limbs. An increase in blood flow induces a rise in heat conduction by blood vessels (Smith and Kampine, 1989).

By warming the lower limbs, the SBF

was increased, and the temperatures at the SCR and SS were raised. The sole of the foot is rich in capillary networks that become expanded by temperature elevation, resulting in an increase of blood flow. Therefore, it is considered that lower limb warming is a more effective method for raising the body temperature than warming at any other sites.

The temperature of the SS at the forehead fell markedly even during warming the lower limbs. It is likely that sweating during the experiment might lead to a fall in SS temperature at the forehead due to heat loss through evaporation. The fall in temperature occurring in the later stages of warming at the mid-thigh and chest may also be caused by sweating. However, the drop in temperature occurred much later, and showed a much smaller range in the mid-thigh and chest than in the forehead. This is probably because the mid-thigh and chest were covered with a blanket, while the forehead was exposed.

The increase in skin blood flow was maximal at the toe, followed by the mid-thigh and then chest. Since the hot-pack was in direct contact with the toe, the raised temperature might have had a direct effect on blood flow within the toe. It is conceivable that the increased blood flow at the mid-thigh and chest was caused by the indirect effects of the warmed blood from the lower limbs. This is consistent with the fact that the rates of increase of temperature in the SCR and SS are also in the same order as above.

Summary

The present study indicated that hot-pack warming might induce sleep by temporally increasing and subsequently decreasing the body temperature, as seen when taking a bath. The hot-pack used in the present study can be easily heated in a microwave oven. Therefore, this hot-pack warming method is useful for sleep induction in elderly people in nursing facilities, where the number of staff is limited

for bathing of residents. We think that this kind of hot-pack can also be applicable for treating sleep-arousal rhythm disorder.

Acknowledgements

This study was supported in part by a Grant-in Aid for Scientific Research (EF, HA) and for Young Scientists (CO) from the Ministry of Education, Culture, Sports, Science and Technology of Japan, and by a Grant from Mitsubishi Foundation (EF)

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