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Original Article

Counteracting effect of verbal ratings of sleepiness on dual task interference

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Abstract: The aim of the present study was to demonstrate the effect of verbal ratings on arousal in the electroencephalogram (EEG) and psychomotor vigilance test (PVT) performance. Thirty participants underwent the PVT for 40 min in three experimental conditions: (1) Rating condition, in which they verbally rated subjective sleepiness with Karolinska sleepiness scale, following pure tone sound played every 20 s during PVT, (2) No-rating condition, in which they underwent PVT with the similar sound as the Rating experiment but without the verbal rating task, and (3) Control condition, in which they underwent PVT with a no-sound stimulus and without the verbal rating task. The results show that during the first half of the task epoch, alpha power density was lower in the Rating than in the No-rating condition, while performance was not different between the conditions. During the second half of the task epoch, performance was better in the Non-rating than in the Rating condition, but no difference in the alpha power density. These results suggest that performance deterioration could be masked by the arousal effect of the dual task itself. It could also explain why the PVT performance and arousal in EEG sometimes dissociate, particularly in dual task situations.

Key words: Arousal, Verbal rating, Dual task interference, Attentional resources

Introduction

It is known that performance in a dual task is worse than that in a single task. This phenomenon is called dual task interference[1)]. In a classical experiment, Ninio and Kahneman reported that reaction time to animal names is prolonged by more than 100 ms in a dual task (listening to sounds in both ears) compared to that in a single task (listening to sounds in only one ear)[2)]. Dual task interference is not only examined in laboratory conditions[2, 3)] but also observed in real-life settings[4–8)]. Some studies demonstrated that the use of a mobile phone during driving prolonged the time required to initiate braking by 560 ms[9)] and increased the number of lapses in detecting a traffic signal change[5)], suggesting that dual task interference is an important factor to be considered for preventing accidents.

In the capacity sharing theory[10, 11)], single[10)] or multiple[11)] "attentional resources" (or mental resources) are assumed for executing tasks. The available attentional resources are also assumed to positively correlate with task performance and physiological arousal. When executing multiple tasks at the same time, the attentional resources are shared among the tasks and those available for each

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task are consequently reduced, which would cause deterioration in performance (dual task interference)[1, 10]. Amount of attentional resources, however, are believed to increase when physiological arousal increases. This means that the higher the arousal level is, the more attentional resources are available for executing the tasks[10]. If this assumption is correct, dual task interference would be alleviated or completely concealed (masked) by the arousal increment.

In fact, some studies have reported performance *improvement* instead of deterioration in a dual task. Oron-Gilad reported that playing trivia quizzes during driving stabilized steering wheel fluctuation[7]. Atchley *et al.* also reported that answering quiz questions during driving reduced lateral fluctuations in a running car[8]. They suspected that the increased arousal in the secondary task could improve the performance of the primary task. Oron-Gilad called the secondary task that causes performance improvement "alertness maintaining task"[7].

The alertness maintaining effect of the secondary task is consistent with the capacity sharing theory because the arousal increment due to the dual task could compensate for performance deterioration (dual task interference). For example, Schwarz *et al.* reported that listening to the radio (a secondary task) while driving a car increased physiological arousal measured by blink duration but did not change the driving performance (a primary task)[12]. Kaida *et al.* also reported that verbal ratings of sleepiness (a secondary task) during the Mackworth clock test (a primary task) increased the arousal measured by electroencephalography (EEG) but did not affect the performance (the number of attentional lapses)[3]. This line of study should be considered further because it is important to understand the theoretical background of dissociation between performance and physiological indicators of sleepiness.

The aim of the present study was to validate the previous study findings[3] using a more sensitive performance task, which is important to detect the compensatory effect of dual task on performance. For the tasks in the present study, we employed the visual psychomotor vigilance test (PVT) as the primary task and frequent verbal ratings as the secondary task (alertness maintenance task). PVT is a validated and a highly sensitive test for evaluating arousal in behavior, frequently used in studies that examine sleep deprivation and sleepiness[13–16]. We hypothesized that the dual task interference on the performance would be compensated or masked by the alerting effect of the verbal ratings.

