We had previously reported on the effect of exposure to light on the human digestive system: daytime bright light exposure has a positive effect, whereas, evening bright light exposure has a negative effect on the efficiency of dietary carbohydrate absorption from the evening meal. These results prompted us to examine whether the light intensity to which subjects are exposed in the evening affects the efficiency of dietary carbohydrate absorption the following morning. In this study, subjects were exposed to either 50 lux (dim light conditions) or 2,000 lux (bright light conditions) in the evening for 9 h (from 15:00 to 24:00) after staying under bright light in the daytime (under 2,000 lux from 07:00 to 15:00). We measured unabsorbed dietary carbohydrates using the breath-hydrogen test the morning after exposure to either bright light or dim light the previous evening. Results showed that there was no significant difference between the two conditions in the amount of breath hydrogen. This indicates that evening exposure to bright or dim light after bright light exposure in the daytime has no varying effect on digestion or absorption of dietary carbohydrates in the following morning’s breakfast. Consequently, this lifestyle of keeping late hours exposes people to artificial light in the evening longer than before. Therefore, we investigated the effect of light exposure on the digestive system and found that digestion and absorption of dietary carbohydrates in the evening was lower when they had their evening meals under bright light than when under dim light between 17:00 and 02:00 (Hirota et al., 2003). Considering these results, we suspected that longer exposure to bright light during the evening in everyday life results in weaker digestive activity in the gastrointestinal tract the following morning. This may be one of the causes of the lack of appetite for a morning meal among young students, who frequently miss breakfast (National Agency for the Advancement of Sports and Health, 2007).

In order to clear up this suspicion and also to control the effect of natural daylight to which the subjects were exposed during the experimental period, we conducted an experiment over six days. In this study, we estimated the amount of unabsorbed carbohydrate by using the breath-hydrogen test. This method has become the ‘gold standard’ or method of choice for diagnosing non-digestion of lactose. When lactose or any other dietary sugar is not completely absorbed, the unabsorbed portion is fermented by colonic bacteria forming hydrogen (as well as methane in some individuals), some of which is absorbed into the portal circulation and exhaled in the breath (Savaiano and Levitt, 2000). Therefore, the more unabsorbed carbohydrates that pass into the cecum, the more breath hydrogen is excreted into the subject’s breath.

Subjects and Methods

Ten female university students volunteered as paid participants. Their physical characteristics are summarized as follows: age (20.5±2.9 years), height (156.9±3.3 cm), and weight (46.9±3.2 kg), as mean±standard deviation, respectively. They were instructed to rise at 07:00 and retire at 24:00 every day for one week prior to participation in the
experiment. All participants were non-smokers and were required to report any antibiotic medication they had taken (Gilat et al., 1978). All subjects underwent the breath-hydrogen test in the follicular phase of their menstrual cycles because the menstrual cycle could affect gastrointestinal activity (Wald et al., 1981). We explained the purpose of the study and procedures involved to the subjects before they gave written consent to participate in this study. The experiment was carried out between July and August 2005.

The subjects’ end-alveolar breath samples were collected every 20 min in special airtight bags (TERAMECS, Kyoto, Japan). Then, hydrogen (and methane) concentrations in these samples were measured by gas chromatography (Breath Gas Analyzer model TGA-2000, TERAMECS, Kyoto, Japan). As it has been shown that there is a roughly linear correlation between the amount of hydrogen in breath and that of unabsorbed carbohydrates (Fritz et al., 1985), the area under the curve for a plot of hydrogen concentration in breath against time (hereinafter referred to as AUC) was used to represent the amount of hydrogen released in the fermentation

Fig. 1 Experimental schedule of 6-day experiment.
of unabsorbed carbohydrates by micro-flora in the large intestine. AUC was calculated according to the trapezoidal rule (Rumessen et al., 1989) and expressed in parts per million·hour (ppm·h). We defined AUC values corresponding to the breakfast as the area under the curve for 3 hours 20 min starting from 20 min before a rise in the breath hydrogen level. This rise was selected as it was greater than 5 ppm above the individual baseline value and followed by at least two more rises (Hirakawa et al., 1988).

