Nature and Science of Sleep

Open Access Full Text Article

ORIGINAL RESEARCH

Effects of Sleep Quality, Acute Sleep Deprivation, and Napping on Facial Emotion Recognition Accuracy and Speed

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Objective: To investigate the effects of sleep quality, sleep deprivation, and napping on facial emotion recognition (FER) accuracy and speed.

Methods: This research included a cross-sectional study (102 qualified participants) and a randomized controlled study (26 in the napping group and 24 in the control group). The stimuli for the FER task were obtained from the Chinese Facial Affective Picture System (CFAPS). Four facial expressions (fearful, disgusted, sad, and angry) were used. The Pittsburgh Sleep Quality Index (PSQI), Self-Rating Anxiety Scale, and Self-Rating Depression Scale were used to measure participants' sleep quality and psychological conditions. In Study 1, FER ability was compared between good and poor sleepers. In Study 2, all participants were sleep-deprived for one night, and completed the FER task before and after sleep deprivation. After different interventions (ie, napping for one hour, or walking around for ten minutes), the participants completed the third FER task.

Results: Study 1: Poor sleepers were able to recognize sad expressions more accurately compared with good sleepers. Study 2: 30-h sleep deprivation had no significant effect on the accuracy (ACC). Napping after sleep deprivation improved the FER ACC of upper-face expressions and marginally significantly improved the FER ACC of disgusted expressions.

Conclusion: Better sleep quality was linked to lower FER accuracy, particularly in recognizing sad expressions, while no significant differences in recognition speed were observed. Additionally, 30 hours of sleep deprivation did not affect FER accuracy, but napping after sleep deprivation improved accuracy for upper-face and marginally for disgusted expressions.

Keywords: facial emotion recognition, sleep quality, facial features, facial emotion, sleep deprivation, sleep loss

Introduction

Spoken language and non-verbal cues, including signs, gestures and facial emotions, were frequently used in daily social interactions.[1,2] An impaired facial emotion recognition (FER) can lead to social and other negative psychological outcomes. Impaired FER has been observed in populations with various disorders such as Alzheimer's disease,[3] autism spectrum disorder,[4] bipolar disorder,[5] insomnia,[6] and sleep deprivation.[7]

Sleep is a crucial physiological process in humans, and it is widely agreed upon that adults need at least seven hours of sleep per day to maintain good health. Acute sleep loss can damage various cognitive functions including memory,[8] attention,[9] emotion processing,[10] and FER.[10] Nowadays, many people suffer from sleep disturbances caused by various factors such as anxiety disorders[11,12] and smartphone addiction.[13]

Facial expressions and recognition of facial expressions are closely related with our brain.[14,15] Activity of the amygdala of the brain is enhanced during the recognition of fearful and sad emotional faces,[15] whereas patients with insomnia disorders are found out atrophic changes in the amygdala.[16] Thus, it could be hypothesized that sleep disturbance could affect our ability to process facial expressions by influencing certain parts of our brain. Meanwhile,

Received: 21 May 2024
Accepted: 20 September 2024
Published: 16 October 2024

growing evidence has indicated that sleep disturbances might impair FER ability. Killgore et al[7] found that sleep deprivation is associated with significantly reduced accuracy (ACC) in identifying happy and sad facial expressions. Helm et al found that sleep-deprived people blunted in the recognition of angry and happy expressions with moderate emotional intensity, whereas no change was observed in the recognition of sad expressions.[17] A large quasi-randomized controlled study with a sample of 181 participants highlighted that FER ability is resilient to night sleep deprivation.[18] Consequently, there is still no consensus on the expression most affected by acute sleep loss.

Wegrzyn and his team found that, for healthy people, the eyes and mouth frequently rely on correctly recognizing facial emotions. In addition, facial features play different roles in recognizing different emotions, as eyes are more important for recognizing sadness and fear, and the mouth is more important for recognizing happiness and disgust.[19] Therefore, masking different parts of the face may impair the FER ability. However, there were some conditions in which the lower face needed to be masked, such as gas masks for military personnel[20] or disposable face masks for medical staff.[21] During the COVID-19 pandemic, people were advised to wear face masks as a prevention tool to reduce airborne transmission of the virus;[22] therefore, people need to communicate with others with their lower face masked. A recent study showed that wearing masks can significantly affect FER ability.[23] Moreover, insufficient sleep is common among military personnel[24] and resident physicians.[25] They sometimes had to wear face masks at work, and such "sleep debt" could result in impaired cognitive function, decreased positive mood,[26] and especially, FER ability. Nevertheless, no study has examined the effects of sleep quality or sleep loss on partial facial recognition. Therefore, it is important to investigate whether poor or insufficient sleep impairs FER.

Several strategies have been developed to counteract the side effects associated with insufficient sleep, such as caffeine consumption and taking a short nap. A systematic review concluded that caffeine consumption after sleep deprivation or restriction can improve attention, executive function, information processing, and memory.[27] However, caffeine could also have side effects such as tremors, irritability, and diuresis,[28] and these negative effects may interfere with work performance and daily life. Short-time napping, as an economical and feasible countermeasure, was shown to be effective in restoring physical energy[29] and fatigue[30] in individuals with insufficient sleep.[31] However, there is no consensus on the duration of the nap to achieve the best restoration effect. According to cross-sectional research conducted at the university where these participants were recruited, the nap duration was 60 (23.7) minutes, according to 500 valid questionnaires. Thus, a 60-min afternoon nap was used as a countermeasure for sleep deprivation in this study.

In conclusion, a cross-sectional experiment was conducted to examine the difference in FER ability between good and poor sleepers. A randomized controlled trial will be performed to investigate the effect of one-night sleep deprivation on FER and to what extent a 60-minute napping could restore FER ability.