Methods

Participants and design

The participants were 30 healthy, native Japanese speakers aged 20–34 yr (mean: 22.1; standard deviation (SD): 2.21; 13 women and 17 men). All participants met the following criteria: (1) a normal sleep-wake cycle, classified as intermediate type by the Morningness–Eveningness (ME) questionnaire[17, 18], (2) no experience of shift work in the 3 months prior to the experiment, (3) no travel to a different time zone in the 3 months prior to the experiment, (4) no use of medication, (5) no use of tobacco products, and (6) a body mass index (BMI) less than 25 (calculated as weight in kilograms divided by the square of the height in meters). The scores were as follows − ME: 51.2 (SD=8.93); and BMI: 20.9 (SD=2.63) kg/m^2. They reported sleeping for 461.0 (SD=80.92) min on the night before the experiment. Participants were paid for taking part in the study.

Participants arrived at the laboratory at 12:30 and received a full explanation of the procedure. Then, they signed an informed consent document. We confirmed that all the participants had eaten lunch before arriving at the laboratory. The experiment began at 13:30 after attaching the electroencephalogram (EEG) and electrooculogram (EOG) electrodes and conducting a practice of performing the task. We followed the protocol described in our previous study[19]. Figure 1 shows the time schedule of the experiment.

Participants took part in the following three experimental conditions in the sound-attenuated experimental room (within-participants design): (1) the rating condition ("Rating"), (2) the no-rating condition ("No-rating"), and (3) the no-sound control condition ("Cont"). In the "Rating" condition, participants evaluated their current sleepiness using the 9-point scale Karolinska Sleepiness Scale (KSS) following a pure tone (duration: 1,000 ms, sound pressure level: 70 dB) presented every 20 s, and they verbally reported the scores to the experimenter through an interphone. In this setting, participants did not have any verbal communication with the experimenter for reporting the scores, as the reporting was prompted by pure tone. Participants reported their sleepiness level in a few seconds. The scores were booked by the experimenter sitting outside of the experimental room. In the No-rating condition, the pure tone was played every 20 s during the stimuli epochs but with no rating task to perform. In the Cont condition, no stimuli were presented during the 40-min task and participants did not rate their sleepiness but

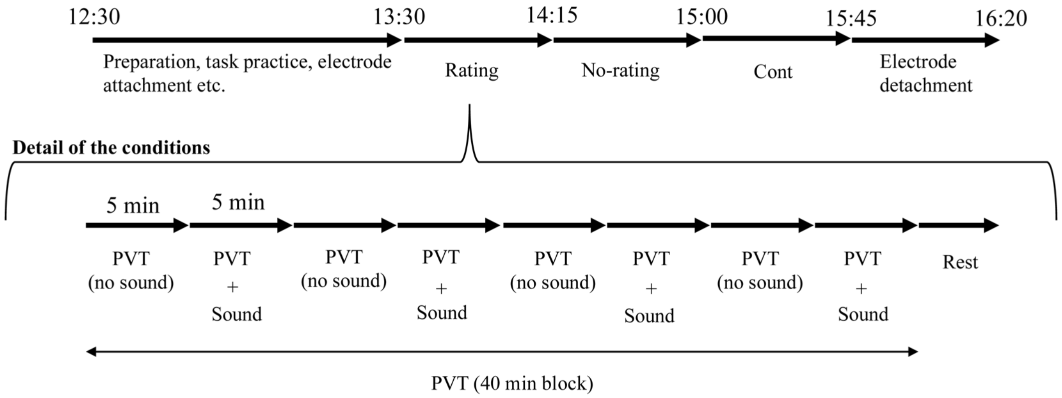

Fig. 1. Time schedule of the experiment.

No-rating: no-rating condition, Rating: rating condition, Con: no-sound control condition (no sound and rating). The order of the conditions was counterbalanced among the participants. KSS: Karolinska Sleepiness Scale, PVT: Psychomotor Vigilance Test. Visual stimuli for PVT were presented with random inter-stimulus intervals from 2–10 s, while a sound was presented every 20 s in the stimuli epochs. No sound was presented and no rating was assigned throughout the test epochs in the Cont condition. The order of the conditions was counterbalanced among the participants.

executed the PVT. The order of the 40-min blocks of the three conditions were counterbalanced among the participants, in which 6 different patterns (3*2 patterns) were allocated to 30 participants.

