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Brief Hourly Exercise during Night Work can Help Maintain Workers' Performance

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Abstract: Increased night work is an important issue because of its implications on workers' health, safety and performance. This study examined the effects of brief hourly exercise as a countermeasure against the adverse effects of night work, especially for workers requiring sustained attention while working in a prolonged sitting posture. During simulated night work (22:00–08:00), participants were required to follow an hourly schedule comprising a 30-min task, 15-min test and 15-min break. The study included 2 experimental conditions: (1) hourly exercise (HE; hourly exercise for 3 min during breaks) and (2) control (without exercise during breaks). Throughout the test period, work performance in the last 10 min of each 30-min task was better under the HE condition than under the control condition (p<0.01). During the second half of the test period, exercise showed an effect on sustained attention (p=0.02). Parasympathetic nerve activity under the HE condition was less than that under the control condition (p<0.01). However, exercise was not effective in reducing subjective fatigue and sleepiness. These results suggest that brief hourly exercise acts as a restraint on parasympathetic nerve activity and is capable of sustaining attention levels during the circadian rhythm nadir that occurs during early morning.

Key words: Brief hourly exercise, Night work, Work performance, Sustained attention, Early morning

Introduction

Night work compels workers to work against their innate circadian rhythm by requiring them to sustain alertness and performance at night. For this reason, night work has been considered problematic because of its association with an increase in sleepiness and fatigue[1, 2], decline in work efficiency[3], increase in human error[3] and increased risk of acquiring diseases[4]. In spite of these findings, the frequency of night work has recently increased and has become an indispensable work pattern in contemporary society because of the progress of industrial technology. Work patterns requiring sustained attention while maintaining a prolonged sitting posture, as is the case of air traffic controllers[5]; bus, taxi and long distance truck drivers[6] and workers working at 24-h call centres, has increased markedly. Therefore, identification of effective measures to counteract the fatigue and sleepiness associated with night work has become an important focus of investigation in the field of occupational health. The effectiveness of naps[7, 8], caffeine[9], ventilation[10], bright light[11] and music[12] as measures to combat the adverse effects of

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night work has been examined in previous studies.

In actual work situations, low-cost physical exercise has been recommended as an effective measure during night work[13]. Some earlier studies investigated the effect of physical exercise intensity and the duration of its effectiveness. The arousal level was higher for a medium exercise intensity than for a high or low exercise intensity, and the relationship between exercise intensity and arousal level showed an inverted U-shape[14, 15]. In other studies, the effectiveness of exercise persisted for 30 min to about an hour after exercise[16, 17]. Furthermore, several studies have supported the effectiveness of exercise in decreasing sleepiness and fatigue under prolonged sleep deprivation, even for as little as 10 min of treadmill exercise (70% VO_2max) after every 2 h[17] or knee bend exercise[18]. However, applying such countermeasures directly to practical occupational situations is difficult because of high exercise intensities or unrealistic test conditions. Another study[19], noting the effect of short breaks taken by airplane pilots, indicated that 7-min breaks can reduce the pilots' sleepiness and fatigue during night flights, although detailed information about the nature of the break was not given by the authors. Though there are some findings regarding exercise and night work, no consensus or standard regarding the duration, type and intensity of exercise during night work has been established.

In this study, we examined the effects of brief hourly exercise as a countermeasure for night work that demanded workers to sustain their attention levels in a prolonged sitting posture.

Methods

Participants

We recruited university students according to the following eligibility criteria: (1) healthy male; (2) neither an entirely a morning nor evening person, as evaluated by morning–evening questionnaires[20]; (3) nonsmoker; (4) without a heavy drinking habit; (5) without sleep disorders; and (6) ability to type on a personal computer keyboard. Although 12 students were chosen to participate in the study, only data from 8 students who completed all measurements were analysed. Their mean ± SD for age, weight and height were 19.4 ± 1 yr, 58.6 ± 5.4 kg and 168 ± 7 cm, respectively. Detailed written and oral explanations of the experiment were provided to those who gave consent for their participation in the experiment. All participants were paid for their participation (68,000 JPY/person). This experiment was approved by the Human Research Ethics Committee of Nagoya City University.