The study received ethical approval from the Ethics Committee of the Naval Medical University (Proposal Number: 20210310041) and was registered on OSF.io in accordance with the Declaration of Helsinki.

Study 1: Methods

Participants

This study plans to fit a linear regression model for the dependent variable using the generalized estimating equation (GEE). It is expected that 10 independent variables will be included in the regression model, which are 3 main effects (group, expression, face part), 2 interaction effects (group*face part, group*expression), and 5 covariates (age, gender, education level, SAS, SDS). Previous research has shown that when building a linear regression model, the sample size should be at least two times the number of independent variables in the model,[32] so based on the number of independent variables predicted in the regression model, the minimum sample size for conducting this study was 20.

Participants were recruited through posters on school billboards and advertising posts on school forums and informed consent was obtained prior to study commencement. Participants were eligible for this study if they fulfilled the following requirements: (a) aged between 18 and 30 years, (b) had normal vision acuity, (c) did not have social anxiety defined as scoring ≥ 60 on the Liebowitz Social Anxiety Scale, and (d) had no severe psychiatric disorders. Out of 154 individuals who registered for the study, only 102 met the inclusion criteria. Each participant was reimbursed by 50 Chinese Yuan for participation in the study.

Instruments

Facial Emotion Classification Task

The facial expression stimuli used in the facial emotion classification task are images of emotional faces from the Chinese Facial Affective Picture System (CFAPS).[33] These stimuli were produced by students or professional actors from the Acting Department of the Chinese University. Stimuli from this database had a minimum recognition rate of 0.6, with a resolution of 260×300 pixels. Stimuli masked by hair, moustache, or any other potential influencing factor were not included in this study. Eighty stimuli representing four negative emotions (fear, anger, sadness, and disgust) were selected from the database. Each facial emotion contained 20 stimuli, half of which was displayed on a male face. Upper and lower face stimuli were created from the same 80 stimuli using Adobe Photoshop 2021. Thus, 160 half-face stimuli with a resolution of 260×113 pixels were generated. The upper-face stimuli contained the eyebrows and eyes, whereas the lower-face stimuli contained only the mouth. Figure 1 shows examples of half-face stimuli.

The entire facial expression recognition program was run on a computer with a black background. Participants were asked to look at the computer screen and focus on the red cross sign at the center (fixation point) for 400 milliseconds. Subsequently, the facial expression appeared for 500 milliseconds and vanished. Empty black screen appears for 300 milliseconds. A classification cue in Chinese appeared until the participants pressed any of the four appointed buttons (ie, S, F, J, L). The experimental process is illustrated in Figure 2 (use whole-face section as an example).

The formal experiment consisted of three sections, respectively containing whole-face, upper-face, and lower-face stimuli. The formal experiment consisted of 240 trials, with each section containing 80 trials. Three sections appeared in

Figure 1 Sample of (**a**) upper-face stimuli; and (**b**) lower-face stimuli.

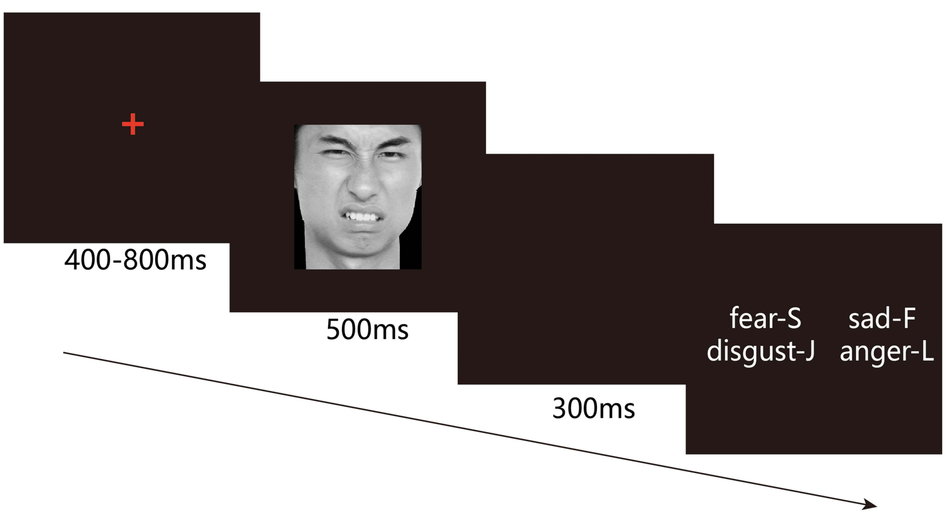

Figure 2 Procedure of FER task.

https://doi.org/10.2147/NSS.S462540

random order. The participants had a rest interval of 30 seconds after every 40 trials. To help the participants become familiar with the experimental procedure, they were instructed to start the FER task in a practice session containing 22 trials. If the correct rate was below 0.45, participants would need to restart the practice session.

Reaction time (RT) and ACC were recorded. ACC was calculated by dividing the number of correct responses by the total number of trials, while RT was defined as the mean RT of trials with correct responses. Outliers were defined as trials with Z scores of the corresponding Face Unit × expression subgroup greater than 3 or less than −3, and were removed from the sample before data analysis.