In each block in the Rating and No-rating conditions, participants underwent the visual PVT[16)] without any auditory sound for 5 min in the “PVT” (No sound epoch; Fig. 1), followed by the “PVT + sound” (Sound epoch) in which participants continued with the PVT while hearing the pure tones for 5 min, and the identical procedure was conducted 3 times (40 min for each block). We inserted the 5 min no sound epochs to reduce habituation effect to tones and verbal ratings. We set the epoch as 5 min based on previous studies[19, 20)]. No auditory stimuli were presented in the Cont condition and participants continued with the PVT in silence for 40 min. In summary, the No-sound epoch in the Rating and No-rating conditions, and the Sound and No-sound epochs in the Cont condition were the same. They took short breaks after the 40 min blocks if they found it necessary.

Participants underwent three test blocks and met with all the experimental conditions, which took them approximately 120 min. The inter-stimulus interval between the PVT visual stimulus and the sound was not controlled (PVT visual stimuli were presented at random, ranging from 2–10 s while sounds were presented exactly every 20 s).

Ethical considerations regarding the experimental protocol were reviewed and approved by the ethical review board of the National Institute of Advanced Industrial Science and Technology (AIST), Japan, based on the principles stated in the Declaration of Helsinki.

Psychomotor Vigilance Test (PVT)

The PVT uses a visual reaction time paradigm with inter-stimulus intervals ranging from 2 to 10 s[16)]. Participants were instructed to monitor a red square shown in the device display and press a response button on the device as soon as a red number counting down by milliseconds appeared within the square. The count-down stopped when the participants responded, and the reaction time in milliseconds was displayed for 1 s as feedback to the participant. Responses within 100 ms received warning signals (FS; false start) for 1 s. The FSs were treated as timeout trials, which continued in the next trial. Eighteen participants underwent the PVT programmed using E-prime version 1.2 (Psychology Software Tools, Inc.). Twelve participants underwent the PVT with the commercial device PVT-192 (Ambulatory Monitoring, Inc., Ardsley, NY, USA).

The mean of the reciprocal reaction times (RRT) and the number of lapses, i.e., responses in exceeding 500 ms in the PVT, were calculated as performance indices, following the standard manner[13, 16)]. The indices were calculated for every 5 min session. There are several indices calculated from PVT reaction time, but RRT and lapses are known as the most sensitive ones for detecting sleep deprivation and sleepiness[16)]. Data with standard deviation of 2.5 or higher (standard deviations of all the RT data on each individual in the three conditions) than the mean were omitted when calculating the RRT.

Electroencephalogram (EEG)

Electrodes were attached at the Cz scalp site for EEG referenced to the linked electrodes at the earlobes, and outside both canthi for EOG. We selected the Cz site because alpha and theta power densities in the Cz correlate with PVT performance and subjective sleepiness[21, 22]. We used the EEG variables as an index of arousal because alpha power density has been known to correlate with subjective sleepiness[21, 23]. The sampling rate was 1,000 Hz (24-bit AD conversion), and the time constants were 0.3 s for the EEG and 3.2 s for the EOG. The electrode impedance was maintained below 5 kΩ. The low-pass filter was set at 30 Hz. Electrophysiological data were recorded with a portable digital recorder (PolymateV AP5148, Digitex Laboratory Co., Ltd., Japan).

Alpha (8.0–12.0 Hz), theta (4.0–7.9 Hz) and total (alpha + theta) power spectra during PVT were calculated using fast Fourier transformation (FFT; frequency resolution: 0.97 Hz) with a Hamming window. FFT was conducted using the data of each stimulus epoch (5–10, 15–20, 25–30, and 35–40 min epochs from the start). The analysis was conducted with the commercial software CSA Sleep Analysis, version 1.16 (NoruPro Light Systems, Inc., Japan). FFT was applied to overlapping (by 0.024 s) EEG segments of 1.024 s and was subsequently averaged for one 300 s epoch. Artifacts in the EEG were removed using high-pass (0.5 Hz) and low-pass (30 Hz) digital filters.

