Indoor Exposure to Natural Bright Light Prevents Afternoon Sleepiness

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Study Objectives: The present study examined the effects of indoor exposure to natural bright light on afternoon sleepiness.

Design: Participants took part in 3 experimental conditions: (1) a natural bright light condition in which they carried out performance and arousal tests sitting near a window (3260 ± 1812.43 lux) from 12:40 PM to 1:10 PM, (2) a nap condition in which they were provided a nap opportunity for 20 minutes from 12:45 PM, and (3) a control condition in which they performed the tests in less than 100 lux surroundings from 12:40 PM to 1:10 PM. Before and after each treatment, the same series of tests were administered.

Setting: A temperature- and light-controlled sleep laboratory.

Participants: Sixteen healthy female paid volunteers aged 33 to 43 (38.1 ± 2.68) years.

Interventions: Indoor natural bright light and a short nap.

Measurements and Results: Arousal levels were measured by the Psychomotor Vigilance Task, Alpha Attenuation Test, Karolinska Drowsiness Test, and Karolinska Sleepiness Scale. The tests were repeated every 30 minutes from 11:00 AM to 4:10 PM. Ambient light intensity was maintained at less than 100 lux, except during natural bright light exposure. Short-term exposure to natural bright light significantly improved afternoon arousal levels, as measured by the Karolinska Drowsiness Test and Alpha Attenuation Test, the effects of which continued for at least 60 minutes (1:10-2:10 PM). However, no significant differences were observed between conditions for Psychomotor Vigilance Test performance.

Conclusions: Brief indoor exposure to natural bright light may decrease afternoon sleepiness. This technique of light could be used in work settings in which napping is not permitted.

Keywords: Bright light, nap, afternoon sleepiness, KDT, AAT, KSS

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INTRODUCTION

SLEEPINESS OFTEN OCCURS IN THE EARLY MORNING AND AFTERNOON.1,2 INCREASED SLEEPINESS HAS BEEN RECOGNIZED NOT ONLY AS A CAUSE OF automobile accidents, but also as a detriment to work efficiency in our business life.3-6,9 Several strategies have been examined as methods for controlling this sleepiness, such as taking caffeine,7,8 blowing cold air on the face,9,10 listening to the radio,10 chewing gum,11 and face-washing.9 In particular, short naps (less than 30 minutes) and exposure to bright light have attracted researchers’ attention.

Many studies have reported that a short nap (or “power nap”) facilitates recovery from drowsiness.8,12-20 Although some researchers warn of a risk of heart attack resulting from drastic fluctuation of the autonomic nervous system on awakening,21,22,23 it seems clear that a short nap has beneficial effects on work efficiency.13

The effect of bright light exposure (above 1000 lux) on arousal level has also been well documented.7,24-40 In a clinical setting, bright light is commonly used for antidepressant therapy to treat seasonal affective disorder16,37 or for resetting internal biologic clocks.38 In a work setting, bright light is effective in controlling workers’ arousal level in nighttime.39

Although the beneficial effects of a short nap and bright light are obvious, there are some difficulties associated with incorporating these strategies into real work settings. Firstly, not everyone can make enough time or create a safe space to take a nap in the workplace. Secondly, not every company can install adequate lighting systems in all workplaces, mainly due to financial considerations. Moreover, the duration of bright light exposure used in many previous studies (longer than 1 hour)34,35,36 would be too long to introduce into normal work hours (i.e., 8 hours), since most workers typically take only a 1-hour break for lunch.

The present study, therefore, attempted to examine the effects of a short (30 minute) natural bright light exposure at lunchtime on workers’ performance and arousal levels. Subjective sleepiness and physiologic arousal measured by electroencephalography were evaluated to quantify “arousal levels” in this study. The advantages of natural light are primarily considered to be its inexpensiveness and convenience. Everyone can afford free natural light if the weather is fine. In addition, 30 minutes of exposure is compatible with the limited lunchtime of working individuals.

If natural bright light exposure is effective for improving arousal levels, the subsequent area of interest would be whether natural bright light or a short nap is most effective. To elucidate this issue, the comparison between natural bright light and a short nap was also conducted in the present study. The hypothesis of the present study was that natural bright light would improve arousal level in the afternoon.

