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Original Article

Is decision-making influenced by interactions between extended wakefulness and weak emotional stressors? An experimental study

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Abstract: In this study, we aimed to determine whether 21-hour continuous wakefulness decreases performance in the Iowa Gambling Task and examine the effect of the interaction between a weak emotional stressor and prolonged continuous wakefulness on the decision-making process, as measured by the Iowa Gambling Task. Approximately half of 38 healthy college students were in the sleep deprivation condition (they performed the task at 4:30 a.m.); the remainder were in the daytime condition (they performed the task during the day). The participants in each sleep condition were further divided into non-exposed and exposed to an emotional stressor via a social exclusion procedure before the task, with the Iowa Gambling Task score as the dependent variable. In the sleep deprivation condition, performance in the final block of the task was significantly worse in the group with an emotional stressor than the group without. There was no main effect of sleep conditions or emotional stressors on the task performance in either block. The results of this study suggest that even 21 hours of continuous wakefulness, which can occur in daily work life, may prevent appropriate learning in people exposed to an emotional stressor, even if the stress caused due to it is low.

Key words: Sleepiness, Stressors, Decision-making ability, Cognitive performance, Learning

Introduction

People are sometimes exposed to stressful situations while simultaneously experiencing a certain level of sleep deprivation in everyday work life, especially in shift workers such as professional drivers[1–3] and medical workers[4–6]. Sleep deprivation can lead to emotional instability[7,8]. The relationship between emotional instability and sleep disturbance has been examined in several experiments, mainly using extended wakefulness as an experimental manipulation. It has been shown that extended wakefulness causes an overreaction to emotional stimuli. For example, Minkel

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et al.[9] found that subjects with one night of complete sleep deprivation reported greater subjective stress, anxiety, and anger when exposed to weak stressors than those in normal sleep conditions. Kahn-Greene, Lipizzi, Conrad, Kamimori, and Killgore[10] compared participants' responses to the Rosenzweig Picture-Frustration (P-F) study following 55 hours of continuous wakefulness with those following normal sleep and suggested that an extended period of continuous wakefulness may reduce inhibition of aggression toward others in frustrating situations.

Yoo, Gujar, Hu, Jolesz, and Walker[11] examined the brain mechanisms involved in the increase in emotional responses during sleep deprivation using fMRI and found that participants who remained awake for 35 hours had stronger amygdala responses to negative emotional stimuli and weaker functional connectivity between the amygdala and the medial prefrontal cortex (PFC) that controls it. Additionally, the results of a study examining the effects of sleep deprivation at a level that is not uncommon in the real world (4-hour sleep × five days; 3-hour sleep × two days)[12, 13] demonstrated that the functional connectivity between the amygdala and the ventral anterior cingulate cortex or medial PFC was reduced under sleep deprivation conditions.

These findings are notable because appropriate emotional control is associated not only with the suppression of overreaction to emotional stimuli but also with the appropriate maintenance of higher functions and decision-making under stress. Presenting emotional stimuli was found to increase the ventral affective system activity (pathways including the orbitofrontal cortex, amygdala, and ventral PFC) and decrease the dorsal executive system activity (pathways including the temporal cortex and dorsal PFC)[14–16]. Furthermore, Chuah *et al.*[17] found that increased distraction by emotional stimuli following sleep deprivation was associated with increased activation of the amygdala and decreased functional connectivity between the amygdala and PFC.

These changes in brain function due to sleep deprivation also affect decision-making[18]. The Iowa Gambling Task (IGT)[19] is one of the tools used to assess the decision-making process. The IGT was developed to assess and quantify the decision-making impairments of neurological patients by simulating real-life decision-making. The score of IGT is known to reflect the functioning of the ventromedial PFC, which is associated with reversal learning[20].