Rated sleepiness

The 9-point KSS[21, 24] was used to rate sleepiness. The participants rated their degree of sleepiness on a scale that included 1 (very alert), 3 (alert), 5 (neither alert nor sleepy), 7 (sleepy, but not fighting sleep), and 9 (very sleepy, fighting sleep) and also in-between even scores (2, 4, 6 and 8) which do not have score descriptions. The ratings (immediately after the tone) were conducted 15 times in each sound epoch in the "Rating" condition.

Statistical analysis

A repeated measures analysis of variance (ANOVA) was conducted with data on "Condition" (Rating, No-rating and Cont) × "Time" (four epochs). The epochs that were inserted between the sound presentation epochs were analyzed separately to avoid complications. Subjective sleepiness and alpha power density in the Rating condition was averaged by the epoch and analyzed by one-way ANOVA (elapsed time). Degrees of freedom greater than 1 were reduced by the Huynh-Feldt ε correction to control the Type 1 error associated with the violation of sphericity assumption. Post-hoc analyses were performed by paired t-tests.

Correlation analyses were performed among PVT reaction time, KSS scores and EEG power densities using the data in the Rating epochs in the Rating condition. Following the previous study[21, 24], the correlation coefficients were calculated for each individual and averaged for the sample which was used for one-sample t-test. All statistical analyses were performed using the SPSS system for Mac, version 25.0. Significance level was set at $p<0.05$.

Results

The results of ANOVA are summarized in Supplementary Table 1. Only the statistically significant results are explained below.

Psychomotor vigilance test (PVT)

Reciprocal reaction time (RRT)

For RRT in Sound epoch, performance was better (shorter RT) during the No-rating than during the Rating condition. The main effects of "Condition" ($F(2, 58)=5.04$, $p<0.01$) and "Time" ($F(3, 87)=11.23$, $p<0.01$) were significant in the Sound epochs (Fig. 2, right). The RRT was larger in the Rating than in the No-rating ($t(29)=4.06$, $p<0.01$) and Cont ($t(29)=2.48$, $p<0.05$) conditions in Epoch 4. There were no significant main effect and interaction in ANOVA in the No-sound epoch (Fig. 2, left).

Lapses

The number of lapses (> 500 ms) was higher in the Rating than in the No-rating condition (Fig. 3, right). For the number of lapses, the main effects of "Condition" ($F(2, 58)=6.43$, $p<0.01$) and "Time" ($F(3, 87)=15.60$, $p<0.01$) were significant in the Sound epochs (Fig. 3, right). The number of lapses was larger in the Rating condition than the No-rating condition in Epoch 4 ($t(29)=4.53$, $p<0.01$).

The main effects of "Time" ($F(3, 87)=21.92$, $p<0.01$)

Table 1. Correlation coefficients

	Lapse	Alpha	Theta	KSS
RRT	**–0.72 (0.34)**	**–0.40 (0.54)**	–0.16 (0.62)	**–0.56 (0.52)**
Lapse		**0.45 (0.52)**	0.20 (0.68)	**0.51 (0.52)**
Alpha			**0.47 (0.60)**	**0.59 (0.54)**
Theta				**0.33 (0.66)**

RRT: reciprocal reaction time, KSS: Karolinska Sleepiness Scale. Bold type indicates statistical significance at $p<0.05$. Standard deviations are shown in parentheses.

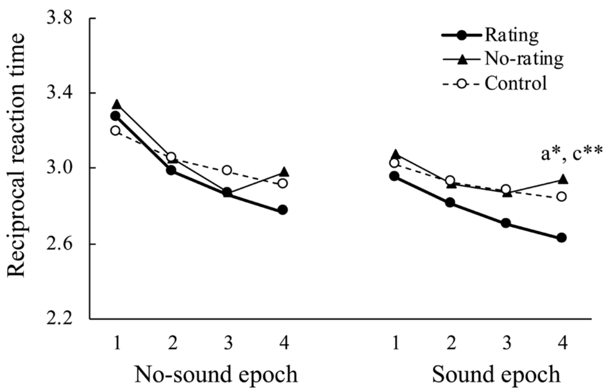

Fig. 2. Reciprocal reaction time in psychomotor vigilance test.
No-rating: no-rating condition; Rating: rating condition.
a: Rating vs. Control, b: No-rating vs. Control, c: Rating vs. Non-rating.
**$p<0.01$, *$p<0.025$.

