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Impaired emotional memory and decision-making following primary insomnia

Xi Chunhua, MD[a,c,*], Ding Jiacui, MD[b], Li Xue, MD[a], Wang Kai, MD[c]

Abstract

Previous studies have indicated that sleep plays an important role in emotional memory and decision-making. However, very little attention has been given to emotional memory and decision-making in patients with primary insomnia (PI). We investigated whether PI influences the accuracy of emotional memory and social decision-making.

We examined 25 patients with PI and 20 healthy controls (HC) using an emotional picture memory task and the Iowa Gambling Task (IGT). In the emotional picture memory task, participants completed two testing sessions: an emotional picture evaluation and a delayed recognition phase. During the emotional picture evaluation phase, participants were presented with 48 pictures with different valence (16 positive, 16 neutral, and 16 negative), which they had to evaluate for emotional valence and arousal. During the recognition phase, participants were asked to make a yes/no memory assessment of a set of pictures, which contained the 48 target pictures intermingled with 48 non-target pictures.

The performance of the participants with PI was the same as that of the HC in the emotional picture evaluation task. However, the PI group showed worse recognition of the positive and neutral pictures than did the HC group, although recognition of negative pictures was similar in the 2 groups. In the IGT, participants in the PI group more frequently selected cards from the risky decks as the game progressed and selected more disadvantageous cards than did participants in the HC group after the first block.

Our findings suggest that insomnia had different effects on memory, depending on the valence of the memory. Specifically, memory performance was impaired for positive and neutral items, but the recognition of negative stimuli seemed to be more resistant to the effects of insomnia. Our results also suggest that decision-making, which is known to be mediated by the ventromedial prefrontal cortex, including decision-making under conditions of uncertainty, may be vulnerable in PI.

Abbreviations: ANOVA = analysis of variance, BAI = the Beck Anxiety Inventory, BDI = Beck Depression Inventory, DSM-V = the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition, ESS = The Epworth Sleepiness Scale, HC = healthy controls, IGT = Iowa Gambling Task, MMSE = the Mini-Mental State Examination, OFC = orbitofrontal cortex, PI = primary insomnia, PSG = polysomnographic, PSQI = The Pittsburgh Sleep Quality Index.

Keywords: decision-making, emotion, insomnia, memory, sleep

1. Introduction

Primary insomnia (PI) is a chronic clinical symptom characterized by the subjective experience of sleep loss and disturbed sleep. Patients with PI show heightened arousal and find it difficult to sleep in bed.[1] It is a very common sleep disorder among the general population. Although many people with PI do not have any identifiable psychological or psychiatric problems, there is evidence to suggest that untreated PI may be important in the development of psychiatric illnesses, such as substance abuse and depression.[2,3] Moreover, insomnia can lead to impairments of many basic cognitive functions, including learning and memory,[4] attention,[5,6] as well as emotional impairments.[7]

Over the past 20 years, the relationship between sleep and memory has attracted much attention, and several reports have confirmed that sleep is important for memory processing.[8–10] Taking a nap can improve memory, which supports the view that even short-term sleep is advantageous for memory consolidation.[11] Memory impairment is thought to be the core symptom of the decline in cognitive function associated with sleep loss[12,13] and may encompass deficits in working memory,[14,15] as well as encoding of new memory information.[16] Functional imaging studies have suggested that memory impairment in patients with PI may be related to decreased brain function in the temporal cortex and frontoparietal network.[17–20]

In recent years, many studies on sleep disorders[21–23] have implied that sleep is also important in emotional memory, and that sleep loss negatively influences emotional memory,[24] but not the categorization of emotional perception.[25] Some studies have indicated that emotional information is remembered better than neutral information, and that there may be a preferential consolidation of emotional memory, as compared to neutral

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memory, during sleep.[26–28] In the past few years, it has been suggested that sleep loss has a greater negative effect on the memory of positive and neutral than of negative stimuli.[29,30]

The formation of emotional memory depends on the activity in specific structures, such as the amygdala, insula, prefrontal cortex, and hippocampus.[31] A study by Motomura et al [32] showed increased activity in the amygdala in sleep-deprived subjects when they were presented with aversive pictures. Baglioni et al[33] also found that the reactivity of the amygdala to negative stimuli does not seem to be impaired in patients with insomnia. The above studies indicate that sleep disorders can lead to amygdala reactivity, especially after exposure to negative emotional stimuli.[31,33] The amygdala is a key brain region in emotion processing, as it not only connects with many other emotion-processing regions, but also integrates local and global networks involved in emotional and cognitive information processing.[31,34] A study by Shao et al [35] showed that sleep deprivation affects the emotion-processing circuit and decreases the functional connectivity between the prefrontal cortex or anterior cingulated cortex and the amygdala. The altered functional connectivity between the amygdala and other brain regions may be dedicated to processing of emotional memory with different valences.[35]