Sleep Status

The Pittsburgh Sleep Quality Index (PSQI) was used to measure sleep quality. The PSQI contains 19 self-report items, each of which can be sorted into seven subcategories: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and time dysfunction. The score for each subcategory ranged from 0 to 3 and the global score ranged from 0 to 21, with higher scores indicating poorer sleep quality. The PSQI has an internal reliability of alpha = 0.83, test–retest reliability of 0.85 for the global scale, sensitivity of 89.6%, and specificity of 86.5%.[34]

Depression and General Anxiety

The Zung Self-Rating Anxiety Scale (SAS)[35] is a 20-item self-report scale, and responses are given on a 4-point scale ranging from 1 (none of the time) to 4 (most of the time). The SAS was shown to have satisfactory internal consistency (Cronbach's alpha= 0.82)[36] and concurrent validity (r= 0.30, Taylor Manifest Anxiety Scale).[35] The conversion to the SAS Index (100-point scale) follows the following equation:

$$\text{SAS Index} = \text{Raw score} \times 1.25$$

Similarly, the Zung Self-Rating Depression Scale (SDS)[37] is a self-report scale containing 20 items, and responses are given on a 4-point scale ranging from 1 (none of the time) to 4 (most of the time). Of the 20 items, 10 had an increasing depression level, and the other 10 had a decreasing depression level. The conversion to SDS Index (100-point scale) follows the following equation:

$$\text{SDS Index} = \text{Raw score} \times 1.25$$

Procedure

The experiment was conducted in a warm, sound-attenuated room at the university. The questionnaires were completed in a paper form, and the FER task was performed using E-prime 2.0 installed on computer. All subjects were prohibited from drinking any beverage containing caffeine on the day before the start of the experiment. After the participants arrived, they were asked to sign an informed consent form followed by questionnaires regarding basic demographic information. Participants were then instructed to read the FER task guidance. Once they understood the guidance, they started the FER task. The RT and ACC values of each trial were calculated and recorded. After completing the FER task, participants were instructed to complete the remaining questionnaires, including the PSQI, SAS, and SDS.

Statistical Analyses

The developers of the PSQI questionnaire, Buysse et al, found that using a cutoff score of 5 on the PSQI total score, the sensitivity to distinguish between individuals with poor sleep quality and those with good sleep quality was 89.6%, with a specificity of 86.5% (Kappa = 0.75, P <0.001).[34] Therefore, in this cross-sectional study, a cutoff score of 5 on the PSQI total score was used to divide the participants into two groups. Participants with a PSQI total score of five were categorized into the good sleeper group, whereas those with a PSQI total score of six were categorized into the poor sleeper group.

The participants' characteristics and psychological information were compared between the two groups. For continuous variables, the mean and standard deviation (SD) were used for normally distributed variables, while the median [interquartile range] was used for skewed variables. Ratios were used to present the results for categorical variables.

Comparisons were assessed using *t*-tests for normally distributed continuous variables and the Mann–Whitney *U*-test for continuous variables that did not conform to normality and homogeneity of variances. The Shapiro–Wilk test was used to test normality, and Levene's test was used to test homogeneity.

A GEE was developed based on the generalized linear model first proposed by Liang and Zeger in 1986.[38] It is a regression model for analyzing panel data using quasi-likelihood estimation methods to estimate parameters in generalized linear models, specifically designed to analyze repeated measures data, including unbalanced longitudinal data (ie, varying numbers of repeated measures and intervals between them) and skewed data.

The first study examined the effects of sleep quality on FER ability. GEE was used to model ACC and RT as continuous outcomes through exchangeable correlation structures. Ten effects were included in the two GEE models, including two within-subject effects—Face Part and Expression, one between-subject effect— group, two interaction effects-The interaction between Group and Face Part, and the interaction between Group and Expression–and five covariates: age, gender, education, SAS, and SDS. Post hoc comparisons between good and poor sleepers were performed according to face and expression categories. P-values of post-hoc analyses were adjusted using the Bonferroni correction.

All statistical analyses were performed using Statistical Package for the Social Sciences v.26 (SPSS, Inc. Chicago, IL, USA), with α set at 0.05, to confirm statistical significance. The figures were generated using GraphPad Prism version 8.

Study 1: Results

Participants Characteristics

The descriptive statistics of demographic and psychological information were presented in Table 1

The participants were divided into two groups based on a cutoff score of 5 on the PSQI. There were 49 participants in the good-sleeper group and 53 in the poor-sleeper group. Good sleepers were significantly different from poor sleepers in SAS and SDS. No significant differences were found in the age and gender distributions between the two groups.

Recognition Accuracy

The GEE model of FER ACC had one significant effect, SDS (χ^2=4.28, P <0.05), and two marginally significant effects — Group (χ^2=3.63, P =0.057), and interaction between Group and Expression (χ^2=6.84, P =0.077). Better sleep quality predicted a lower FER ACC (B=−0.074, 95% CI (−0.124,-0.023)). Table 2 presents the model and parameter estimates.

Table 1 Descriptive Statistical of Demographic Information and Psychological Dimensions in Study 1

	Good Sleepers (n=49)	Poor Sleepers (n=53)	*p*
Age	21 [20,23]	21 [20,24]	>0.05
Gender (F:M)	20:29	22:31	>0.05
PSQI[a]			
Global score	4 [4,5]	7 [6,8]	<0.01
sleep quality	1 [0,1]	1 [1,2]	<0.01
sleep latency	1 [0,1]	2 [1,2.5]	<0.01
sleep duration	1 [0,1]	1 [0,1]	<0.05
sleep efficiency	0 [0,0]	0 [0,0]	<0.01
sleep disturbances	1 [1,1]	1 [1,1]	<0.01
sleep medication	0 [0,0]	0 [0,0]	>0.05
daytime dysfunction	1 [1,2]	2 [2,3]	<0.01
SDS[c]	37.5 [32.5,44.4]	45.0 [38.1,50.6]	<0.01
SAS[b]	32.5 [30.6,35.6]	37.5 [35,46.3]	<0.01

Notes: Values are presented as median [interquartile range] and ratio. P-values were obtained using the Mann–Whitney *U*-test for continuous variables and χ^2 test for categorical variables. a: Pittsburgh Sleep Quality Index, b: Self-Rating Anxiety Scale, c: Self-Rating Depression Scale.