PARTICIPANTS AND METHODS

Participants

Participants were 16 healthy female paid volunteers aged 33 to 43 (38.1 ± 2.68) years. All participants met the following criteria: (1) had a normal sleep-wake cycle classified as “intermediate type” according to the Morningness-Eveningness questionnaire,9,41 (2) did not report any physical or mental health problems
and scored less than 15 points on the Center for Epidemiological Studies-Depression Scale (CES-D).\textsuperscript{43} (3) had not experienced shift work within the 3-month period prior to the experiment, (4) had not experienced travel to a different time zone within the 3-month period to the experiment, (5) were not using medication, (6) were nonsmokers, and (7) had a body mass index less than 25 (calculated as weight in kilograms divided by the square of height in meters). As a result, participants’ Morning/Eveningness score, Center for Epidemiological Studies-Depression Scale score, and body mass index (mean ± SD) were 53.8 ± 4.38, 7.2 ± 5.99, and 21.6 ± 2.71 kg/m\textsuperscript{2}, respectively.

Conditions

Participants took part in 1 preparation day and 3 experimental days that included a natural bright light condition, an afternoon short nap condition, and a control condition. They were requested to abstain from beverages containing caffeine and alcohol in the preparation and experimental days. Participants’ sleep-wake cycles were monitored during the experimental days by the Actiwatch (Mini Mitter Co., Inc. Bend, OR) and a sleep diary. On the preparation day, participants provided their informed consent and practiced the task described below. The experimental protocol was reviewed and approved by the Ethics Committee in Research Involving Humans at the National Institute of Industrial Health, Japan.

Task

The task for measuring performance and arousal level consisted of the Psychomotor Vigilance Task (PVT)\textsuperscript{44} using the Psychomotor Vigilance Task Monitor (PVT-192, Ambulatory Monitoring, Inc., Ardsley, NY), the Karolinska Drowsiness Test (KDT),\textsuperscript{45} the Alpha Attenuation Test (AAT),\textsuperscript{46} and the Karolinska Sleepiness Scale (KSS).\textsuperscript{45} The time schedule of the task was 10 minutes for the PVT, 1 minute for the KSS, 7 minutes for the KDT, 8 minutes for the AAT, and 4 minutes for rest (total: 30 minutes). During the 5 minutes of eyes-open in the KDT, the participants were seated on a chair in a quiet room and were asked to stare at a postcard on the wall. Then they were asked to close their eyes for additional 2 minutes while seated in the same position.

The task schedule is depicted in detail in Figure 1. The PVT uses a simple visual reaction time (RT) paradigm with interstimulus intervals ranging from 2000 to 10,000 milliseconds.

Procedure

All experimental procedures were carried out in less than 100 lux of illumination, except during light exposure in the natural bright light condition. Illumination of horizontal and vertical planes was measured at eye level of the participants using an illuminometer (T-10, Konica Minolta Holdings, Inc., Japan).

Participants arrived at the laboratory at 10:30 AM and were connected to electrodes. From 11:00 AM to 12:00 NOON, the task was repeated twice (Session 1 and 2) to establish a baseline. During a break from 12:00 to 12:40 PM, lunch (consisting of mean ± SD, carbohydrate, 200 ± 0 g; protein, 16.8 ± 3.49 g; fat, 23.2 ± 5.77 g; caloric value, 765.4 ± 63.8 Kcal for all) was served by the experimenters. From 12:40 to 1:10 PM, the participants performed the task beside the windows (at a distance of 70 cm from the windows) and were exposed to natural bright light of more than 2000 lux (natural bright light condition). The natural bright light entered the experimental room through window glass to avoid the harmful effects of ultraviolet waves in the natural light. In the control condition, the task was continued in less than 100-lux surroundings. Participants in the nap condition moved to a bedroom and were allowed a 20-minute nap opportunity from 12:45 PM to 1:05 PM. After this, the participants had to wait for approximately 5 minutes sitting on a chair until the next session. The nap was taken in a dimly lit room (less than 5 lux). From 1:10 PM to 4:10 PM, the tasks were repeated in session 4 to session 9 in less than 100 lux illumination for all 3 conditions. Thus, except during session 3, the procedure was exactly the same for all 3 conditions.