Another functional change includes the prefrontal lobe, which is more prone to be affected by sleep loss. A study by Thomas et al [36] showed that, after 24 hours of sleep deprivation, there is a significant decrease in metabolic activity in the prefrontal cortex, including the orbitofrontal regions, which are involved in decision-making under conditions of uncertainty, such as that required for the Iowa Gambling Task (IGT).[37] Altena et al[38] also revealed that patients with PI exhibit smaller gray matter volumes in the left orbitofrontal region, a finding that strongly correlated with the subjective severity of insomnia. A wide body of literature has provided evidence of the neural mechanisms underlying IGT performance, which involve the function of the prefrontal cortex, and especially of the orbitofrontal regions.[39–41] Moreover, several studies have reported that this neural circuitry maybe sensitive to insomnia.[19,42–45] Previous studies have shown impaired decision-making ability in the IGT in participants with sleep deprivation, as evidenced by their increased number of choices from disadvantageous decks.[46,47] A recent study from Seeley et al[48] suggested that sleep improves strategy-decision learning ability in the IGT; these results provide new insights into the relationship between sleep and IGT learning. Decision-making in the IGT is associated with the orbitofrontal regions,[40,49] and decision-making ability has been shown to be impaired in participants with sleep deprivation.[46,50] Previous studies have also confirmed functional abnormalities in the prefrontal cortex of patients with PI.[38,45] These functional abnormalities may underlie the significant cognitive deficits associated with PI, which may include deficits in emotional memory and decision-making. However, whether PI shows analogous outcomes in emotional memory and decision-making, similar to sleep deprivation, remains unclear.[21,22,46]

In the current study, we hypothesized that patients with PI would have deficits in emotional memory of different valences and in decision-making. We administered an emotional picture recognition task that included a phase of emotional picture evaluation and a delayed recognition phase. In order to investigate whether emotional memory impairment is attributed to emotional perception, we also asked participants to evaluate the valence and arousal of the emotional pictures with scores during the emotional picture evaluation phase. We also tested the decision-making ability of participants using the IGT and a series of neuropsychological tests, to determine if the above cognitive deficits could be detected in patients with PI.

2. Materials and methods

2.1. Participants

Participants provided written informed consent before the study and the present study was approved by the Third Affiliated Hospital of Anhui Medical University Ethics Committee (2016063) on 20 November 2016.

Twenty-five medication-naive outpatients with PI, from the Department of Neurology in the Third Affiliated Hospital of Anhui Medical University, and 20 HC participants, matched for sex, age, and years of education, were included in this study. Before the trial experiment, we contacted participants and their family members by phone or in person and collected information on whether their clinical manifestations included night snoring, daytime sleepiness, apnea, or restless legs syndrome; if so, the participants were excluded. All participants were screened based on a complete 1-week sleep diary. The Pittsburgh Sleep Quality Index (PSQI)[51] was also used to assess the quality of sleep. The Epworth Sleepiness Scale (ESS) questionnaire was used to measure daytime sleepiness. Moreover, all participants underwent a night of polysomnographic (PSG) measurement the day before the test day. A standard PSG was used involving electromyographic (EMG; submental), electrooculographic (EOG: horizontal and vertical), and electroencephalographic (Fp1 [neutral], C3, P3 [reference], O1, Fpz, Fz, Cz, Pz, Oz, F4, C4) recordings. Sleep was recorded on PSG for 8 hours from "lights out" (22:00) until "lights on" (06:00). All participants showing PSG evidence of other sleep disorders, such as periodic leg movements or sleep apnea syndrome, were excluded from the study.

The diagnostic criteria for PI included a PSQI higher than 5, a sleep diary showing an average sleep efficiency $<85\%$, and the following diagnostic criteria for PI of the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-V):

(1) the presence of a subjective complaint of insomnia, including sleep difficulties ≥ 3 nights/week for at least 3 months ((a) sleep onset latency >30 min (difficulty initiating sleep) or time awake after sleep onset >30 min (maintaining sleep), (b) early morning awakening and insufficient amount of sleep (<6 hours of sleep));
(2) insomnia or its perceived consequences causing significant impairment in daytime functionalities (e.g., mood disturbances, fatigue, attention, social or occupational function).

Twenty-four healthy participants were recruited through an advertisement in the local community and had to self-define as good sleepers. Healthy participants were satisfied with their sleep (in an interview and based on sleep diaries), did not use medication to facilitate their sleep, reported having 7 to 9 hours of total sleep time per night in their sleep diary, had no daytime performance complaints, and their PSQI was lower than 5.