Table 2 Model Effects and Parameter Estimates of GEE Model of FER ACC in Study 1

	ACC			
	χ^2	*P*	*B*	95% CI
Intercept	52.94	<0.01	0.73	(0.58, 0.88)
Group	3.63	>0.05	–	–
Poor Sleeper			Reference	
Good Sleeper	8.18	<0.01	−0.07	(−0.12, −0.02)
Expression	454.30	<0.01	–	–
Sad			Reference	
Angry	14.37	<0.01	−0.10	(−0.16, −0.05)
Disgusted	36.60	<0.01	−0.14	(−0.18, −0.09)
Fearful	40.49	<0.01	0.15	(0.10, 0.19)
Face Part	692.79	<0.01	–	–
Whole			Reference	
Lower	283.89	<0.01	−0.24	(−0.26, −0.21)
Upper	176.40	<0.01	−0.15	(−0.17, −0.13)
Groups*Face Part	1.15	>0.05	–	–
Group*Expression	6.84	>0.05	–	–
Gender	0.27	>0.05	–	–
Age (year)	0.50	>0.05	–	–
Education	0.53	>0.05	–	–
SDS[a]	4.28	<0.05	–	–
SAS[b]	0.18	>0.05	–	–

Notes: a: Self-rating Depression Scale; b: Self-Rating Anxiety Scale.

Post-hoc comparisons performed separately for each expression and face-part group showed that good sleepers were less accurate at recognizing sad expressions, with an MD of −0.079 and 95% CI of (−0.124 to −0.035). The results of all the post-hoc comparisons are presented in Table 3.

Recognition Speed

The recognition speed is recorded in ms. The model effects and parameter estimates are listed in Table 4. Group, the interaction between Group and Face Part, and the interaction between Group and Expression had no significant effects on

Table 3 Post-Hoc Comparisons of ACC and RT Between Good Sleepers and Poor Sleepers

	ACC		RT (ms)	
	MD(SE)	Adjusted *P*	MD(SE)	Adjusted *P*
All	−0.23 (0.01)	>0.05	85.35 (74.05)	>0.05
Face Part				
Lower	−0.02 (0.02)	>0.05	114.51 (106.63)	>0.05
Upper	−0.03 (0.02)	>0.05	83.61 (81.18)	>0.05
Whole	−0.02 (0.02)	>0.05	57.92 (79.16)	1.00
Expression				
Sad	−0.08 (0.02)	<0.01	106.71 (80.78)	>0.05
Fearful	−0.01 (0.02)	1.00	124.76 (74.70)	>0.05
Angry	0.00 (0.03)	1.00	8.81 (81.20)	1.00
Disgusted	−0.01 (0.03)	1.00	101.10 (84.19)	>0.05

Table 4 Model Effects and Parameter Estimates of GEE Model of FER RT in Study 1

	RT (ms)			
	χ^2	***P***	***B***	**95% CI**
Intercept	0.12	>0.05	66.9	(−1107.7, 1241.6)
Group	1.33	>0.05	–	–
Poor Sleeper			Reference	
Good Sleeper	0.82	>0.05	79.3	(−92.3, 250.9)
Expression	94.61	<0.01	–	–
Sad			Reference	
Angry	11.36	<0.01	109.6	(45.9, 173.4)
Disgusted	3.00	>0.05	53.5	(−7.0, 113.9)
Fearful	27.45	<0.01	−211.4 (−290.5, −132.3)	
Face Part	33.98	<0.01	–	–
Whole			Reference	
Lower	14.75	<0.01	252.5	(123.6, 381.3)
Upper	1.60	>0.05	57.5	(−31.5, 146.4)
Groups*Face Part	0.34	>0.05	–	–
Group*Expression	7.12	>0.05	–	–
Gender	2.81	>0.05	–	–
Age (year)	1.78	>0.05	–	–
Education	7.54	<0.01	–	–
SDS[a]	0.32	>0.05	–	–
SAS[b]	0.34	>0.05	–	–

Notes: a: Self-rating Depression Scale; b: Self-Rating Anxiety Scale.

FER RT (all P >0.05). Further post-hoc analyses showed that no significant difference between poor and good sleepers was present in the FER RT of any stimulus subgroup. The results are presented in Table 3.

Study2: Methods

Ethical approval for this study was obtained from the Committee on Ethics of Medical Research, Naval Medical University (Research Proposal No. 20210310041), and was registered in OSF.io.

Participants

The present study plans to fit a linear regression model using GEE on the dependent variable, and if randomization of the groups is effective, there should be no significant differences in the distributions of variables such as baseline demographics, anxiety symptoms, depressive symptoms, social anxiety symptoms, and hours of sleep at night between the two groups of subjects, and these variables may not be included in the regression model. Based on this assumption, it is expected that 4 main effects (group, time point, expression category, face unit) and 3 interaction effects (group* time point, group* time point* face unit, group* time point* expression) will be included in the regression model. Previous research has shown that when building a linear regression model, the sample size should be at least two times the number of independent variables in the model,[32] so based on the predicted number of independent variables in the model, the minimum sample size for conducting the present study was 14 individuals.