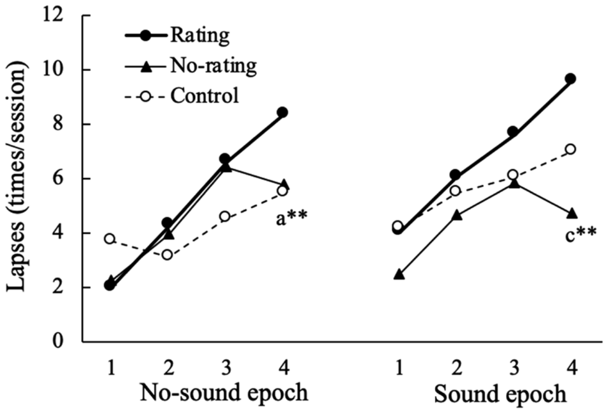

Fig. 3. Number of lapses (>500 ms) in psychomotor vigilance test
No-rating: no-rating condition; Rating: rating condition.
a: Rating vs. Control, b: No-rating vs. Control, c: Rating vs. Non-rating.
**$p<0.01$.

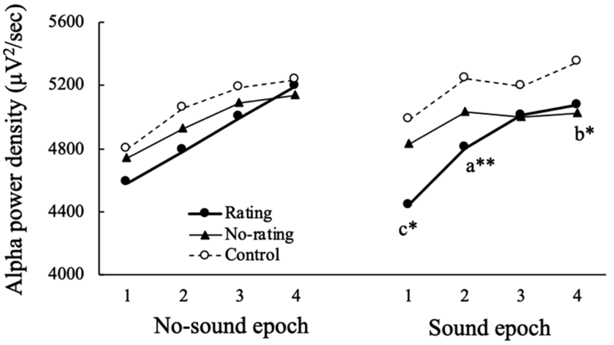

Fig. 4. Alpha power density.
No-rating: no-rating condition, Rating: rating condition.
a: Rating vs. Control, b: No-rating vs. Control, c: Rating vs. Non-rating.
**$p<0.01$, *$p<0.05$.

and the interaction between "Condition" and "Time" ($F(6, 174)=2.85$, $p<0.05$) were significant in the No-Sound epochs (Fig. 3, left). The number of lapses was larger in the Rating condition than the Cont condition ($t(29)=2.84$, $p<0.05$) in Epoch 4.

Spectral power density of EEG

Alpha power

In Sound epoch, alpha power density was significantly smaller in the Rating than in the No-rating condition (Fig. 4, right). For alpha power density, the main effects of "Condition" ($F(2, 58)=5.26$, $p<0.05$) and "Time" ($F(3, 87)=29.05$, $p<0.01$) and interaction between "Condition" and "Time" ($F(6, 174)=2.55$, $p<0.05$) were significant in the Sound epochs (Fig. 4, right).

In the Epoch 1, the alpha power density was significantly smaller in the Rating condition than in the No-rating condition ($t(29)=2.53$, $p<0.05$). In the Epoch 2, the alpha power was significantly smaller in the Rating condition than in the Cont condition ($t(29)=2.95$, $p<0.01$). In Epoch 4, the alpha power was significantly smaller in the No-rating condition than in the Cont condition ($t(29)=2.57$, $p<0.05$). Only the main effect of "Time" was significant in the No-sound epochs ($F(3, 87)=26.18$, $p<0.01$; Fig. 4, left).

Theta and total power densities did not show any main effect of "Time" and interaction between "Condition" and "Time" as shown in Supplementary Table 1.

Subjective ratings and alpha power density

The subjective sleepiness during the task increased as time elapsed, as shown in Fig. 5. For KSS scores during the task in the "Rating" condition, the effect of "Time" in one-way ANOVA was significant ($F(3, 87)=28.45$, $p<0.01$). Subjective sleepiness significantly increased from Epoch 1 to 2 ($t(29)=5.56$, $p<0.01$), from Epoch 2 to 3 ($t(29)=2.12$, $p<0.05$), and from Epoch 3 and 4 ($t(29)=2.43$, $p<0.05$).