Exclusion criteria for both groups were as follows: other sleep disorders, such as periodic leg movements and sleep apnea syndrome; color blindness; neurological disease; drug abuse; current or previous psychiatric diagnoses; and history of diffuse brain damage.

2.2. Background information and neuropsychological tests

The following neuropsychological tests were administered to all participants:

(1) the Mini-Mental State Examination (MMSE) was used to evaluate global cognitive function;[52]
(2) the Beck Depression Inventory (BDI) was used to assess the presence of depression;
(3) the Beck Anxiety Inventory (BAI) was used to assess the presence of anxiety;
(4) a verbal fluency test (number of animals per min) was used to assess frontal lobe functions; [53]
(5) trail-making tests A and B were used to assess executive functioning; [54]
(6) a digit-span test, including forward digit span and backward digit span,[55] was used to estimate short-term memory; and
(7) a digit symbol substitution test was used to measure psychomotor speed.

2.3. Emotional memory task

The emotional memory task included two parts:

(1) emotional pictures evaluation, and
(2) a delayed (30 min) recognition activity.

The pictures used fell into 1 of 3 valence categories: positive, neutral, or negative, and were chosen from the Chinese Affective Picture System.[56]

During the emotional picture evaluation phase, the participants viewed 48 target pictures, including 16 positive, 16 neutral, and 16 negative pictures. Each emotional picture was presented (for 1000 ms) after a fixation cross on a computer screen, and the pictures were presented in a pseudo-random order after the cross disappeared from the screen. After each picture was presented, the subjects were asked to evaluate its valence using scores ranging from 1 (very negative) to 5 (neutral) to 9 (very happy), as rapidly as possible, and to give arousal ratings on a scale from "not arousing at all" (1 point) to "very arousing" (9 points). The emotional picture valence and arousal display remained visible until the participant responded, up to a maximum of 5000 ms.

During the delayed recognition phase, participants viewed 96 pictures comprising a mix of the 48 target pictures ("old") and 48 new distractors pictures, including 16 positive, 16 neutral, and 16 negative pictures. Each presentation began with a fixation slide (for 1000 ms) followed by the emotional picture (for 2000 ms). The participants were then asked whether the presented picture included the same target, "old," as shown in the emotional picture evaluation phase (yes/no). For each subject, the number of "old" pictures accurately recognized (hits) and the number of false alarms (inaccurately recognized "old" pictures) were calculated. The discrimination index (d′ value) was obtained by subtracting the false alarms (i.e., the new distractor pictures, identified as old) from the hits (i.e., the old pictures accurately recognized). Thus, a higher accuracy rate, represented by the d′ value for different valence pictures (positive, neutral, and negative), indicated better memory discrimination performance.

2.4. The Iowa Gambling Task

The IGT has often been used to test the ability of social decision-making under conditions of uncertainty.[57] We used the computerized version of the IGT in Chinese, described in detail in our previous publication.[58]

The subject was asked to select a card repeatedly from four decks of cards (1–4). Four decks of 40 cards were used, labeled "1," "2," "3," and "4" in Chinese. Subjects were given ¥2000 of play money and instructed to select a card from any deck in order to win as much money as possible, 1 card at a time. The subjects would win an amount of money with some selections, while losing an amount of money with other selections. Decks 1 and 2 were characterized by large wins (¥100 on each trial) but with occasional large punishments (e.g., ¥1250 on deck 2), leading to losses over repeated choices, and these were defined as the disadvantageous cards. Decks 3 and 4 were associated with smaller wins (only ¥50 per trial) but smaller losses, leading to profit over repeated choices, and these were defined as the advantageous cards. The task included 100 selections. The risks of each deck yielding rewards or penalties and the number of selections allowed were not disclosed to the subjects. The main dependent variables of the IGT task included the number of disadvantageous cards chosen from deck 1 or deck 2, and the number of advantageous cards chosen from deck 3 or deck 4. The 100 cards selected by the participants were divided into 5 blocks of 20 cards, according to the selection sequence. The first 20 trials represented the learning phase and were thus analyzed separately from trials 21 to 100, which represented the "test phase." We then calculated the total number of selected advantageous cards (decks 3 and 4) and disadvantageous cards in each block. The net score was calculated from each block using the formula [(3 + 4) – (1 + 2)]. After the task, we rewarded each participant with the money earned based on the results of the experiment. Positive net scores indicated that participants selected more advantageous cards, as a pattern of favorable behavior, while negative scores indicated that they selected more disadvantageous cards, determined as a pattern of disadvantageous behavior.