Protocol

We instructed the participants to prepare for the experiment by refraining from detrimental behaviour, such as excessive exercise, taking a nap or ingesting caffeine, which might influence their arousal level. Prior to the experiment, each participant wore a wrist watch-shaped actigraph unit (Actiwatch64; Mini Mitter Company, Inc., Bend, OR, USA) to monitor sleeping/waking patterns for 3 d before each experiment.

On the appointed day, participants arrived at the laboratory at 18:00 h and after having dinner, from 19:00 h practised and adapted to the task, tests and exercises. The experimental period was fixed from 22:00 to 08:00 h the next morning. Each participant was instructed to independently perform an hourly exercise consisting of a 30-min task, 15-min test and 15-min break according to the schedule shown in Fig. 1. At the laboratory, participants were supplied with calorie-controlled meals prepared by a registered dietician (dinner at 18:00 h; 815 kcal and nocturnal snacks at 21:00 and 02:00 h; 555 kcal) and 50 ml water during each break, with the intention of regulating the effects of meals on the arousal level during the experiment.

Participants were required to perform a 30-min English transcription task (ETT) at every hour during the test period. This consisted of the transcription of English sentences shown on the left half of a computer monitor onto the right half of the monitor by typing them. Participants were instructed to pay attention to both speed and accuracy in typing the sentences. After each task, participants were also required to report their subjective fatigue and sleepiness and to perform a psychomotor vigilance test (PVT) as an index of sustained attention during the test period. Participants were only allowed to visit the lavatory once every 3 h in addition to the designated exercise, so that their amount of exercise during the break could be controlled. Therefore, they were generally encouraged to sit on a chair except when they were performing these actions.

The experimental conditions were as follows (Fig. 1): (1) an hourly exercise (HE) condition, in which the participants performed 1 set (3 min) of physical exercises every hour, a total of 9 times during the experimental period and (2) a non-exercise (control) condition, in which the participants did not perform any exercise during their 9 breaks.

Total exercise time was 27 min under the HE condition. Exercise under the HE condition began 6 min before the subsequent task, so that the participants could finish the exercise 3 min before the task and be prepared to execute it. The experimenters kept the participants under surveillance using a remote camera. If a participant dozed off during simulated night work, the experi-

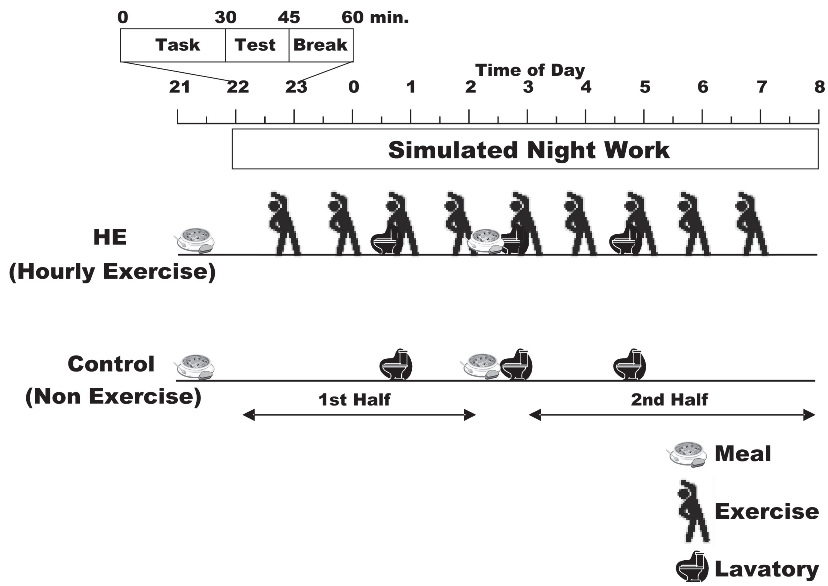


Fig. 1. Experimental schedule.

menters would wake him up by touching his shoulder.

The condition on any particular experimental day was allocated randomly among the individual participants. To prevent any carry-over effects of the previous experiment, each experiment was implemented at intervals of at least 5 d.