The participants were recruited through posters on the online forum of a university and informed consent was obtained prior to study commencement. Participants had to fulfill the following requirements to be eligible for the experiment: (a) aged between 18 and 30 years, (b) normal vision acuity, (c) denying having severe psychiatric disorders, (d) having a habit of napping at noon (defined as a frequency of more than three times a week). 53 participants fulfill all the entry requirements and were included in the study. Participants were randomly assigned to either the napping or control group using random number generated in Excel. Those who received a "1" were assigned to the control group, while those who received a "2" were assigned to the napping group. Two participants dropped out of the experiment during sleep deprivation, and another participant was excluded from the final data analyses for frequently falling asleep during the FER task. In conclusion, data from 50 participants were used for data analysis.

Instruments

Same instruments as in task 1 and napping questionnaire were used.

Procedure

Three days before the start of the experiment, all the subjects were prohibited from drinking any beverage containing caffeine. Each participant was asked to complete a sleep diary for three days prior to the experiment. All participants gathered in an online group chat, and an assistant posted a sleep-diary link in the group chat at 6:00 AM. The participants were required to fill out a sleep diary immediately after waking up. Staying up was forbidden. On the test day, all the participants were asked to wake up at 6:00 AM and visit the laboratory at 11:20 AM. After completing questionnaires about sleep and psychological characteristics, the participants started the first FER test at 12:10 PM (time point 1). The participants were free to move around inside the laboratory; however, strenuous exercise was not allowed. Except for bathroom visits and meals, they could only stay in the laboratory. During sleep deprivation, an assistant supervised participants to prevent them from falling asleep. The assistant periodically patrols the laboratory and spends the rest of the time on a raised platform observing the subjects to prevent them from falling asleep during the experiment. To keep alert and focus, two assistants worked on a 4-hour shift during the night. The second test day consisted of two FER tasks. To test the effect of sleep deprivation on FER ability, the first FER task of the day was set at 12:10 PM (Time Point 2). After the test, participants were randomly assigned to the napping and control groups. Participants were not informed of the details of the other group and were forbidden from talking about their own group's requirements with others. Participants in the napping group were allowed to nap in their dormitory from 12:40 to 14:00, and were instructed to fill out a questionnaire about the napping situation immediately after waking up. To blind participants in the control group, they were allowed to walk outside the laboratory from 12:40 to 12:50. The final FER test to examine the effect of napping on FER ability was performed at 14:30 (Time Point 3).

Statistical Analyses

Basic information was compared between the two groups using the same statistical methods as in Task 1.

GEE was used to model FER ACC and FER RT as continuous outcomes through an autoregressive correlation structure, which is suitable for data involving time-related variables.[39] The second study aimed to examine the effect of sleep deprivation and the subsequent short nap on FER ability. There were three within-subject variables (Test Session, Face Part and Expression) and one between-subject variable (group). The two models with ACC and RT as dependent variables included seven independent effects, with four main effects: Group, Test Session, Face Part, Expression, and 3 interaction effects— Group and Test Session, Group and Test Session and Expression, Group and Test Session and Face Part. Other covariates (ie, age, gender, SAS, SDS, and PSQI) were included in the models if the two groups differed significantly in these variables.

Post-hoc analyses were performed to determine the interaction between the groups and sessions. First, the napping group was compared with the control group at time points 1, 2, and 3. For each group, the results were compared between time points 3 and 2 and 2 and 1. In total, three horizontal and four longitudinal comparisons were performed.

For the interaction among Group, Session, and Face Part, and the interaction among Group, Session, and Expression, post-hoc comparisons were performed for each face part or expression in the same manner as described above. P-values of post-hoc analyses were adjusted using Bonferroni correction.

Data analyses were performed using SPSS v.26, with α set at 0.05, to confirm statistical significance. The figures were generated using GraphPad Prism version 8.

Study 2: Results

Participants Characteristics

Demographic, psychological, and sleep conditions were compared between the two groups, and the results are presented in Table 5. The sleep diary before the experiment showed that the mean and SD of nocturnal sleep duration was 6.74 (0.69) hours, and no significant difference was found for the basic sleep duration between the two groups. All Participants in the napping group successfully fell asleep at noon within 15 min, and the nap duration was 62.38 (13.53) minutes. Between-group comparisons showed no significant differences in demographic, psychological, and sleep conditions at the initial stage. Therefore, age, gender, PSQI, SDS, SAS, and nocturnal sleep were not included in the GEE model.

Recognition Accuracy

Table 6 presents the model effects and parameter estimates. The interaction between Group, Session and Expression, and the interaction between Group, Session and Face Part were shown to have a statistically significant influence on ACC (*P* <0.05).

Post-hoc comparisons between different time points showed that the ACC at time point 3 was not significantly different from that at time point 2 for the two groups (napping group: MD=0.0194, 95% CI (0.0024, 0.0363), adjusted *P* >0.05; control group: MD=0.0101, 95% CI (−0.0141, 0.0343]).

adjusted *P* >0.05). No difference was found between the napping group and control group at time point 1 (MD=0.0075, adjusted *P* >0.05), indicating that there was no significant difference in the FER ACC between the two groups at the initial stage. No significant change was observed between before and after sleep deprivation for both groups (napping group: MD=−0.0176, 95% CI (−0.0366, −0.0016), adjusted *P* >0.05, control group: MD=−0.0038, 95% CI (−0.0205, 0.0128), adjusted *P* >0.05).

Recognition Accuracy for Different Expressions

The FER ACC of the different groups was significantly different for different expressions. The change curves are shown in Figure 3.

First, the ACC of the two groups at the same time point was compared horizontally. No significant differences were observed between the control and napping group for any facial expression (ie, angry, disgusted, sad, and fearful) at the three time points (all adjusted *P* >0.05).