An experimental study that used the IGT[19] to examine the effects of 49.5 hours of continuous wakefulness[21] found that, as the task progressed, sleep-deprived participants were more likely to choose high-risk, high-reward options—options that were ultimately less likely to be beneficial—suggesting that decision-making based on correct learning became more difficult under drowsy conditions. Another study that examined changes in brain function after 24 hours of continuous wakefulness using a roulette-like task[22] found that the activity of the nucleus accumbens when making a high-risk decision increased in the sleep deprivation condition. In contrast, the activity of the insula and orbitofrontal cortex in response to losses decreased, suggesting that sleep deprivation makes it difficult to learn emotionally from the outcomes of one's decisions and may contribute to the learning deficits described above.

The previous study using IGT[19] involved an extreme sleep-deprived condition (49 hours of continuous wakefulness). However, because changes in emotional responses can occur even with a more realistic length of continuous wakefulness, and sleep deprivation can induce an overreaction to weak stressors, decision-making may be significantly impaired when exposed to stressors less substantial following sleep loss. Thus, in this study, we attempted to determine whether continuous wakefulness for 21 hours causes a decrease in IGT performance and to examine the effect of the interaction between the presence of a weak emotional stressor and continuous wakefulness on the decision-making process.

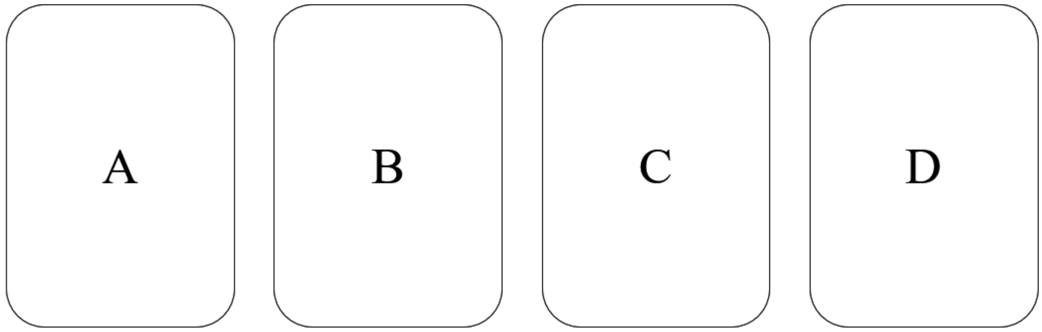
Subjects and Methods

Participants

Participants were recruited from the classes about psychology that the author oversaw. Students indicated their willingness to participate in the experiment through a questionnaire. They were also given the choice of participating in the daytime or the nighttime experiment. Forty people participated; two of the nighttime participants were excluded due to sleep habits. Thirty-eight healthy university students (Mean (M) = 20.9 years, range = 18–30 years, average (SD) = 1.93, 18 males) who signed a consent form participated in the experiment. At the end of the experiment, participants received an honorarium.

Experimental apparatus

Stimuli were presented by a personal computer and a TFT monitor (VG284QE, ASUSTeK Computer Inc., Taipei, Taiwan) connected to the computer. The responses were collected using a mouse. PsychoPy3[23] (Open Science Tools Ltd., Nottingham, England) was used to control stimulus presentation and record the responses.



	A	B	C	D
Gain per card	10,000 yen	10,000 yen	5,000 yen	5,000 yen
Loss and its probability	15,000 yen～35,000 yen（50%）	125,000 yen（10%）	5,000 yen（50%）	25,000 yen（10%）
Gain (or loss) when ten cards are drawn	－25,000 yen	－25,000 yen	25,000 yen	25,000 yen

Fig. 1. The properties of cards in each deck.
Decks A and B were the so-called bad decks, with large gains and losses and a greater chance of net loss.
Decks C and D were the so-called good decks, with small losses and gains and a greater chance of net gain. Bad decks were set to have lower wins than drawing cards from good decks.

Task

Emotional stressor task: This task was designed to provide participants with an emotional stressor. A dummy questionnaire was prepared as a personality test to predict the future of the participants. Question items in the Japanese version of the Eysenck Personality Questionnaire[24] were used, and participants were asked to rate the degree to which each question was valid for them on a 5-point scale. Immediately after the responses were made, a description as in the Japanese translation of the one used in the social exclusion procedure by Twenge, Baumeister, Tice, and Stucke[25] was presented as a test result. Participants who were placed in the future belonging condition (FB condition) were given positive feedback that they were the type who maintained fruitful relationships throughout their lives, and participants who were placed in the future alone condition (FA condition) were given negative feedback that they were the type who tended to live alone in old age. All participants received feedback uniformly according to the condition in which they were placed, regardless of how they answered the questions.