The schedule of the experiment is also shown in Figure 2.

The order of the conditions was counterbalanced among the participants. When the intensity of illumination by the window

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Schedule of 1 session of the task. PVT refers to Psychomotor Vigilance Task; KSS, the Karolinska Sleepiness Scale; KDT, the Karolinska Drowsiness Test; AAT, the Alpha Attenuation Test; open, eyes-open; close, eyes-closed.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Time schedule of the experiment. S refers to session; CNT, participant continued the task in surroundings with less than 100 lux; NBL, natural bright light—participant moved to the window side (> 2000 lux) and continued the task; NAP, participants took a 20-minute nap on a bed within 30 minutes of Session 3. The intensity of illumination in all sessions and lunch time was set at less than 100 lux, except Session 3 with the natural bright light.}
\end{figure}
was less than 1000 lux at 9:00 AM and when the weather forecast supplied by the Japan Meteorological Agency showed more than a 20% possibility of rain, the natural bright light condition was replaced by another condition. The counterbalance was not disordered by this manipulation.

Recording

Polysomnography

Electrodes were attached at C3 and O1 on scalp sites for an electroencephalogram referenced to A2 and outside of both the canthi for an electrooculogram. In addition, a bipolar submental electromyogram was recorded. The sampling rate for recording was 500 Hz (16-bit AD conversion), and the time constants were 0.3 seconds for the electroencephalogram, 3.2 seconds for the electrooculogram, and 0.03 seconds for the electromyogram. Electrode impedance was maintained below 5 kΩ. The high-cut filter was set at 30 Hz. Electrophysiologic data were recorded with a portable digital recorder (Polymate AP1000, Digitex Laboratory Co., Ltd, Japan).

Data Analysis

Psychomotor Vigilance Test

Performance indexes (e.g., mean of the RTs, fastest 10% of the RTs, slowest 10% of the RTs, lapses i.e., > 500 ms) were delivered automatically by standard software (PVTcmmW, version 2.71/REACT, version 1.1.03, Ambulatory Monitoring, Inc.). The mean of the RTs were transformed to reciprocal RTs (1/RTs), since the mean could be subject to outliers. The numbers of lapses were transformed as sqrt(x) + sqrt(x+1), where x is the corresponding number, following the recommendation of Dr. Dinges’ laboratory.

Sleep Variables

Sleep stages were visually scored every 20 seconds according to the criteria of Rechtschaffen and Kales.

Karolinska Drowsiness Test

Alpha (8.0-12.0 Hz) and theta (4.0-7.9 Hz) power spectra during eyes-open (5 minutes) and eyes-closed (2 minutes) conditions were calculated using the fast Fourier transform with a Hamming window. Power spectra were calculated for every 15-second epoch on a single central derivation (C3-A2). Artifacts on electroencephalogram were removed using low-cut (0.5 Hz) and high-cut (30 Hz) digital filters and also were visually checked.

Alpha Attenuation Test

During the AAT, participants opened (eyes-open) and closed (eyes-closed) their eyes alternately every 2 minutes for a total of 12 minutes while staring at a small postcard on the wall. The first eyes-closed (2 minutes) and eyes-open (2 minutes) conditions were overlapped with the KDT procedure described above. Power spectra were calculated using fast Fourier transform for every 5-second epoch of data on a single occipital derivation (O1-A2). The alpha attenuation coefficients (AAC) per each 12-minute test session were calculated as the ratio of mean power in the alpha frequency band during eyes-closed conditions to the mean alpha power during eyes-open conditions. Thus, the higher the AAC, the higher the physiologic arousal level.

To control for a high degree of interparticipant variability, the data from the KDT, AAT, and KSS were transformed to baseline deviations for each participant. The baseline was the average between Session 1 and Session 2.

Statistical Analysis

All data were submitted to a “Condition (natural bright light, nap, control conditions)” × “Session (from session 4 to session 9)” or “Condition (natural bright light, nap, control conditions)” repeated-measures analysis of variance (ANOVA) with the SPSS system for Windows, version 11.5 (SPSS Japan Inc., Japan). To control for the type 1 error associated with violation of the sphericity assumption, degrees of freedom greater than 1 were reduced by the Huynh-Feldt ε correction. Posthoc analysis was conducted using Tukey’s procedure and a paired t test.