2.5. Statistical analysis

The statistical analyses were carried out using the SPSS software (version 23.0 for Windows). Parametric tests were used for normally distributed data (*t* test for 2 independent samples or analysis of variance [ANOVA]). Pearson correlations were used to examine potential relationships among emotional memory, decision-making, background characteristics, and neuropsychological tests in the PI and HC groups. The level of significance for all statistical tests was set at $P = .05$.

3. Results

3.1. Background characteristics and neuropsychological tests

We did not find any significant differences between the groups regarding age, sex, years of education, the MMSE score, forward digit span, and digit substitution symbol (all $P > .05$), and *t* tests for 2 independent samples showed significant group differences in scores for the PSQI, BDI, BAI, verbal fluency, backward digit span, and trail-making test (part B–part A) (all $P < .05$). As expected, the PI group showed shorter total sleep time, lower sleep efficiency, and higher sleep onset latency than the HC group (all $P < .05$); however, there was no difference in the objective level of time in bed and subjective ESS (both $P > .05$) (Table 1).

Table 1

Background characteristics and neuropsychological test results for the Primary Insomnia and Healthy Control groups (mean ± standard deviation).

	PI (n = 25)	HC (n = 20)	Statistics value	*P* value
Age (years)	42.40 ± 8.99	40.35 ± 7.01	$t = 0.83$	.41
Education (years)	9.12 ± 3.63	11.20 ± 4.76	$t = 1.61$	.11
Sex (M, F)	15, 10	9, 11	$X^2 = 1.00$	.32
MMSE	29.00 ± 1.55	29.15 ± 1.46	$t = 0.33$	.74
Course of disease (months)	21.08 ± 15.01	—	—	—
PSQI	15.64 ± 2.41	3.35 ± 1.31	$t = 21.78$	<.001
BDI	9.40 ± 1.95	4.35 ± 2.36	$t = 7.83$	<.001
BAI	9.44 ± 1.19	3.65 ± 2.23	t =11.15	<.001
ESS	2.52 ± 0.82	2.35 ± 0.75	$t = 0.72$	.48
Total time in bed (min)	465.6 ± 17.58	470.0 ± 14.14	$t = 0.91$	.37
Total sleep time (min)	328.68 ± 13.05	422.55 ± 14.66	$t = 22.69$	<.001
Sleep efficiency (%)	70.65 ± 3.15	89.91 ± 1.75	*t = 25.97*	<.001
Sleep onset latency	47.96 ± 5.34	19.25 ± 2.71	*t = 21.85*	<.001
Verbal fluency	9.40 ± 2.66	13.55 ± 3.48	$t = 4.53$	< .001
Forward digit span	6.80 ± 1.11	7.20 ± 1.15	$t = 1.17$	.25
Backward digit span	4.48 ± 0.91	5.45 ± 1.35	$t = 2.85$	.007
Trail making test:				
Part B–Part A (s)	52.32 ± 25.37	37.55 ± 15.60	$t = 2.39$	.02
Digit substitution symbol (number)	30.88 ± 5.41	33.25 ± 4.29	$t = 1.59$	.12

PI = primary insomnia; HC = healthy control; M = male; F = female; MMSE = Mini-Mental State Examination; PSQI = Pittsburgh Sleep Quality Index; BDI = Beck Depression Inventory; BAI = Beck Anxiety Inventory; ESS = Epworth Sleepiness Scale.

3.2. Emotional picture evaluation: valence ratings

In the emotional picture evaluation phase, we conducted a 2 (group [PI and HC]) × 3 (valence [positive, neutral, and negative]) ANOVA on the score for the 3 valence-type emotional pictures. There was no significant main effect of group [$F(1,43) = 1.26$, $P = .26$] and group × valence interaction [$F(2,43) = 1.24$, $P = .29$], but there was a significant effect of valence [$F(2,86) = 1726.12$, $P < .001$]. Post-hoc analysis showed that the valence score for neutral pictures was lower than that for positive pictures ($P < .001$) and higher than that for negative pictures ($P < .001$) in the PI and HC groups (Table 2).

3.3. Emotional pictures evaluate: arousal ratings

A 2 group × 3 valence (positive, neutral, and negative) ANOVA on arousal showed no significant main effect of group [$F(1,43) = 0.043$, $P = .84$],valence [$F(2,86) = 0.3$, $P = .74$], or group × valence interaction [$F(2,43) = 0.044$, $P = .95$], indicating no significant differences in arousal evaluation among the three valence pictures during the emotional picture evaluation between patients with PI and HC (Table 2).