The IGT task: The IGT task used in this study was created using PsychoPy3, following the method of Bechara *et al*[19]. Four cards were displayed in the lower half of the monitor screen, and the current amount of money on hand and the loan amount were shown in the upper right corner. Four cards, from left to right, were from four decks A, B, C, and D, respectively. Fig. 1 shows the properties of the cards in each deck. Decks A and B were the so-called bad decks, where the amount of gain is large, but the amount of loss is also large, with a greater chance of net loss. On the other hand, decks C and D were the so-called good decks, where the amount of gain is small, but the amount of loss is also small, with a greater chance of net gain. In the long run, the final amount of money won by continuing to draw cards from bad decks is set to be lower than that won by continuing to draw cards from good decks.

At the beginning of the task, participants were instructed to borrow 200,000 yen from the experimenter and to increase the amount on hand as much as possible by selecting cards (we explained to the participants that this money would be used only in the game, and the amount of money gained in this game would not be reflected in the honorarium for their participation). Participants selected their favorite card from the four cards by clicking on it using the mouse. Once the card was chosen, the amount of money won by the card was displayed in green letters in the center of the screen, and the amount of money lost by the card was displayed in red letters. Participants were told that there were good and bad decks but were not told which was which. Participants were instructed to keep selecting cards

Table 1. Number of data and average age (SD) for each condition

		Sleep Deprivation		Daytime	
		FA	FB	FA	FB
Male	*N*	4	4	5	5
	Mean age (*SD*)	20.5 (1.29)	20.5 (1.73)	21.6 (0.55)	20.6 (0.89)
Female	*N*	6	4	5	5
	Mean age (*SD*)	22.0 (3.95)	19.0 (1.41)	21.0 (1.41)	21.0 (0.71)

until they were told to stop. The task was automatically terminated when the participant selected the 100th card.

Measurement of sleepiness

The Japanese translation of the Karolinska Sleepiness Scale (KSS-J)[26] was used to measure the participants' sleepiness. Participants were asked to circle the item that best described their sleepiness at the time of response from a list of nine items ranging from "extremely alert" to "very sleepy, great effort to keep alert, fighting sleep".

Procedure

The data in this study were collected after obtaining approval from the research ethics review committee of the author's institution. This study was divided into daytime and nighttime experiments, and both were conducted simultaneously with other experiments. Specifically, in the daytime experiment, a Stroop task (about 10 minutes) and a facial expression evaluation task (about 10 minutes) were conducted in addition to the experimental tasks—a visual search task (about 10 minutes), a facial expression recognition task (about 5 minutes), and a face Stroop task (about 20 minutes).

Participants were randomly assigned emotional stressors in each sleep condition. The number and mean age of the participants in each condition are shown in Table 1. Participants in the nighttime experiment were asked to record their sleep time for four days prior to the experiment on a sleep chart and wear the activity meter (MTN-220, ACOS Co., Ltd., Nagano, Japan) from the evening three days prior to the experiment. They were also asked to go to bed at 0:00 and wake up at 7:00 as far as possible in the three days before the experiment. They gathered at the laboratory at 22:00 on the day of the experiment and collected their activity meters; it was confirmed whether they had slept five to eight hours for three days before the experiment, and any discrepancies with the sleep chart were determined. Those who did not get five to eight hours of sleep or drank alcohol on the day before were excluded from the experiment. Additionally, participants in the sleep deprivation condition were prohibited from excessive physical activity, drinking alcohol, smoking, napping, and imbibing caffeine on the day of the experiment.

At 3:00, a series of tasks began, and the tasks related to the present study began at 4:30. Meanwhile, participants in the daytime experiment were asked to maintain their usual sleep habits before participating in the experiment. The daytime experiment was conducted for one hour between 10:00 and 18:30, and the tasks related to the present study were conducted in the last 30 minutes.