The alpha power density during the task increased as time elapsed ($F(3, 87)=21.69$, $p<0.01$) as shown in Fig. 5 (gray bars). Alpha power density significantly increased from Epoch 1 to 2 ($t(29)=4.29$, $p<0.01$) and from Epoch 2 to 3 ($t(29)=3.34$, $p<0.01$), while no significant increase was found from Epoch 3 to 4 ($t(29)=0.97$, $p=0.34$).

Correlation analysis

Two out of 30 participants were excluded from the correlation analysis because they did not show any change in KSS scores between epochs. Correlation coefficient be-

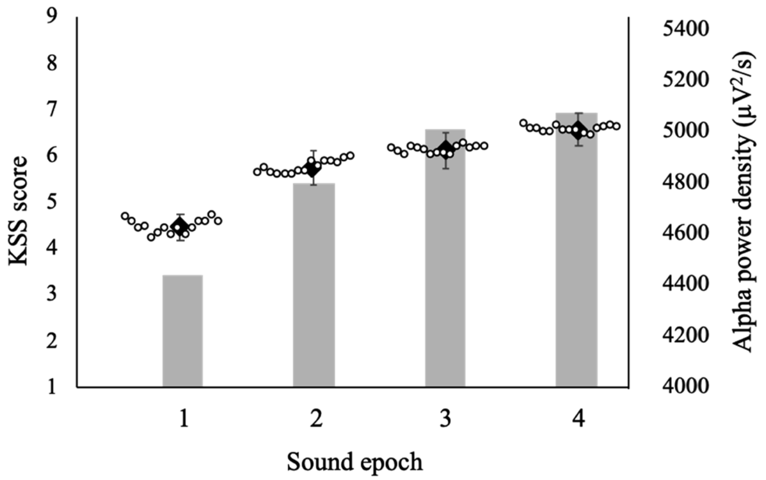

Fig. 5. Subjective sleepiness and alpha power density in the Rating condition.
KSS: Karolinska Sleepiness Scale. Circular dots denote the scores rated every 20 s. Diamond dots denote the average score in each epoch. Gray bars indicate absolute alpha power densities in the rating epochs in the Rating condition.

tween alpha power density and KSS was *r*=0.59 (*SD*=0.54), other correlations among performance, EEG and KSS in the rating epochs in the Rating condition are shown in Table 1.

Discussion

The most important finding in the present study was the dissociation between EEG arousal and performances in PVT. As our results demonstrate, alpha power density was significantly lower in the Rating than in the No-rating condition in Epoch 1, while performance (RRT and number of lapses) was not different among the conditions of the same epoch. Dissociation was not observed in the No-sound epoch but only in the Sound epoch. We believe that the dissociation between the conditions in Sound epoch is caused by dual task interference and arousal increment due to verbal ratings in the "Rating" condition.

Dissociation between EEG arousal and performance could be explained by the capacity sharing theory[10)], which states that attentional resources reduced by dual task are compensated by the arousal triggered by the stimuli that maintains alertness (frequent verbal ratings of sleepiness in the present study). The data of the present study support this assumption; performance difference was not observed in the No-sound epoch but only in the Sound epoch in the Rating condition. According to a previous study, however, EEG arousal and PVT performance are supposed to change in a similar way[21)]. Considering that, the dual task interference is counteracted (or masked) by performance improvement as a result of increased physiological arousal (attentional resources) by the dual task, by which our hypothesis was supported.

The capacity sharing theory also explains why some previous studies reported not deteriorating but improving the effect of dual task on performance. The important rationale behind the theory is that the alertness maintaining effect can occur in dual task when the arousal increase due to the secondary task is strong enough to overcome the dual task interference. For this purpose, stimuli that evoke physiological arousal should be used as the secondary task. For example, in the study by Oron-Gilad *et al.*, intriguing trivia quizzes were used as the secondary task during driving, and it was found that the quizzes evoked physiological arousal measured in terms of heart rate variability. Self-relevant information, such as the participant's name, is the other option. It is reported that merely listening to one's own name increases arousal and improves performance more than listening to another person's name[20)] or pure tone[19)] (information less relevant) does. The arousal effect in these name stimuli experiments, however, did not last more than 20 min, probably because of repeated presentations that might have caused habituation[19, 20)]. To investigate the stimuli that counteract dual task interference but hardly cause habituation should be an interesting topic. In addition, the mechanism of the habituation is itself, an interesting topic for future studies.