Devised exercises

One set of physical exercises (Fig. 2) consisted of 9 types of movement, each performed for 20 s, as follows: (1) neck twisting, (2) arm swinging, (3) leaning backwards and forwards, (4) twisting the torso, (5) bending and stretching the knees, (6) side stretching the legs, (7) stretching the lower legs, (8) spreading the legs and (9) deep breathing.

After considering what exercises would be feasible in the workplace, we designed the exercises so that they could be performed easily in a small space (within a radius of 1.5 m) and without instructions from a specialist. The participants were instructed to perform the exercises according to video images displayed on their personal computers.

Measurements

(1) Work performance

Work performance was measured as per the number of English characters input during a 30-min ETT.

(2) Subjective fatigue and sleepiness

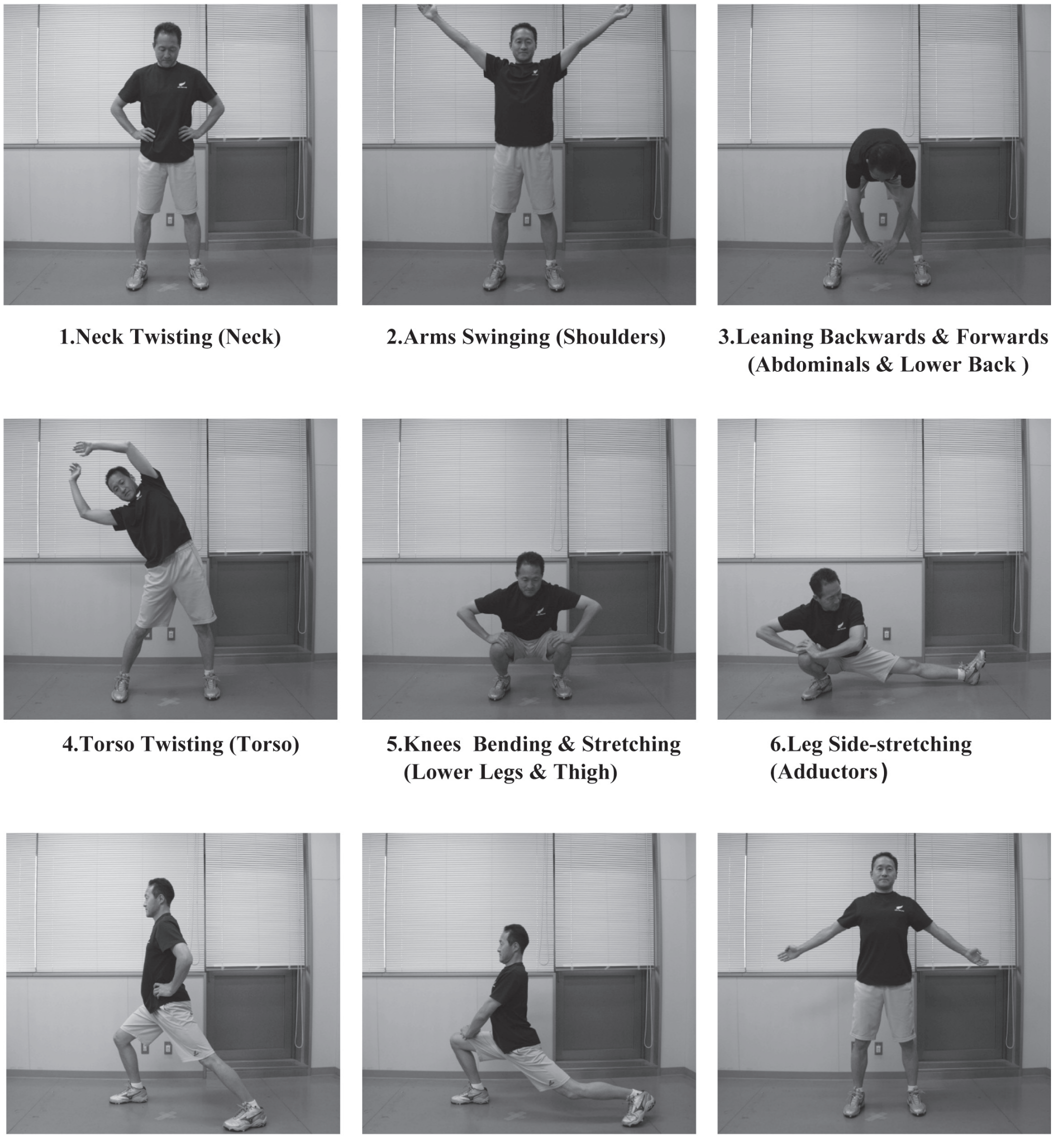
A visual analogue scale (VAS) was used to provide an index of subjective fatigue and sleepiness. A 100-mm horizontal line was shown on the display screen of the personal computer. The participants rated their sleepiness and fatigue at the time by marking the 100-mm line using the mouse cursor. The value ranged from 0 mm (not at all sleepy or tired) to 100 mm (extremely sleepy or tired).