Longitudinal comparisons of ACC between time point 2 and time point 1 showed no significant difference for all facial expressions in the two groups (adjusted *P* >0.05). After different interventions, for disgusted expression, the napping group showed a marginally statistically significant improvement (MD=0.0394, 95% CI (0.0092, 0.0696), adjusted *P* =0.077), while the control group showed a non-significant improvement (MD=0.0241, 95% CI (−0.0039, 0.0521), adjusted *P* >0.05). No significant change was observed for angry, fearful, and sad expressions in both groups

Table 5 Comparisons of Demographic and Psychological Conditions Between Two Groups in Study 2

	Nap Group (n=26)	Control Group (n=24)	P	Total
Age (year)	20 [20, 21]	20 [20,22]	>0.05	20 [20,21]
Gender (F:M)	11:15	11:13	>0.05	22:28
PSQI[a]	5.23 (2.63)	5.50 [4,6]	>0.05	5.00 [4,6]
SDS[b]	37.50 [31.10, 49.25]	42.54 (9.06)	>0.05	42.10 (10.56)
SAS[c]	35.00 [31.00, 43.00]	36.67 (5.93)	>0.05	36.50 [31.00, 42.00]
Nocturnal sleep (h)	6.79 (0.76)	6.70 (0.60)	>0.05	6.74 (0.69)
Nap (min)	62.38 (13.53)	–	–	–

Notes: Normally distributed variables were presented as mean (SD). Skewed distributed variables are presented as median [interquartile range]. *P* was derived from independent *t*-tests or Mann–Whitney *U*-tests for skewed distributed variables, ratios, and *P* in χ^2 test for categorical variables. a: Pittsburgh Sleep Quality Index, b: Self-Rating Depression Scale c: Self-Rating Anxiety Scale.

Table 6 Model Effects and Parameter Estimates of GEE Model of FER ACC in Study 2

	ACC			
	χ^2	*P*	*B*	95% CI
Intercept	3745.67	<0.01	0.59	(0.53, 0.65)
Group	0.01	>0.05	–	–
Control			Reference	
Nap	1.54	>0.05	0.05	(−0.03, 0.13)
Session	5.06	>0.05	–	–
Time point 1			Reference	
Time point 2	0.08	>0.05	0.01	(−0.04, 0.06)
Time point 3	3.68	>0.05	0.05	(0.00, 0.11)
Expression	1.71	>0.05	–	–
Sad			Reference	
Angry	3.10	>0.05	0.06	(−0.01, 0.13)
Disgusted	0.29	>0.05	0.02	(−0.05, 0.08)
Fearful	0.03	>0.05	0.01	(−0.05, 0.06)
Face Part	439.77	<0.01	–	–
Whole			Reference	
Lower	63.56	<0.01	−0.19	(−0.23, −0.14)
Upper	21.01	<0.01	−0.11	(−0.15, −0.06)
Groups*Session	1.39	>0.05	–	–
Group*Session*Face Part	18.49	<0.05	–	–
Group*Session*Expression	19.18	>0.05	–	–

(angry: nap MD=0.0205 95% CI (−0.0041, 0.0451), control MD=−0.0029 95% CI (−0.0458, 0.0399); fearful: nap MD=0.0133 95% CI (−0.202, 0.0469), control MD=−0.0155 95% CI (−0.0507, 0.0196); sad: nap MD=0.0042 95% CI (−0.0429, 0.0514), control MD=0.0347 95% CI (−0.0108, 0.0803), all adjusted *P* >0.05).

Recognition Accuracy for Different Face Parts

The differences between face units in ACC recognition were relatively large; therefore, the changing curves of the three face parts are shown in Figure 4.

Similarly, with regard to horizontal comparisons, no significant difference in the ACC between the napping and control group was observed for lower-, upper-, and whole-face stimuli at the three time points (all adjusted *P* >0.05).

Further longitudinal comparisons between time point 3 and time point 2 demonstrated that 1-hour napping could improve the ACC of upper-face stimuli (MD=0.0499, 95% CI (0.0206, 0.0791), adjusted *P* <0.01), while the control group did not show significant improvement in the ACC of upper-face stimuli (MD=0.0090, 95% CI (−0.0220, 0.0399), adjusted *P* >0.05). However, neither napping nor staying awake changed the ACC of lower face stimuli (nap: MD=0.0099, 95% CI (−0.0182, 0.0381), adjusted *P* >0.05; control: MD<0.001, 95% CI (−0.0354, 0.0354), adjusted *P* >0.05) or whole-face stimuli (nap: MD=−0.0017, 95% CI (−0.0371, 0.0336), adjusted *P* >0.05; control: MD=0.0213, 95% CI (−0.0150, 0.0576), adjusted *P* >0.05). Comparisons between time point 2 and time point 1 showed that no significant effect on ACC was derived from 30-hour sleep deprivation for the lower face (nap: MD=0.0015, 95% CI (−0.0257, 0.0286); control: MD=−0.0023, 95% CI (−0.0314, 0.0267), all adjusted *P* >0.05), upper face (nap: MD= −0.0328, 95% CI (−0.0655, −0.0001); control: MD=−0.0080, 95% CI (−0.0396, 0.0235), all adjusted *P* >0.05), or whole