While the dissociation between performance and EEG arousal in a dual task condition was found in the present study, that between performance and subjective sleepiness is still unknown. If there is no dissociation between subjective sleepiness and performance, subjective sleepiness could be a better predictor of performance than EEG indicators. Supporting this assumption, the correlation coefficient was larger between KSS and RRT (r=−0.56) than between alpha power and RRT (r=−0.40). The results were almost the same as a previous study[21)], in which correlations between KSS and RT (r=0.57) was larger than between alpha power and RT (r=0.40).

While the overall protocol of the present study is in line with the previous study[3)] that used the Mackworth clock test as a primary task to test the counteracting effect of dual task on its interference, a few differences from the previous studies can be pointed out. The most notable difference is in the frequency of ratings. In the present study, sleepiness was rated more frequently (every 20 s) than the previous study (every 4 min). The frequent ratings might cause habituation to maintaining the alertness. If the habituation to verbal ratings occurs, arousal level will be reduced. In fact, the increased EEG arousal in the Rating condition in the first epoch returned to the same level as the No-rating condition in the last epoch. It suggests that the counteracting effect of arousal on the dual task interference would disappear along with the disappearance of the compensatory effect of arousal, or attentional resources, on performance. Supporting this assumption, PVT performances were significantly worse in the last epoch in the Rating than in the No-rating condition (Fig. 2, right). We assume that the significantly higher arousal level in the first epoch due to the verbal ratings in the Rating condition got lowered along with the repetition of the ratings (habituation) and thus the counteracting effect of arousal on performance in the Rating condition eventually disappeared in the last epoch.

Another difference from the previous study[3)] is the setting of verbal communication with experimenter during dual task. In the present study, participants did not communicate with the experimenter but presented their sleepiness orally, prompted by the pure tone, which had no verbal meaning. On the other hand, in the previous study, participants briefly talked with experimenter to rate sleepiness, which could not clarify whether the counteracting effect was due to communication, verbal ratings, or both. The sleepiness rating method in the present study allows us to assume that even speaking without interpersonal communication during a task can have a counteracting effect on dual task interference. Similar findings have been reported in a driving-simulator study[8)]. We demonstrated that verbal ratings without communication works as an alertness maintaining task. Tasks with communication such as in playing quizzes could exert stronger alerting effect[7, 8)]. The effect of communication on the dissociation among performance, physiological arousal and subjective sleepiness could be an interesting topic for future study.

In the present study, we largely refer to the capacity sharing theory to discuss the counteracting effect of verbal ratings on dual task interference. Apart from it, bottleneck models[25)] could be another way to explain the counteracting effect because the bottleneck in information processing could be widened by arousal, which also would improve performance. We are, however, hesitant to discuss the potential of bottleneck process with our results because the timing of stimuli in PVT (S1) and sound for verbal ratings (S2) were not controlled. Stimulus onset asynchrony between S1 and S2 should be exactly controlled for examining the bottleneck process[26)]. Also, we cannot discuss our results referring to the cross-talk models[27)] because the secondary task in the experiment was not controlled to detect cross-talk with the primary task. Regarding the mechanism of dual task interference, task switching is one possibility that can explain the interference. In the present study, pure tones for rating and visual stimuli for PVT did not overlap most of the time. Therefore, dual task interference can be explained by the requirement of additional attentional resources while preparing for task switching in the Rating condition. The detailed mechanism underlying the counteracting effect of arousal on the dual task interference should be scrutinized in future studies.

Finally, in the present study, we could not evaluate whether the visual stimuli in PVT increased arousal or not. The combination of stimuli in both primary and secondary tasks can be an important factor for boosting arousal. Additionally, the problem of sensitivity of performance task still remains. The null finding that PVT performance in the early part of epochs has the alternative explanation, suggests that they are less sensitive than EEG measures. The null result possibly arises from the lack of power. To understand the dissociation between physiological and behavioral indices they should be studied further in future.

In conclusion, the present study suggests that dual task interference can be counteracted by the alerting effect of the verbal rating of sleepiness. The results suggest that the dissociation between physiological arousal and task performance could be explained partly by the capacity sharing theory in multitasking conditions.

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