(3) Sustained attention

A psychomotor vigilance test (PVT) was used as an index of sustained attention. According to previous research[21, 22], PVT is considered a behavioural index that is sensitive to the influence of sleep deprivation. Single numerals of the series 2, 4, 6, 8 were shown consecutively as a stimulus on the display screen. The participants were required to respond by correctly typing the key corresponding to the displayed number as quickly and accurately as possible. The interval between 2 stimuli varied randomly from 5 to 20 s, and the test lasted for 10 min. If the participants did not respond within 2 s after having received the stimulus, the response was counted as an omission error and the screen was switched to the next stimulus.

(4) Autonomic nervous activity

The high frequency (HF, 0.15–0.4 Hz) band of heart rate variability (HRV) was used as an index of parasympathetic nerve activity[23, 24]. A Holter electrocardiogram (ECG) monitoring system (Active Tracer AC301; GMS Inc., Tokyo, Japan) was used to measure HRV and heart rate during the entire test period. HRV data were downloaded and a power spectrum analysis was conducted every 5 min using the MemCalc system (Suwa Trust Co., Ltd., Japan). Because of the effect of exercise on respiration, the data obtained within 30 min after exercise were excluded.



1.Neck Twisting (Neck)

2.Arms Swinging (Shoulders)

3.Leaning Backwards & Forwards (Abdominals & Lower Back)

4.Torso Twisting (Torso)

5.Knees Bending & Stretching (Lower Legs & Thigh)

6.Leg Side-stretching (Adductors)

7. Lower Leg Stretching (Achilles Tendon & Posterior Lower Leg)

8.Leg Spreading (Quadriceps)

9.Deep Breathing (Midriff)

Fig. 2. The 9 components of the physical exercise programme.
The brackets show the body regions targeted by the 9 exercise components.

(5) Intensity of physical exercise

Heart rate (HR, beats per minute [bpm]) and the Karvonen formula[25] values during exercise were used as the indices of physical exercise intensity.

Data analysis

All data were expressed as mean ± SEM. To remove the effect of inter-individual variations, work performance was defined as the increase or decrease in the number of characters input during the 30-min ETT compared with the baseline (number of letters input in the first battery) under each condition. Logarithmic transformation was applied to adjust the HRV data to a normal distribution. Generalized linear mixed models[26] with repeated measures for the 2 factors (experimental condition and time of day) were used to incorporate a parameter accounting for within-individual variations. In the statistical analyses concerned with the period when the arousal level declines, all data were classified as relating to the first (22:00–2:00) or second halves (03:00–8:00) of the test period. Paired *t*-tests were used to compare the measurement data at the beginning of the first and second halves. All statistical analyses were performed on a personal computer using SPSS for Windows (Version 14.0J; SPSS, Chicago, IL, USA).

Results

Work performance

Throughout the test period, work performance on ETT tended to be higher under the HE condition than under the control condition (first half, $p=0.09$; second half, $p=0.07$). In the first (Fig. 3a) and middle 10 min (Fig. 3b) of the task, there were no significant differences between HE and control conditions. In the last 10 min (Fig. 3c) of the task, however, performance under the HE condition was significantly higher than that under the control condition in both the first and second halves of the test period ($p<0.01$, for both).

Subjective fatigue and sleepiness

Changes in subjective fatigue and sleepiness measured using VAS are shown in Fig. 4a and 4b. The scores for subjective fatigue increased significantly (first half, $p=0.02$; second half, $p<0.01$) with time. Subjective fatigue under the HE condition was significantly greater than that under the control condition during only the first half of the test period ($p=0.03$). However, no significant difference was observed in subjective sleepiness between HE and control conditions.