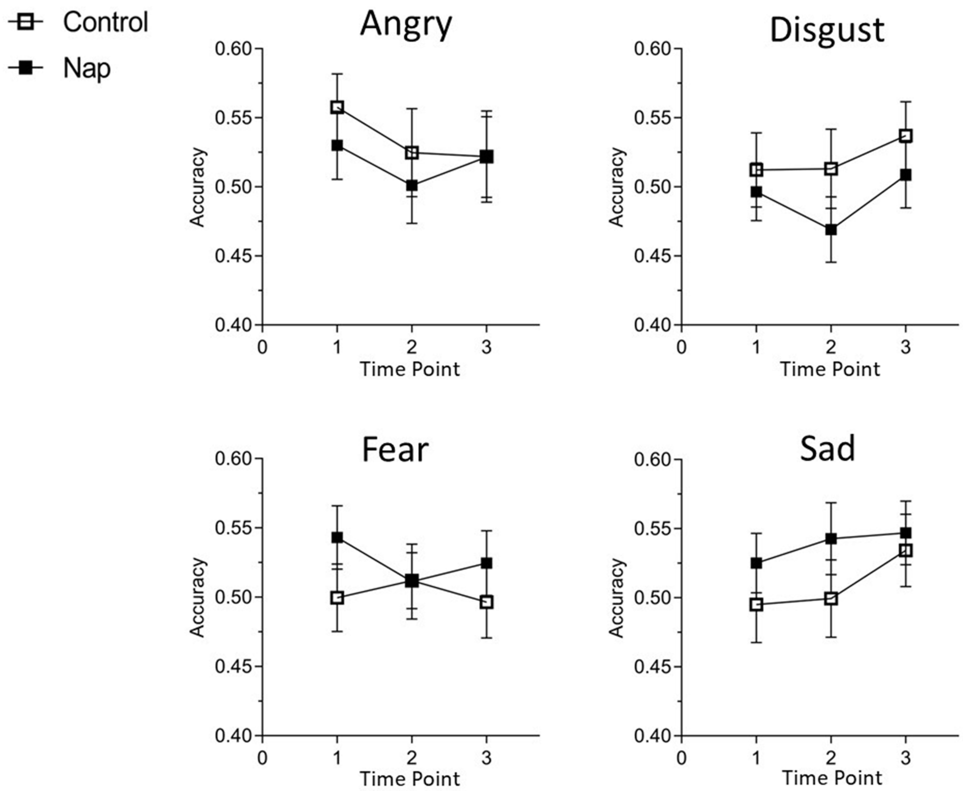

Figure 3 Recognition accuracy of nap and control group as time advances for different expressions.

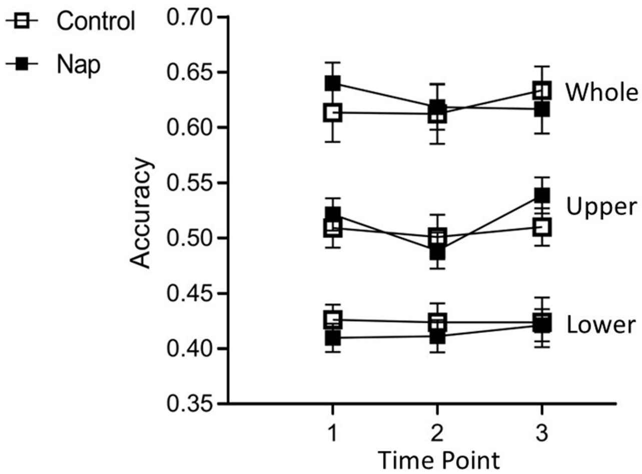

Figure 4 Recognition accuracy of nap and control group as time advances for different face parts.

face (nap: MD=−0.0215, 95% CI (−0.0544, 0.0114); control: MD=−0.0011, 95% CI (−0.0352, 0.0329), all adjusted P >0.05) stimuli in the two groups.

Recognition Speed

Table 7 presents the model effects and parameter estimates. The interaction between Group, Session and Expression had a statistically significant influence on recognition speed (P <0.001).

No significant difference was observed between the two groups at any of the time points. A significantly higher FER speed was observed after sleep deprivation in both the groups. RT at time point 2 was quicker than that at time point 1

Table 7 Model Effects and Parameter Estimates of GEE Model of FER RT in Study 2

	ACC			
	χ^2	*P*	*B*	95% CI
Intercept	533.48	<0.01	1060.85	(855.45, 1266.25)
Group	0.13	>0.05	–	–
Control			Reference	
Nap	1.74	>0.05	−163.46	(−406.48, 79.56)
Session	14.46	<0.01	–	–
Time point 1			Reference	
Time point 2	1.05	>0.05	−107.01	(−311.73, 97.71)
Time point 3	4.22	<0.05	−214.51	(−419.22, −9.80)
Expression	80.69	<0.01	–	–
Sad			Reference	
Angry	27.10	<0.01	−315.45	(−434.22, −196.672)
Disgusted	6.66	<0.05	179.84	(43.27, 316.41)
Fearful	0.51	>0.05	−51.89	(−194.50, 90.72)
Face Part	23.41	<0.01	–	–
Whole			Reference	
Lower	5.50	<0.05	187.34	(30.83, 343.85)
Upper	0.01	>0.05	7.64	(−182.31, 197.57)
Groups*Session	1.60	>0.05	–	–
Group*Session*Face Part	5.91	>0.05	–	–
Group*Session*Expression	43.51	<0.01	–	–

(MD = −159.47 ms, 95% CI (−241.73, −77.20), adjusted *P* <0.01). After different intervention, neither two groups acquired significant improvement in FER speed (nap: MD=−13.50 ms, 95% CI (−144.85, 117.84), adjusted *P* >0.05; control: MD=−64.16 ms, 95% CI (−174.91, 46.59), adjusted *P* >0.05).

Discussion

It was hypothesized that poor sleep quality or acute sleep loss could damage FER ability and that napping at noon could eliminate this possible effect. This study examined four facial expressions (sadness, fear, anger, and disgust) and three face parts (upper, lower, and whole) to investigate the impact of sleep quality and acute sleep loss on recognition of negative expressions.