Table 2

Valence and arousal for the negative, neutral, and positive pictures (mean ± standard deviation) for the Primary Insomnia and Healthy Control groups.

	Positive	Neutral	Negative
Valence			
PI group	6.72 ± 0.53	5.06 ± 0.22	2.80 ± 0.24
HC group	6.90 ± 0.37	5.05 ± 0.17	2.82 ± 0.22
Arousal			
PI group	5.21 ± 0.30	5.18 ± 0.33	5.22 ± 0.32
HC group	5.19 ± 0.27	5.16 ± 0.35	5.23 ± 0.29

PI = Primary Insomnia; HC = Healthy Control.

3.4. Delayed recognition phase: accuracy rate

A 2 (group) × 3 (valence) ANOVA for the emotional accuracy rate (d′ value) showed a significant main effect of group [$F(1,43) = 29.10$, $P < .001$] and a lower memory recognition ability in the PI than in the HC group; in addition, there was a significant effect of valence [$F(2,86) = 4.99$, $P = .008$], but no significant interaction between valence and group [$F(2,43) = 2.27$, $P = .11$]. Post-hoc analysis revealed that the PI group performed worse than the HC group in recognizing positive ($P = .001$) and neutral pictures ($P < .001$). However, there was no significant difference in d′ values for negative pictures ($P = .15$) between the 2 groups. This suggested that the PI group remembered negative pictures better than positive or neutral pictures (Fig. 1).

3.5. Decision-making in the IGT

Two independent *t* tests were employed to investigate whether PI and HC groups differed in terms of the selection of advantageous cards. We found that the PI group chose significantly fewer advantageous cards than the HC group ($t(43) = 3.17$, $P = .003$) (Fig. 2). We performed a 2 (group) × 5 (block) ANOVA and considered group (HC or PI) as the between-subjects factor and the net score in each block (1–5) as the within-subject factor. There was a significant main effect of group [$F(1,43) = 20.39$, $P < .001$], a significant main effect of block [$F(4,172) = 2.42$, $P = .04$], and no significant interaction of group × block [$F(4,43) = 1.61$, $P = .17$]. A post-hoc *t* test revealed that the HC group selected a greater number of advantageous cards than did the PI group in block 2 ($t(43) = 2.09$, $P = .042$), block 3 ($t(43) = 2.06$, $P = .045$), block 4 ($t(43) = 2.28$, $P = .03$), and block 5 ($t(43) = 3.47$, $P = .001$), but not in block 1 ($t(43) = 0.46$, $P = .65$) (Table 3). The results indicated that, as the IGT progressed, participants in the HC group gradually shifted their preference towards advantageous choices (decks 3 or 4) and away from disadvantageous ones (decks 1 or 2), after block 1, more so than did patients with PI (Fig. 3).

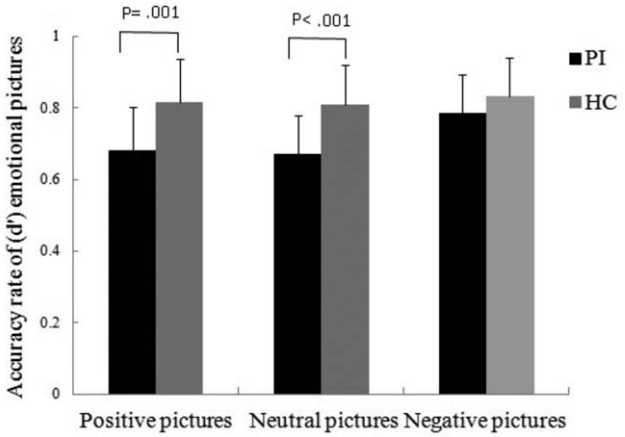

Figure 1. Performance in the delayed recognition phase. Mean scores (± standard deviations) indicating the function of recognition accuracy rate (d′ value, hits minus false alarms) of 3 types of valence pictures (positive vs neutral vs negative) for the PI and HC groups. Patients in the PI group exhibited worse memory of neutral and positive pictures than subjects in the HC group.