RESULTS

Sleep Efficiency at Night

Time in bed and total sleep time, night before the experimental days, are shown in Table 1. No significant differences were observed for total sleep time [F(2,30) = 1.09, P = .92, ε = 0.92], time in bed [F(2,30) = 0.25, P = .76, ε = 0.91], or sleep efficiency [F(2,30) = 0.08, P = .92, ε = 1.00]. Participants slept around 6 hours per night, which is generally considered as a partial sleep deprivation.

Light Intensity

The intensity of illumination in session 3 of the natural bright light condition was measured every 10 minutes during natural bright light exposure. Mean intensities were 2123.6 ± 1131.08 lux in the horizontal plane and 3260.0 ± 1812.43 lux in the vertical plane to the windows at eye level of the participants. In all other sessions, the intensities of illumination were maintained at less than 100 lux.

Sleep Variables During the Nap

Total sleep time in the nap condition was 13.0 ± 5.74 minutes. Slow-wave sleep and rapid eye movement sleep did not appear during the naps, as shown in Table 2.

Neurobehavioral Performance

Exposure to natural bright light did not produce a significant effect on any aspect of PVT performance. In addition, PVT performances after Session 3 (i.e., Session 4-9) did not show any

| Table 1—Time in Bed and Total Sleep Time on the Experimental Days |
|------------------|------------------|------------------|------------------|------------------|
|                  | CNT              | NBL              | NAP              | P value          |
| Total sleep time | 362.2 ± 52.56    | 365.3 ± 49.17    | 359.8 ± 53.86    | NS               |
| Time in bed      | 411.6 ± 55.07    | 409.7 ± 63.68    | 400.0 ± 54.89    | NS               |
| Sleep efficiency | 0.89             | 0.90             | 0.90             | NS               |

Data are presented as mean ± SD. CNT refers to control condition; NBL, natural bright light; NAP, participants took a 20-minute nap.
significant differences between the 3 conditions. Results of ANOVA (the main effect of “Condition” and the interaction between “Condition” and “Session”) are as follows: reciprocal mean RTs [F(2.30) = 2.11, P = .14, ε = 0.89; F(10,150) = 0.98, P = .45, ε = 0.70], reciprocal fastest RTs [F(2.30) = 1.46, P = .24, ε = 1.00; F(10,150) = 0.74, P = .68, ε = 1.00], reciprocal slowest RTs [F(2.30) = 2.73, P = .08, ε = 0.93; F(10,150) = 1.35, P = .22, ε = 0.81], reciprocal median RTs [F(2.30) = 2.84, P = .07, ε = 1.00; F(10,150) = 0.74, P = .67, ε = 0.94] and lapses [F(2.30) = 2.59, P = .09, ε = 0.96; F(10,150) = 0.92, P = .51, ε = 0.94]. Mean and SD of those measures are shown in Table 3.

Karolinska Drowsiness Test

**Eyes-Open**

The main effect of “Condition” [F(2,30) = 4.04, P < .05, ε = 1.00] was significant for alpha power density, and the interaction between “Condition” and “Session” was not significant [F(10,150) = 2.17, P = .07, ε = 0.46] (left panel of Figure 3). The main effect of “Condition” was also significant between the natural bright light and control conditions [F(1,15) = 4.86, P < .05, ε = 1.00] as well as between the control and nap conditions [F(5,15) = 5.53, P < .05, ε = 1.00]. Alpha power density with eyes-open was significantly lower in the natural bright light and nap conditions than in the control condition. The effects of natural bright light were observed in Session 4 (P < .05) and Session 5 (P < .01) and indicated significantly lowered sleepiness after natural bright light than after control. While the effects of nap appeared in Session 4 (P < .01), Session 5 (P < .01) and Session 6 (P < .05), alpha power density was lower in the nap condition than in the control condition. No significant difference was observed during natural bright light exposure (i.e., Session 3).