This cross-sectional study had a relatively large sample size of 102 participants, aiming to identify the impact of sleep quality on the recognition of negative expressions. Contrary to the initial hypothesis, the results demonstrated that poor sleepers were able to recognize sad expressions more accurately. However, a randomized controlled study confirmed that 30-h of sleep deprivation did not impair the recognition accuracy of sad, angry, disgusted, and fearful expressions, whereas napping after sleep deprivation improved the recognition accuracy of upper-face stimuli.

Previous findings have shown that sleep-deprived people tend to rate neutral or positive emotional stimuli as more negative[40,41] and respond more to negative events than to positive events.[42] Similar to previous findings, the present study also indicates that poor sleepers may be more alert to negative stimuli. The association between poor sleep quality and social anxiety has been identified,[43] and with the present findings that poor sleepers are better at recognizing sad expressions, a new assumption could be raised regarding whether social anxiety in a population with poor sleep quality is derived from the increased alertness of negative facial emotions. For example, if individuals are more sensitive to negative emotions and tend to misinterpret neutral expressions as negative, they are more likely to experience unfavorable social situations, leading to the manifestation of social anxiety.

A study including 65 patients with chronic insomnia disorder and 55 healthy controls found atrophic changes in the amygdala of individuals with chronic insomnia disorder.[16] Additionally, a meta-analysis indicated that people with insomnia have reduced ability to accurately recognize fearful expressions.[44] These findings suggest that sleep problems can lead to changes in the FER ability by influencing specific brain regions. A large meta-analysis found that there were differences in the brain regions involved in the processing of different expressions, with the processing of sad expression associated with activation of the right amygdala and left lingual gyrus, the processing of disgust expression associated with activation of the bilateral insula and right thalamus, the processing of angry expression associated with activation of the insula and right suboccipital gyrus, the processing of fearful expression associated with activation of the bilateral amygdala, medial frontal gyrus.[15] Combining the findings of previous research and the present study, we hypothesized that poor sleep quality may lead to enhanced activity in the right amygdala or left lingual gyrus. However, given the complexity of cognitive function and its brain mechanisms, this hypothesis needs to be verified in future studies.

Sleep deprivation could affect the function of the frontal lobe, thereby reducing its modulatory role in the amygdala, leading to increased amygdala responsiveness to negative emotional stimuli[45,46] or even rating neutral stimuli as emotionally unpleasant.[10,40,45] The present study found no change in the accuracy of recognizing sad and fearful expressions after sleep deprivation, which may be explained by the possibility that subjects could have enhanced amygdala activation after sleep deprivation, which is associated with the processing of fear and sadness,[15] thus counteracting the negative cognitive effects of sleep deprivation.

However, the recognition accuracy for disgusted and angry emotions was resilient to one-night sleep deprivation. There are two possible reasons for this. First, acute sleep deprivation could activate the right thalamus (associated with processing disgusted expressions), right suboccipital gyrus (associated with processing angry expressions), or insula (associated with processing disgusted and angry expressions). Second, the 30-hour sleep deprivation period may be too short to exert a significant influence. In the present study, by visually checking the changing curves of the four negative expressions, the recognition accuracy of angry expressions decreased most significantly with the accumulation of sleep debt, although this change was not statistically significant. A previous study showed that sleep-deprived individuals blunted in the recognition of angry expressions in the moderate emotional intensity range, whereas no change was observed in the recognition of sad expressions.[17] Our results also suggest that recognition of anger expression is more vulnerable to sleep deprivation than recognition of fearful, sad, and disgusted expressions. Future studies should consider extending the duration of sleep deprivation to examine whether the accumulation of "sleep debt" actually has the greatest effect on the recognition of angry expressions.

The reaction time of the formal-session trials in Study 2 decreased after sleep deprivation. We speculated that the number of practice session trials (22 trials) was insufficient. The practice effect was unavoidable in this study. As the participants were not fully familiar with the FER task at time point 1, they might have performed worse than their true ability. At time point 2, when participants became more familiar with the FER task, even if sleep deprivation could affect their FER ability, the effects of sleep deprivation might have been counteracted. If all participants were fully familiar with the FER task at the beginning, the ACC at time point 1 might be higher and the results at time point 2 might be lower than those before sleep deprivation. However, this assumption could only be verified in future research by including more practice session trials before starting the experiment.

Despite the influence of the practice effect, this study provides valuable evidence. Napping for one hour after sleep deprivation improved the accuracy of recognizing upper face stimuli. No improvement was observed in the control group, indicating that the improvement in FER accuracy of upper-face expressions after one-hour napping could not be solely attributed to the practice effect. These results suggest that napping after sleep deprivation may enhance the ability to recognize facial expressions partially covered by a face mask.

Conclusions

Better sleep quality was associated with lower FER accuracy. Specifically, good sleepers were less accurate in recognizing sad expressions compared to poor sleepers. No significant differences in FER speed were found between good and poor sleepers.

30-h sleep deprivation had no significant effect on the FER accuracy. Napping after 30-h sleep deprivation improved the FER accuracy of upper-face expressions and marginally significantly improved the FER accuracy of disgusted expressions. However, given the limitation that the current study only contains 30-h sleep deprivation, future studies should consider extending the duration of sleep deprivation to examine whether the FER ability could be further damaged as the "sleep debt" accumulated. Meanwhile, unexpected and novel outcomes suggest that poor sleepers are more capable of recognizing sad facial expressions than are good sleepers.

Data Sharing Statement

The data will be available from the corresponding author.

Funding

This work was supported by the Changzheng Hospital Pyramid Talent Project (2020) of Naval Medical University, and the Logistics and Health Care Research Project (Grant number 20BJZ09).

Disclosure

The authors report no conflicts of interest in this work.

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