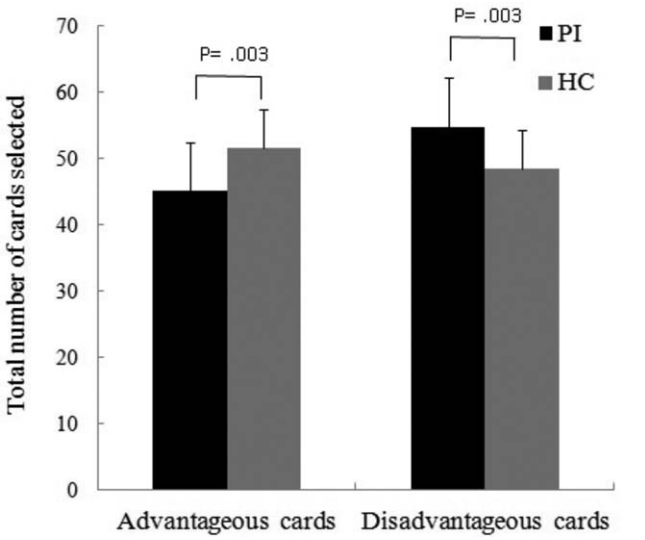

Figure 2. Performance in the Iowa Gambling Task (total number of selected cards). Each bar represents the mean (± standard deviation) of the total number of cards selected from the advantageous and disadvantageous decks. Patients with primary insomnia (PI) chose significantly more of the disadvantageous cards than did the healthy control (HC) group.

3.6. Correlations of d′ values and decision-making with background characteristics, PSG sleep parameters, and neuropsychological indexes in the P and HC groups

Pearson correlations among d′ values, performance on the IGT, background characteristics, PSG sleep parameters, and neuropsychological test scores were computed for the PI group. The results showed no significant correlation among d′ values and PSG sleep parameters, background characteristics, or neuropsychological test scores. The number of advantageous choices in the IGT significantly correlated with BAI scores ($r=-0.447$, $P=.025$); sleep efficiency significantly correlated with the trail-making test result (part B–part A) ($r=-0.49$, $P=.01$); and there was no correlation between any the neuropsychological indexes and the other d′ values and IGT results (all $P>.05$) (Table 4). Moreover, there were no significant correlations of d′ values and performance on the IGT with PSG sleep parameters, background characteristics, and neuropsychological test scores in the HC group (all $P>.05$) (Table 5). Considering the impact of depression and anxiety on participants with PI, we considered BDI and BAI scores as covariates in statistical analyses. Analysis of covariance showed that the BDI score had no covariate effect on the accuracy of d′ values for positive, neutral, or negative pictures ($P=.57$, $P=.99$, and $P=.67$, respectively) or on the total number of advantageous choices in the IGT ($P=.53$) between the 2 groups. Similarly, the BAI score had no covariate effect on the accuracy of positive, neutral, or negative pictures ($P=.81$, $P=.89$, $P=.69$, respectively), or on the number of advantageous choices in the IGT ($P=.27$) between the 2 groups.

4. Discussion and conclusions

The aim of the present study was to investigate the effects of PI on emotional memory and decision-making. As hypothesized, our results indicated a generalized deleterious effect of PI on emotional memory, while decision-making ability was also significantly impaired in patients with PI.

We first assessed the influence of PI on emotional memory. Patients in the PI group performed well in the emotional picture evaluation task, but not in the emotional recognition task. These results are consistent with previous studies reporting impairment in emotional memory in patients with sleep deprivation.[21,22,59] Other studies have indicated that sleep plays a key role in emotional memory processing.[24,26,27] Cunningham et al[27] reported that sleep can lead to preferential consolidation of negative emotional memory. A study by Cellini et al[28] indicated that daytime napping is beneficial for consolidating emotional memory presented before and after sleep, irrespective of valence. However, poor sleep quality has been reported to affect the emotional valence of memory negatively.[59] Previous studies on the relationship between sleep and emotional memory have mostly utilized experimental methods testing sleep deprivation[22,60] or have included only HC subjects.[61,62] Although many studies have shown that emotion[63] or memory[18,64] may change in patients with PI, there has been little research on emotional memory in these patients. Our findings imply that patients with PI have impaired performance on emotional memory tasks.

Table 3

Total number of advantageous cards chosen by the Primary Insomnia and Healthy Control groups (mean ± standard deviation).

Group	Block 1 (1–20)	Block 2 (21–40)	Block 3 (41–60)	Block 4 (61–80)	Block 5 (81–100)
PI (n = 25)	8.84 ± 1.62	9.12 ± 2.01	9.28 ± 2.35	9 ± 2.25	8.92 ± 2.25
HC (n = 20)	8.6 ± 1.88	10.5 ± 2.42	10.75 ± 2.40	10.75 ± 2.92	10.95 ± 1.47
Statistics value	t = 0.46	t = 2.09	t = 2.06	t = 2.28	t = 3.47
P value	P = .65	P = .042	P = .045	P = .03	P = .001

PI = Primary Insomnia; HC = Healthy Control.