Sustained attention

Changes in reaction times in the PVT are shown in Fig. 5. No significant difference was observed between HE and control conditions during the first half of the test period. However, during the second half, reaction times under the HE condition were significantly faster than those under the control condition ($p=0.02$).

Autonomic nerve activity

There was no significant change in the HF component of HRV with time in either the first or second halves of the test period (Fig. 6). However the value was significantly lower under the HE condition than under the control condition during both halves of the test period ($p<0.01$ for both).

Physical exercise intensity

Heart rate increased to 90 bpm during every exercise. HR during exercise (88.1 ± 3.1 bpm) was significantly higher than that during rest breaks (61.8 ± 1.2 bpm) in both the first and second halves of the test period ($p<0.01$ for both). The Karvonen formula values showed $13.1 \pm 1.5\%$ of HRR that could be interpreted as low level intensity.

Comparison of the baseline data at the beginning of the first and second half

All measurements except HF under the HE condition, work performance in the first and middle 10 min under both conditions and the last 10 min under the HE condition indicated significant differences between the first and second baseline data ($p<0.05$).

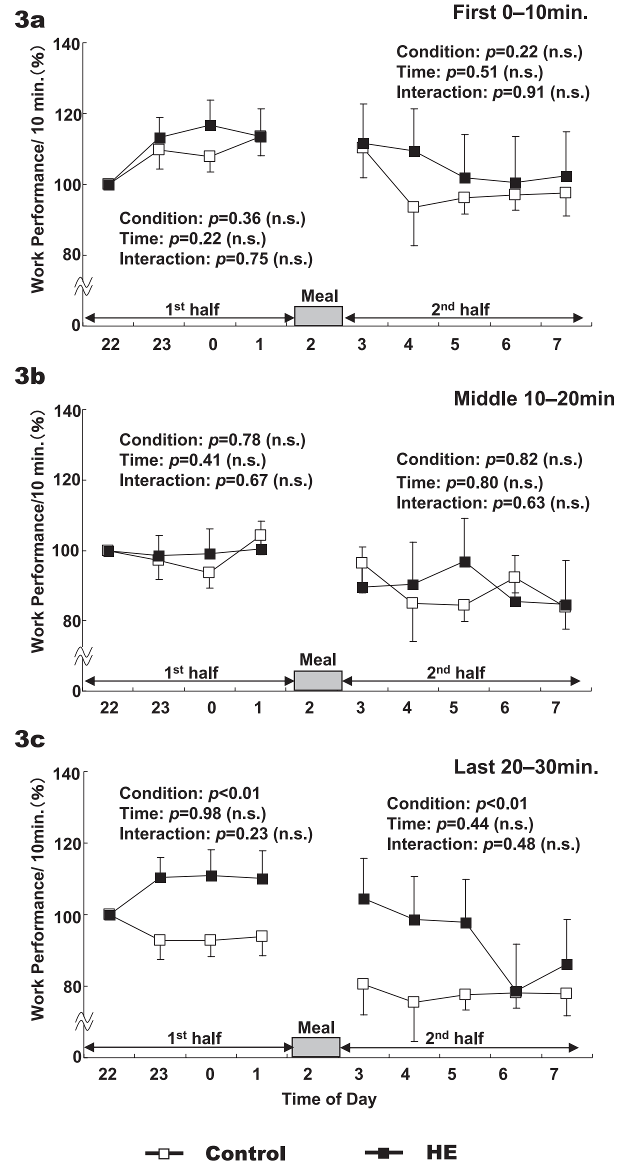


Fig. 3. Changes in work performance during the English transcription task (ETT) during the first (a), middle (b) and last 10-min periods after the break (c).

Data are expressed as mean ± standard error (SE).