Figure 1 shows the experiment protocol of the six-day-long experiment. In this experiment we could not carry out the experiment under a counter-balanced design with a long interval as in that of Kubota et al., where the effects of nocturnal bright light or dim light on human physiology were revealed (Kubota et al., 2002). Because we had to carry out the experiment under two light conditions within a week in which the subjects’ intestinal micro-flora did not change much, we carried out the dim phase first and then the bright phase to avoid as much as possible the long lasting effect of evening bright light exposure on the subjects’ physiology.

In this experiment, a light box (a fluorescent illuminator, ST-6000, Panasonic, Osaka, Japan) was placed about 1 meter in front of the subjects and the light intensity was positioned at the subjects’ eye level. Under bright light conditions, the subjects were required to gaze at the light source (2,000 lux at eye level) every 30 min for a period of at least 10 min to ensure bright light exposure. The subjects were required to wear sunglasses when they took breaks and when they left the room during the daytime. They were not allowed to listen to stimulating music, take naps, exercise, or operate personal computers when they were in the experimental room. They slept in the experimental room on the night of days 1, 2, 4, and 5. The average experimental room temperature and humidity were 24.1±1.9°C and 34.2±4.5%, as mean±standard deviation, respectively.

The subjects entered the experimental room at 20:30 on day 1 and stayed under 200 lux until 24:00. On day 2, the subjects woke up at 07:00 and stayed under 2,000 lux until 15:00. Then, the light intensity was adjusted to 50 lux and this condition was maintained until 24:00. On day 3, the subjects woke up at 07:00 and had a test meal at 08:00. Breath samples were collected every 20 min from 08:00 to 01:00. In the evening of day 3, subjects returned home and resumed their normal activities. On the next day, day 4, the subjects entered the experimental room at 20:30 and stayed under 200 lux, as in day 1. On day 5, the subjects woke up at 07:00 and stayed under 2,000 lux until retiring at 24:00. On day 6, the subjects woke up at 07:00, had the test meal at 08:00, and stayed under 200 lux for the collection of breath samples until 17:00. In the experiment, subjects ate lunch 40 min after a 5-ppm rise in their breath hydrogen level above the individual baseline value. Breakfast, the test meal, was prepared from commercially available products: ready-to-eat minestrone soup, boiled potatoes, and a serving of macaroni (Hirota et al., 2003).

All data are shown as mean±standard error (SE).

Differences between mean values of breath hydrogen production after different light conditions were assessed by a subject’s paired t-test. A $p<0.05$ was considered to be statistically significant.

**Results**

Considering the prolonged effect of very bright light (in this case, outside sunlight) on human physiology (Park and Tokura, 1999), we conducted a six-day-long experiment as indicated in Fig. 1. In the “dim phase” subjects were exposed to artificial light of 2,000 lux for 8 hours (from 07:00 to 15:00) prior to exposure to 50 lux for 9 hours (from 15:00 to 24:00), while exposure to 2,000 lux was continuous in the “bright phase” (from 07:00 to 24:00). Figure 2 shows the comparison of breath hydrogen production for each of the ten subjects in the morning after bright light (grey bar) or dim light (black bar) exposure the previous evening. This figure shows that two out of ten subjects clearly produced more breath hydrogen after the bright phase than after the dim phase, while the other eight subjects excreted more breath hydrogen after the dim phase than after the bright phase. Comparison of the mean breath hydrogen production between the bright and dim phases indicates that there is no significant difference in AUC ($82.1±41.6$ and $92.2±27.7$ ppm·h, respectively; $p=0.538$).

Consequently, these results indicate that there is no significant difference in the influence of evening exposure to bright or dim light after staying under bright light in the daytime (from 07:00 to 15:00) on digestion or absorption of dietary carbohydrates in the following morning’s breakfast.