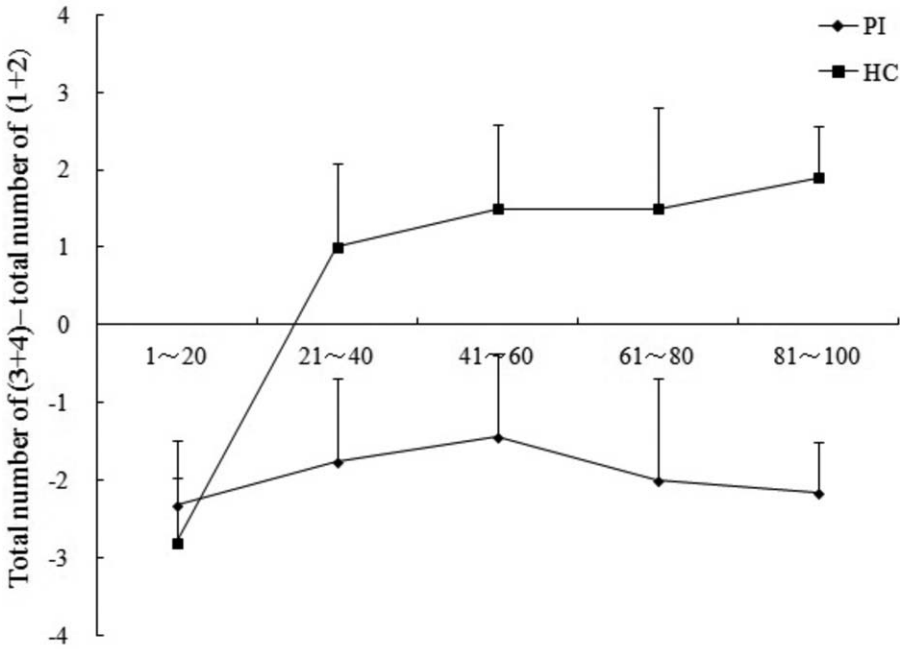

Figure 3. Performance in the Iowa Gambling Task (net scores and task progression). Net score difference is expressed as mean (± standard error) of the frequency of advantageous (decks 3 + 4) selections minus that of disadvantageous selections (decks 1 + 2), as a function of 5 blocks (1–20, 21–40, 41–60, 61–80, 81–100). There was a distinct pattern in decision-making between the 2 groups as the task progressed over the 5 blocks.

We also found different patterns of alterations in the recognition of emotional pictures, as a function of their valance. Specifically, we showed that PI adversely affects recognition of positive and neutral pictures, but not of negative pictures. Previous studies have suggested that negative stimuli may be remembered better than other stimuli.[21,65,66] A study by Tempesta et al[29] indicated that the accuracy of remembering negative pictures is more stable than that of remembering neutral or positive emotional pictures, in subjects with sleep deprivation. This might be attributed to the facilitating effect of negative stimuli during the encoding phase,[67] which seems to be mediated by the amygdala.[68] Moreover, previous studies have shown that negative stimuli increase activity in the amygdala during sleep loss.[32,33] This indicates that the greater stability of negative stimulus memory may be attributed to the increased reactivity to negative pictures, induced by insomnia,[31] and the heightened amygdala responses to negative stimuli.[33] Our results are similar to those of previous studies on individuals with sleep deprivation.[21,29] Previous studies have suggested that emotional memory relies on many brain regions, including the hippocampus, prefrontal cortex, and amygdala,[31,69] and that sleep loss negatively affects the functionality of these regions.[70] Structural and functional neuroimaging studies have provided insight into the alterations of regional brain function in PI. These studies have shown that gray matter in the orbitofrontal and cingulate cortex, hippocampus, and middle temporal gyri is affected by chronic PI.[38,71,72] Changes due to PI include decreased connectivity in the frontoparietal network[19,43] and emotional circuits.[73] The deleterious effects of PI on memory retention of positive and neutral pictures, but not of negative pictures, may be related to the amplified reactivity of the amygdala to negative stimuli,[25,74] as well as the decreased functional connectivity of the amygdala with the prefrontal cortex.[35,75,76]