After Session 3, theta power density was significantly lower in the nap condition than in the control condition in Session 4 (P < .01) and Session 5 (P < .05). Theta power density was lower in the nap condition than in the natural bright light condition in Session 4 (P < .05). The main effect of “Condition” [F(2,30) = 3.56, P < .05, ε = 0.82] and the interaction between “Condition” and “Session” [F(10,150) = 2.79, P < .05, ε = 0.31] were found to be significant. No significant difference was observed during natural bright light exposure (i.e., Session 3).

**Eyes-Closed**

Alpha power density with eyes-closed was significantly lower in the control condition than in the nap condition (right panel of Figure 3). A main effect of “Condition” [F(2,30) = 3.54, P < .05, ε =
No significant difference was observed between eyes-open and eyes-closed subjects during natural bright light exposure (i.e., Session 3). A main effect of napping appeared in Session 4—6, as shown in the left panel of Figure 4. A main effect was observed for “Condition” \([F_{230} = 5.05, P < .05, \epsilon = 1.00]\) among the 3 conditions. The main effect of “Condition” was also significant between the natural bright light and control conditions \([F_{1,15} = 7.11, P < .05, \epsilon = 1.00]\), and between the nap and control conditions \([F_{1,15} = 6.99, P < .05, \epsilon = 1.00]\). Consistently higher AACS were observed after natural bright light than after control conditions, with significant differences observed in Session 6 and Session 9 (P < .05). The effect of napping appeared in Session 4 and Session 7 (P < .05). No significant difference was observed during natural bright light exposure (i.e., Session 3).

**Subjective Sleepiness**

During natural bright light exposure, subjective sleepiness significantly reduced \([t_{15} = 2.90, P < .01]\), as shown in the right panel of Figure 4. Although no significant differences were observed

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**Figure 3**—Alpha and theta power density in the Karolinska Drowsiness Test. The bars on the figure show standard errors (SE). S refers to session; CNT, control condition; NBL, natural bright light; NAP, participants took a 20-minute nap.

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= 0.87] was observed among the three conditions. The main effect of “Condition” was also significant between the nap and the control conditions \([F_{1,15} = 15.03, P < .01, \epsilon = 1.00]\). No significant differences were detected between the natural bright light and control conditions \([F_{1,15} = 0.98, P = .34, \epsilon = 1.00]\) or between the natural bright light and nap conditions \([F_{1,15} = 1.98, P = .18, \epsilon = 1.00]\).

Theta power density with eyes-closed was significantly higher in the control condition than in the natural bright light condition during natural bright light exposure (i.e., Session 3) \([t_{15} = 2.08, P < .05]\). Theta power spectrum with eyes-closed did not show a main effect for “Condition” \([F_{1,30} = 0.17, P = .84, \epsilon = 0.98]\) or the interaction between “Condition” and “Session” \([F_{10,150} = 1.02, P = .42, \epsilon = 0.80]\).

**Alpha Attenuation Test**

AAC was significantly lower in the control condition than in the other two conditions in all sessions after Session 3 (i.e., Session 4 - 6), as shown in the left panel of Figure 4. Although no significant differences were observed
DISCUSSION

The present study demonstrates that short-term exposure to natural bright light improves afternoon levels of the physiologic arousal, though its effect may be weaker and last shorter than that of a short nap. Indeed, exposure to natural bright light produced a significant decrease in eyes-open electroencephalogram alpha power density during 60 minutes followed by the postexposure period, as compared with the control condition. By contrast, napping significantly reduced both eyes-open electroencephalogram alpha and theta power densities throughout 90 and 60 minutes after the nap, respectively. The similar effects were observed for AAC. However, the natural bright light exposure did not significantly affect subsequent levels of PVT performance or subjective sleepiness.