Discussion

One of the most interesting findings of this study was that the effects of the exercise were observed distinctly during the second half of the test period, including the period when the arousal level declined, despite low exercise intensity. Effects appeared in indices, such as the reaction time and the HF component of HRV, which

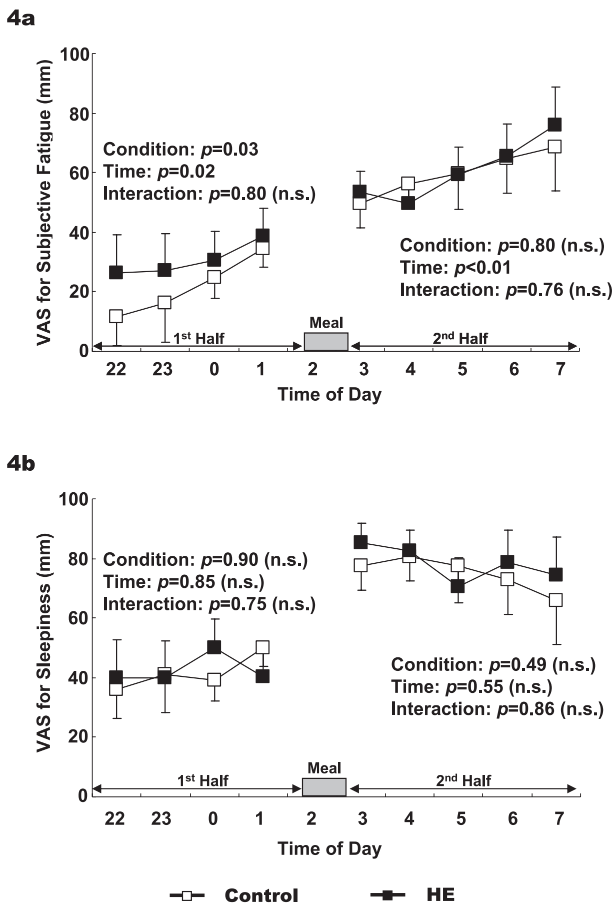


Fig. 4. Changes in subjective fatigue (a) and sleepiness (b) during simulated night work.
Data are expressed as mean ± SE.

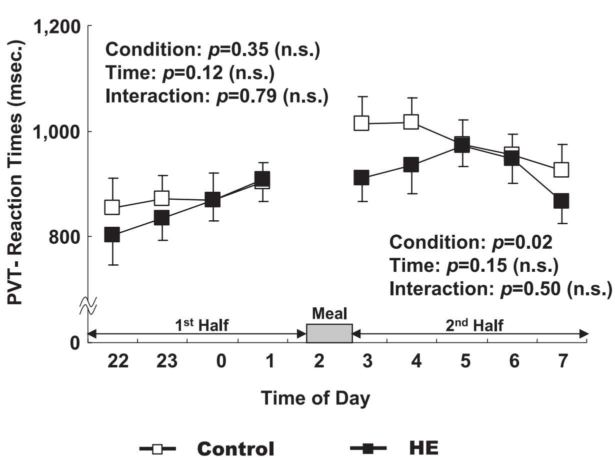


Fig. 5. Changes in psychomotor vigilance test (PVT) performance (reaction time) during simulated night work.
Data are expressed as mean ± SE.

were relevant to the function of the reticular activating system in directing autonomic nerve activity. From a neurophysiological perspective, sleep deprivation is

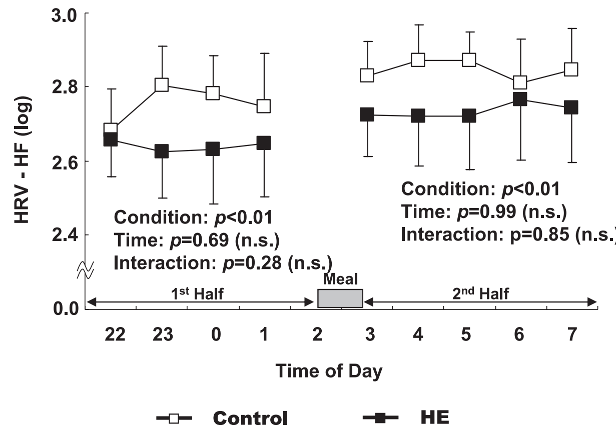


Fig. 6. Changes in heart rate variability (high frequency component, HF) during simulated night work.
Data are expressed as mean ± SE.