**Discussion**

As described in the “Introduction,” our previous experiment showed that more unabsorbed dietary carbohydrates from the evening meal passed into the cecum after exposure to bright light compared to dim light in the evening for 9 hours between 17:00 and 02:00 after 200 lux daytime exposure (Hirota et al.,...
The present experiment showed that the amount of unabsorbed dietary carbohydrates from the breakfast did not differ between evening bright light exposure (2,000 lux) and evening dim light exposure (200 lux) for 9 hours from 15:00 to 24:00 the previous evening after 2,000 lux daytime exposure. This suggests that bright or dim light exposure during the previous evening after daytime bright light has no varying influence on carbohydrate digestion the following morning. Prior to this experiment, we carried out a preliminary experiment without the 8-hour exposure to 2,000 lux of light before exposure to dim or bright light in the evening (from 17:00 to 24:00) with twenty-one female subjects whose ages were the same as those of this experimental group (see Fig. 3). In that preliminary experiment, we obtained almost the same results as in the present study: nine out of twenty-one subjects clearly produced more breath hydrogen after the “bright phase” than after the “dim phase,” while the other 12 subjects produced more breath hydrogen after the “dim phase” than after the “bright phase.” Comparison of the mean breath hydrogen production between the bright and dim phases indicates that there is no significant difference in AUC (105.8±53.1 ppm·h and 117.3±56.9 ppm·h, respectively; \( p=0.342 \)). Regarding the results of the preliminary experiment, we suspected that no light intensity control prior to the subjects’ entrance into the experimental room on the first day affected their physiological state in the evening due to the possible long lasting effect of bright light exposure (natural light exposure). Therefore, to avoid this “very bright” light effect, we added 8 hours of exposure to 2,000 lux of artificial light prior to the dim or bright light exposure that evening. However, the results obtained in both the preliminary and present experiments showed no significant varying effect from either “dim” or “bright” conditions. These two experiments indicate that there is no significant influence of evening exposure to bright or dim light after staying under bright light in the daytime (from 07:00 to 15:00) on digestion or absorption of dietary carbohydrates from breakfast the following morning. In this study, two subjects (S1, S2) excreted more breath hydrogen in the morning after bright light exposure than dim light exposure, indicating that their gastrointestinal activity to digest and absorb dietary carbohydrates the following morning was reduced while the activity of the other subjects was enhanced (see Fig. 2). It is very hard to explain this phenomenon at present, but it is very interesting from the viewpoint of biological polymorphism to light environment.

In our previous experiment (Hirota et al., 2003), we discussed that a more suppressive effect of evening “bright light” exposure than “dim light” exposure on the absorption of dietary carbohydrates in the evening meal was due to the enhancement of sympathetic activity by bright light exposure in the evening (Brainard et al., 1988; Lewy et al., 1980), which resulted in poorer gastrointestinal activity in the evening. In this experiment, we supposed that poorer gastrointestinal activity caused by the enhancement of the sympathetic nervous system by bright light exposure in the evening persists the following morning, which affects gastrointestinal activity, but the results obtained in this experiment did not coincide with our proposal (persistence of bright light effect on gastrointestinal activity).

We must mention that these results were obtained by single evening dim or bright light exposure not by repeated evening dim or bright exposure. In addition, we did not carry out this experiment as a counter-balanced experiment, but we may conclude that evening bright light exposure after staying under bright light in the daytime does not influence the digestion of
carbohydrates from breakfast the following morning. From a human nutritional viewpoint, if the efficiency of carbohydrate absorption reflects the total gastrointestinal activity, these results indicate that prolonged bright light exposure in the evening might not affect digestive activity at breakfast. Many researchers point out the importance of having breakfast regularly to maintain a healthy life while following a proper circadian rhythm. Harada et al. (2007) summarized the importance of having breakfast for young students: having breakfast is one of the triggers needed to keep a proper circadian rhythm; tryptophan (an essential amino acid in the human diet) intake from breakfast is recommended because it is a precursor of serotonin (a monoamine neurotransmitter), which gives a good morning sensation. It is also a precursor of melatonin. These results encourage young students to have breakfast regularly because evening bright light exposure after daytime bright light does not result in reduced morning gastrointestinal activity.

References


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