The positive effects of natural bright light on the physiologic arousal, as measured by the KDT and AAT, were observed in the present study. Alpha power density decreased during the eyes-open condition after natural bright light exposure from 1:10 PM to 2:10 PM, as shown in Figure 3. An almost identical result was observed for the AAT (i.e., AAC). The lowest level of AAC was observed in the control condition in all sessions. Therefore, we believe that natural bright light exposure may prevent the decline of physiologic arousal that usually occurs in the midafternoon (around 2:00 PM).12

In some previous reports,49,50 however, the effects of brief, daytime exposure to bright light were not observed. Presumably, this discrepancy could be caused by some factors in the exposure conditions. For example, in the present study, natural light was used, rather than the fluorescent lights or incandescent lamps that were generally used in the previous studies. Other studies have indicated that high color temperature light (i.e., green or blue) can have an especially strong effect on melatonin secretion,51-53 core body temperature,54 and physiologic activity.55 Thus, it is thought that the high color temperature of natural light could possibly affect arousal level. However, other differences still remain between the present study and previous studies,49,50 such as intensity of illumination, time of day during exposure to bright light, experimental setting (e.g., field or laboratory), and age of the participants.

In the present study, the effects of natural bright light exposure occurred in the daytime when melatonin secretion is at its lowest.56 It has been reported that the effects of bright light occur mainly at night via melatonin suppression.57 However, the present findings would not be explained by such a mechanism because the former study has confirmed that daytime melatonin level does not change even after 5 hours of 1000 lux light exposure. Another neurochemical candidate may be adenosine, which is currently receiving considerable attention as a factor in sleep-wake regulation in both animal and human.56 Adenosine is known as a neurotransmitter that increases sleepiness,57 and it has been proposed that the synthesis and/or transport of adenosine may be suppressed by bright light exposure.58 Whether the suppressed action of adenosine would produce improved arousal levels during or after exposure to natural bright light may be an interesting question for future study.

Apart from the role of sleep-regulating substances, it should be noted that there is a possibility that natural bright light might have directly activated brain regions promoting the physiologic arousal through the suprachiasmatic nucleus.59 The data from the previous9 and current experiments will stimulate research to elucidate the brain mechanisms of a light-induced increase in physiologic arousal during the daytime.
Another area of interest in the present study was the comparison of the effects between the natural bright light and nap conditions. A major advantage of natural bright light may be that people can receive its benefits while performing other activities (e.g., eating lunch or walking) without any equipment. Compared with napping, natural bright light could be a practical method for controlling arousal level in the work environment.

We found a higher physiologic arousal at least 30 minutes after the nap than after the natural bright light, as reflected in a significant decrease in theta power density with eyes-open and increased A/M. Nevertheless, from 60 minutes after the natural bright light or nap, the differences between the natural bright light and the nap conditions had almost disappeared. Therefore, these results might suggest a superiority of napping to natural bright light, though an exact control condition for the nap condition in which participants do not perform the task in Session 3 was not included in the design of the present study. In the nap condition, it is notable that sleep inertia (i.e., severe sleepiness just after awakening) was not detected. Sleep inertia might have diminished because of a few minutes of rest period after the nap before the tests.

Significant differences in PVT performance between conditions were not detected in the current study. In contrast, Phripps-Nelson et al. \(^{16}\) reported that daytime bright light exposure induced improvement in PVT reaction times using both visual and auditory stimuli. In the present study, the responses of participants were measured for visual stimuli only, which may have produced the different results. In addition, some differences exist between the experimental settings of the present study and the previous study. \(^{16}\) which include intensity of illumination for the control condition (< 100 lux vs < 5 lux), duration of exposure (30 minutes vs 5 hours), and duration of prior sleep (2 nights of 5 hours each vs 6 hours).

Previous studies have demonstrated that a short nap improves several kinds of task performances and physiologic arousal level. \(^{8,12-20}\) The results of the physiologic arousal found here are consistent with the previous data. On the other hand, the current findings show no significant effects on the PVT performances. It might be masked by increased sleepiness due to a total sleep time of approximately 6 hours in our participants (Table 1), since this duration of sleep may be deemed as being insufficient according to recent evidence (e.g., Van Dongen et al). \(^{46}\) To our knowledge, no study has evidenced the effect of a short nap (< 30 minutes) on PVT performance after a night of sufficient sleep. This issue would be open for further studies.

In conclusion, our results demonstrate that brief indoor exposure to natural bright light improves the physiologic arousal in the afternoon, the effects of which lasted for at least 60 minutes (1:10 PM-2:10 PM). Although the favorable effects of natural bright light exposure seemed slightly shorter than those of a brief nap, the present findings may suggest the use of natural light as a practical strategy to reduce afternoon sleepiness.

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