thought to cause a decline in sustained attention, possibly owing to deactivation of Brodmann area 24 of the anterior cingulate cortex (ACC) in the reticular activating system[27–30]. Furthermore, an increase in sleepiness and a decline in physiological responses, such as body temperature and heart rate, normally occur during late in the night, especially around the circadian rhythm nadir, when arousal levels decline[31–33]. Although high exercise intensity has the transient effect of improving the arousal level, low exercise intensity does not have such an effect[14, 15]. The ergometry experiment of Kamijo *et al.*[14] showed that the arousal level was higher for medium exercise intensity than for high or low exercise intensity. The relationship between exercise intensity and arousal level showed an inverted U-shape. HR was about 90 bpm during exercise in the present study; this level of exercise is similar to the low exercise intensity[34, 35] of a light walk (50–60 m/min). One possible explanation for this finding may be related to the overall stimuli acting on the whole body during the 9 types of exercise. After referring to the exercises used by Lee and Waikar[36] in a study targeting visual display terminal (VDT) workers, we devised a set of exercises composed of twisting and stretching of the neck, shoulders, arms, back, waist and legs for use in the present study (see Methods). It is likely that the overall stimulation of the whole body in this study, even though the intensity exercise was low, had a restraining effect on parasympathetic nerve activity in terms of the function of the reticular activating system.

With regard to subjective sleepiness, however, the interpretation of our results remains debatable. One possibility is that the effect of exercise on subjective sleepiness disappeared owing to the lapse of time, since the data were measured more than 30 min after exercise in this study. For example, Neri *et al.*[19] reported that breaks improved subjective sleepiness for 25 min after the break in a simulated night flight experiment. If we had obtained data within 30 min of an ETT, we could have measured the effect of exercise against subjective sleepiness.

Additional interpretations on subjective fatigue may be gathered from position emission tomography (PET) studies. Regional cerebral blood flow in the orbitofrontal cortex (Brodmann areas 10 or 11) is activated[37] or inactivated[38] with the development of subjective fatigue, suggesting that regions of the brain play a role in the perception of subjective fatigue. In the present study, the difference in subjective fatigue between HE and control conditions was observed during the first half but disappeared during the second half of the test period. In other words, although the interpretation requires further discussion, it seems reasonable to conclude that the brief exercise programme at a low intensity and at intervals of 1 h did not improve subjective fatigue in the orbitofrontal cortex.

Another aspect that needs to be discussed is the effect of exercise on work performance. Throughout the test period, work performance under the HE condition was higher than that under the control condition in the last 10 min of the 30-min task. This result provides evidence that the effectiveness of exercise with respect to work performance persisted for at least 20 min after the exercise. This finding is in line with the results of previous studies[16, 17] showing that the effectiveness of exercise persisted between 30 min to about an hour after exercise. Work performance has been used as a behavioural index of fatigue[21, 39], and cumulative workload induced fatigue was expressed as a transient decrease in work performance. However, it should be borne in mind that work performance is affected by a number of factors, such as sustained attention, circadian rhythms and extrinsic and intrinsic motivation[7, 40, 41]. Therefore, interactions among these factors make it difficult to interpret data on work performance.

A meal during late in the night can be considered as a break like lunchtime during the day. However, the measured indices did not recover completely after the meal under both HE and control conditions. Therefore, other countermeasures would also be necessary to attain recovery against fatigue during night work.

This study has some limitations. Because the exercise condition in this study consisted of multiple factors (exercise frequency and time), the factors directly influencing the main effect are not clear. The participants in this study were university students who were younger and less experienced in night work and had fewer coping skills while performing night work than regular night workers. Another limitation is that the sample size used in this study was smaller than that used in previous studies. Therefore, the results should be interpreted carefully.

In conclusion, during night work, a brief period of hourly exercise can act as a restraint on the level of parasympathetic nerve activity and may help sustain the attention level during the circadian rhythm nadir, which occurs during early morning. However, the exercise programme used in this study was not effective in reducing subjective fatigue and sleepiness. Therefore, the introduction of a brief exercise period alone into the practical setting of night work might not be adequate as a countermeasure. Combinations of other countermeasures such as nap-taking and modification of the shift schedule should be considered as comprehensive measures against fatigue during night work.

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