In both the daytime and nighttime experiments, the tasks related to this study were conducted in the following way: participants responded to the KSS, answered questions of the personality test that predicted their future as an emotional stressor, and were presented with feedback. Afterward, instructions were given on the IGT, and participants underwent four practice trials of the IGT before 100 actual trials and again responded to the KSS.

Statistical Analysis

Sleep variables before the experiment were subjected to a two-factor (2 x 2) between-subject analysis of variance: two sleep conditions (daytime and sleep deprivation conditions) × two emotional stressors (FA and FB conditions).

The KSS scores measured before and after the task was subjected to a three-factor (2 x 2 x 2) mixed analysis of variance: two sleep conditions (daytime and sleep deprivation conditions) × two emotional stressors (FA and FB conditions) × two time-points (before and after the task). The time factor was the only within-subjects factor.

The net score of the IGT task (the difference between the number of times the card was pulled from a good and a bad deck) was calculated by dividing the 100 trials into five blocks of 20 contiguous selections. A negative net score signified that more cards were pulled from bad decks than from good ones. By focusing on the trends in the net scores of the five blocks, we can examine the trends in the learning effect of pulling cards from good or bad decks.

The net scores were subjected to a three-factor mixed analysis of variance: two sleep deprivation conditions (day-

Table 2. Nocturnal sleep pattern before the experimental day

Emotional Stressor	Sleep Deprivation		Daytime	
	FA	FB	FA	FB
Bedtime	0.15 (0.76)	0.55 (0.39)	1.65 (1.94)	1.45 (2.03)
Wake-up time	8.13 (1.82)	7.65 (1.45)	8.35 (1.83)	8.40 (2.26)
Time in bed	7.98 (1.38)	7.10 (1.21)	6.70 (1.57)	6.65 (2.73)

time and sleep deprivation conditions) × two emotional stressors (FA and FB conditions) × five blocks (blocks 1–5). The block factor was the only within-subjects factor.

The final IGT scores were subjected to a two-factor between-subjects analysis of variance: two sleep conditions (daytime and sleep deprivation conditions) × two emotional stressors (FA and FB conditions).

Ethical Approval

The study methods conformed to the principles outlined by the Declaration of Helsinki and were approved by the research ethics review committee of the authors' institution.

Results

Nocturnal sleep pattern before the day of the experiment

Table 2 shows the participants' nocturnal sleep patterns before the day of the experiment. The values of the sleep deprivation condition were estimated with the data of the activity meter using SleepSign Act (KISSEI COMTEC Co., Ltd., Matsumoto, Nagano, Japan), and the values of the daytime condition were estimated with the data from the sleep log. The participants in the sleep deprivation condition went to bed and woke up later than the experimental instruction (i.e., 00:00–07:00). In the daytime condition group—those who maintained their usual sleep habits—the bedtime was around 01:30 and wake-up time was around 8:20. The main effect of sleep condition was significant in bedtime, which shows the delayed bedtime of the participants in daytime condition (F (1, 34) =5.946, p=0.02, η_p^2=0.18). There were no other significant main effects and interactions in the sleep variables (all p>0.10).

KSS scores before and after the task

It was found that the main effect of sleep condition was significant (F (1, 34) =19.823, p=0.0001, η_p^2=0.36) and that participants in the sleep deprivation condition (6.9) were significantly sleepier than those in the daytime condition (4.0). These results may reflect the validity of experimental manipulation of sleep conditions in this study.

In addition, the interaction between sleep condition and emotional stressors was significant (F (1, 34) =5.266, p=0.0280, η_p^2=0.13). A simple main effect test revealed a significant difference in the emotional stressor in the daytime condition (F (1, 34) =4.924, p=0.0333, η_p^2=0.12), indicating that participants in the FB condition were significantly sleepier than those in the FA condition.

In addition, the main effect of time was significant (F (1, 34) =3.297, p=0.0782, η_p^2=0.09), indicating that participants tended to be sleepier before the task than after it.

The interaction between emotional stress and time also tended to be significant (F (1, 34) =3.297, p=0.0782, η_p^2=0.09), and a simple primary effect test revealed a significant difference in time in the FB condition (F (1, 34) =6.595, p=0.0148, η_p^2=0.16), indicating that participants in the FB condition were significantly sleepier before the task than after it.

Net score of the IGT task

It was found that the main effect of the block factor was significant (F (1, 34) =5.078, p=0.0008, η_p^2=0.13), and that blocks 5 (2.3), 4 (2.9), and 3 (1.0) had significantly higher net scores than block 1 (−2.7), and that the values for blocks 5 and 4 were significantly higher than those for block 2 (−1.9).

In addition, the interaction of the three factors tended to be significant (F (1, 136) =2.284, p=0.0635, η_p^2=0.06), and the analysis of the simple interaction showed that the simple interaction between emotional stressors and blocks was significant in the sleep deprivation condition (F (4, 136) =2.590, p=0.0395, η_p^2=0.07). Furthermore, a simple main effect test for the sleep deprivation condition revealed a significant difference between the two emotional stressors only in block 5 (F (1, 170) =5.090, p=0.0253, η_p^2=0.03), indicating that the net score in the FA condition (−4.2) was

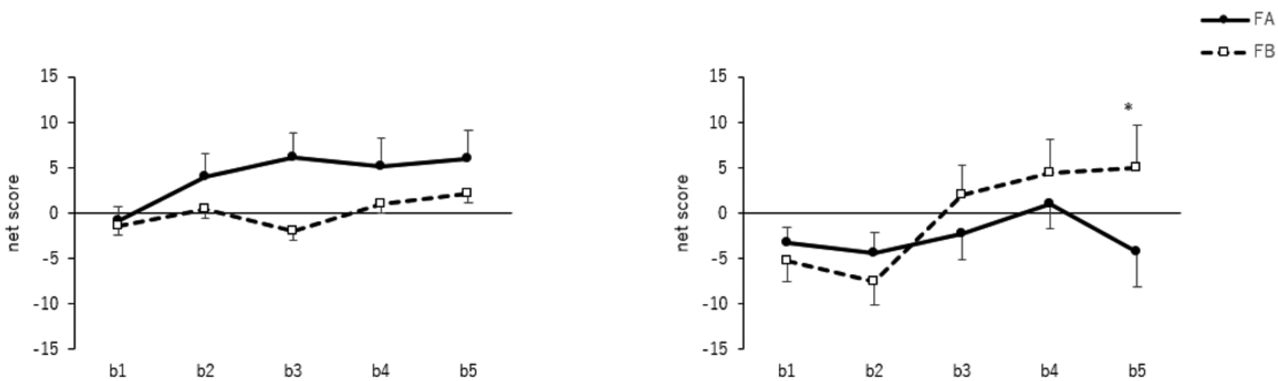


Fig. 2. IGT net score of each block for each emotional stress condition.
The IGT net score of each block for each emotional stress condition; daytime condition is on the left and sleep deprivation condition on the right. In the sleep deprivation condition, the test revealed a significant difference between the two emotional stressors only in block 5 (F (1, 170) =5.090, p=0.0253, ηp^2=0.03), indicating that the net score in the FA condition (−4.2) was significantly lower than that in the FB condition (5.0).

significantly lower than that in the FB condition (5.0) (as shown in Fig. 2).

The final IGT score

The final IGT scores (final amount earned) were subjected to a two-factor between-subjects analysis of variance: two sleep conditions (daytime and sleep deprivation conditions) × two emotional stressors (FA and FB conditions). The results showed that neither the main effect nor the interaction was significant (Fs (1, 34) < 1.447, *ns.*).

Discussion

This study examined the effects of continuous wakefulness for 21 hours and the interaction between the presence of a weak emotional stressor and 21 hours of continuous wakefulness on the decision-making process, as measured by the IGT. Although no effect of these factors on the final amount of money earned on the IGT was observed, the main effect of block and the interaction between sleep conditions and emotional stressors were found when the net IGT score, which is a measure of whether the subject can make rational, learning-based decisions, was used as the dependent variable. Specifically, the main effect of the IGT block was observed, and the results of subsequent multiple comparisons showed that the net score improved in later blocks compared to earlier blocks. This trend in net scores was similar to that observed in the learning process of control groups (that is, participants in the normal sleep condition and typical healthy adults) in previous studies[19, 21)], suggesting that the participants in this study, as a whole, exhibited appropriate learning progress from the decision-making and feedback for each trial, which allowed them to make rational, learning-based decisions in the following half of the task.

On the other hand, no main effect of sleep condition on the net IGT score was found, even though subjective sleepiness was significantly higher in the sleep deprivation condition than in the daytime condition. Considering that 49.5 hours of continuous wakefulness has been shown to lead to irrational decision-making in the IGT[21)], it is notable that 21 hours of continuous wakefulness did not impair the decision-making process in the IGT by itself, although it did increase subjective sleepiness.

In research using the social exclusion procedure, experimental manipulation of an emotional stressor, as in the present study, was reported to increase aggression[25)] and decrease performance on an IQ test and the Graduate Record Examination[27)] in the group presented with the emotional stressor (that is, FA condition). Additionally, studies have shown that IGT performance is reduced when IGT is performed under speech stress[28, 29)]. However, in the present study, the main effect of the presence of the stressor through the social exclusion procedure on IGT performance was not found. This difference may be due to the characteristic of the cognitive task as the dependent variable and differences in the procedures used to inflict emotional stress on participants. It is possible that the intensity of the emotional stress caused by the procedure used in the present study was weaker than in previous studies, and its effect was not as profound to impair the learning process of the participants as measured by the IGT. However, the social exclusion procedure used in this study is a commonly used procedure in the field of social psychology[30]. In a meta-analysis of the relationship between social exclusion procedures and emotional responses[31], it was found that compared to the effect size on emotions of a group exclusion procedure such as the Cyberball task, the effect size on emotions of a procedure that anticipates future exclusion was small but significant. As mentioned earlier, the purpose of this study is to explore the interaction effects between "weak" stressors and the realistic length of sleep deprivation. Hence, we adopted the social exclusion procedure for this experiment. However, other types of stress-induced procedures, for example, the Cyberball task and speech stress task, which can induce severe social stress, should be used to explain further the interaction between social stress and sleep problems in cognitive functions.

However, in the sleep deprivation condition in the present study, the FA group, which was exposed to the emotional stressor, had a higher rate of choosing cards from bad decks in the final block of the IGT compared to the FB group, which was not exposed to the stressor. This result may suggest that exposure to emotional stressors during sleep deprivation may have prevented appropriate learning. This decrease in the net IGT score in the later blocks was similar to that observed in a study of subjects with 49.5 hours of continuous wakefulness[21], and the results of the present study suggest that even 21 hours of continuous wakefulness, which can occur in daily life, can cause cognitive deficits comparable to those of participants who had been awake for more than two full days when exposed to emotional stress.

It has been found that sleep deprivation weakens the functional connectivity between the amygdala and the medial PFC[10, 12]. The presentation of emotional stimuli activates the ventromedial PFC, which reduces the activity of the dorsolateral PFC, and IGT performance reflects the function of the ventromedial PFC[19]. Based on these findings, it may be inferred that, in the present study, although the brain function was not measured during the task, the participants exposed to the stressor during sleep deprivation suffered from overactivity of the amygdala, which caused higher cognitive dysfunction in the PFC.

However, the results of the KSS score did not necessarily support this interpretation of the mechanism of the interaction on IGT performance. Reported sleepiness was higher in FA group than FB group in the daytime condition, suggesting the alerting effects of the social stressor. If extended wakefulness increased the effects of the stressor, the difference in sleepiness between the FA and FB groups would be prominent in the sleep deprivation condition. However, the results of this study showed that the difference between the FA and FB groups was diminished in the sleep deprivation condition and partly suggested the decreased effects of the social stressor in extended wakefulness. One of the possible reasons for this is blunted affective reactions to feedback accompanying sleep deprivation[32]. In this study, the participants were given stressors through feedback on a personality test. It is possible that the effects of stressful feedback may not have worked well for the sleepy participants. Even though the effects of stress were not pronounced in the sleep deprivation condition, the process of learning, as measured by the IGT, was impaired by the combination of sleepiness and social stressors. It is possible that sleep deprivation makes the decision-making function vulnerable against a weak stressor even if the stress was not recognized by sleepy participants. In order to clarify the mechanism of the interaction (sleep deprivation x social stress) on IGT scores, it is necessary to examine the relationship between the assessed stress level, as a manipulation check of the stress condition, and IGT scores in each group of sleep condition.

One limitation of this study is the adoption of a between-group design. This design was adopted so that learning in the IGT would not affect the results, but this may be why the subjective sleepiness of the FB group was higher than that of the FA group in the daytime condition. Additionally, there was no randomization; the participants' self-selected the group assignment for sleep condition. Therefore, it is possible that the participants who were less sensitive to sleep deprivation participated in the sleep deprivation condition. This might have decreased the effects of sleep deprivation on IGT performance. Furthermore, since it is difficult to deny between-group differences in learning abilities and personality traits, such as neuroticism, conscientiousness, and sensation seeking, which have been reported to be associated with the evening chronotype[33–35], future research will require an examination based on a within-subjects design by devising tasks to control the effects of repetitive tasks on learning outcomes.

Another limitation is the insufficient control of sleep and experimental study schedule in the daytime condition. Participants in the daytime condition were instructed to maintain their usual sleep habits, while those in the sleep deprivation condition were instructed to have sleep from 00:00 to 07:00 as well as possible. The results from sleep logs of the daytime condition group show that their bedtimes were around 01:30, which is significantly later than that of the sleep deprivation condition group (around 0:20). In addition, the time in bed of the daytime condition group was less than seven hours, while there are no significant differences compared to that of the sleep deprivation condition group. This sleep pattern in the daytime condition group is considered to be similar to the average pattern of Japanese university students[36, 37]. However, their sleep time may be insufficient compared to the guideline of the National Sleep Foundation, which recommends 7–9 h of sleep for young adults aged 18–25 years old[38]. In addition, the time of day of the experiment was not consistent in the daytime condition. This insufficient control of the experimental schedule may have caused circadian effects on cognitive performance. The insufficient control of sleep and task schedule may have caused a decline in cognitive performance among the daytime condition group (i.e., control condition), resulting in undermining the effects of manipulated sleep deprivation.

In addition, for the comparison in the results of decision-making performance between the results of the present study and that of Killgore *et al.* (2006)[21], which showed a decline of the performance in sleep-deprived participants using IGT, we used the original IGT. However, Lin's[39–41] group, in a series of studies, showed that even healthy people were unable to suppress the Deck B selection process, which ultimately lead to poor outcomes (the prominent Deck B phenomenon). As the IGT used in this study was originally proposed by Bechara *et al.*[19], the results of this study may also be affected by "the prominent Deck B phenomenon", and it may be preferable to use a modified version of the IGT[42].

The results of the present study show that the combination of a weak emotional stressor and sleep deprivation, which may occur in everyday work life, at a certain level can disrupt appropriate decision-making based on learning. Since situations that require extended wakefulness, such as overextended working hours or emergencies, can be stressful, the results of this study suggest that it is important to be cautious about the possibility of irrational decision-making in such situations.

Acknowledgements and Declarations

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Disclosure Statement of Conflicts Related to Financial Arrangements

This research is not an industry-supported study. The Sleep Research Institute of Edogawa University and Paramount Bed Holdings Co., Ltd. conducted a collaborative research project on this subject, but it has a different objective from that of this study. Thus, there is no known conflict of interest associated with this publication, and there has been no significant financial support extended for this work that could have influenced its outcome.

Disclosure of Non-financial Interests

None.

Author Contribution

RN, KM, and SA designed the study. KM and MK collected the data. KM and RN analyzed the data. RN and SA wrote the paper.

Data Availability Statement

The data are not publicly available due to privacy and ethical restrictions.

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