The second aim of the present study was to assess the social decision-making ability in patients with PI. Patients with PI had significantly impaired performance in the IGT. In this task, the PI group more often selected disadvantageous cards and placed higher bets, based on simple probabilistic decisions. In the first block, participants in both the PI and HC groups tended to select more disadvantageous cards. This result suggests that the 2 groups were unaware of the rule at the beginning. However, analyses showed that the HC group improved significantly by making advantageous choices in the test phases over the PI group. The results indicated that the participants in the HC group could gradually shift their more disadvantageous card selections toward the advantageous decks after the first learning phase, but the PI group did not show this beneficial behavior pattern and failed to learn the rules to select cards from advantageous decks. Two studies from Killgore et al[46,77] also showed that, after sleep deprivation, volunteers tended to choose from the disadvantageous high-risk deck more frequently. An event-related potential study showed that the N250–400 amplitude was smaller after sleep deprivation in the feedback stage of the IGT.[50] The results suggested that sleep loss affects risk-taking behavior due to reduced individual responses to negative feedback stimuli. Both Pace-Schott et al[78] and Seeley et al[48] provided new evidence that sufficient sleep can improve understanding of decision-making rules, as well as behavioral outcomes. Decision-making ability under conditions of uncertainty, as assessed using the IGT task, has been proven to be sensitive to abnormal functioning of the orbitofrontal cortex (OFC) and ventromedial prefrontal cortex.[79–81] Several functional brain imaging studies have also demonstrated that the medial frontal cortex is activated when

Table 4

Pearson's correlation coefficients for correlations of d' values and decision-making with background characteristics, polysomnography sleep parameters, and neuropsychological indexes in the Primary Insomnia group.

		Age	Education	MMSE	Course of disease	PSQI	BDI	BAI	ESS	Total time in bed	Total sleep time	Sleep efficiency	Sleep onset latency	Verbal fluency	Forward digit span	Backward digit span	Trail making test: Part B – Part A (s)	Digit symbol substitution
d'value (positive)	Pearson's r	−0.04	0.05	0.17	−0.02	0.19	−0.31	−0.27	−0.03	0.31	−0.11	0.17	0.13	0.26	−0.13	0.04	0.17	−0.17
	P	0.86	0.82	0.43	0.93	0.37	0.14	0.20	0.89	0.13	0.59	0.42	0.54	0.21	0.55	0.86	0.41	0.42
d'value (neutral)	Pearson's r	−0.31	0.26	0.20	−0.24	0.33	−0.12	0.004	0.20	0.13	−0.03	−0.32	0.18	−0.22	0.01	0.21	0.05	0.10
	P	0.14	0.20	0.33	0.26	0.11	0.57	0.99	0.34	0.54	0.89	0.11	0.38	0.28	0.98	0.31	0.82	0.65
d'value (negative)	Pearson's r	−0.07	0.18	−0.05	0.05	0.28	−0.08	0.02	0.09	−0.13	−0.01	0.10	−0.05	−0.15	0.35	0.25	−0.16	0.02
	P	0.76	0.40	0.83	0.81	0.18	0.72	0.92	0.69	0.55	0.95	0.62	0.82	0.47	0.09	0.23	0.45	0.92
Total number of advantageous cards selected	Pearson's r	−0.08	0.17	0.27	−0.21	0.31	−0.14	−.447	−0.16	0.21	0.02	0.17	0.22	−0.11	−0.27	−0.34	0.29	0.26
	P	.72	.42	.19	.32	.13	.49	.025*	.45	.31	.93	.43	.30	.59	.20	.10	.15	.21

MMSE = Mini-Mental State Examination; PSQI = Pittsburgh Sleep Quality Index; BDI,Beck Depression Inventory; BAI = Beck Anxiety Inventory; ESS = Epworth Sleepiness Scale.
*Correlation is significant at the .05 level (2-tailed).
†Correlation is significant at the .01 level (2-tailed).

Table 5

Pearson correlation coefficients for correlations of d' values and decision-making with background characteristics, polysomnography sleep parameters, and neuropsychological indexes in the Healthy Control group.

		Age	Education	MMSE	PSQI	BDI	BAI	ESS	Total time in bed	Total sleep time	Sleep efficiency	Sleep onset latency	Verbal fluency	Forward digit span	Backward digit span	Trail making test: Part B - Part A (s)	Digit substitution symbo
d'value (positive)	Pearson's *r*	−.31	.11	.10	−.15	.18	.11	−.01	−.06	−.08	−.02	−.24	.08	.03	−0.07	−0.25	0.11
	P	.19	.65	.67	.54	.45	.63	.98	.82	.73	.95	.32	.73	.91	.79	.29	.65
d'value (neutral)	Pearson's *r*	−.06	−.21	−.14	.02	.14	−.03	−.28	−.09	−.04	.15	−.01	.16	.37	.08	−.08	.02
	P	.80	.37	.56	.95	.56	.89	.23	.70	.86	.52	.97	.52	.11	.74	.74	.95
d'value (negative)	Pearson's *r*	−.20	−.35	.05	−.09	.24	−.12	−.22	−.19	.10	.31	−.12	−.17	.23	.07	−.24	−.33
	P	.39	.13	.82	.72	.32	.61	.36	.42	.67	.19	.62	.48	.34	.76	.30	.15
Total number of advantageous cards selected	Pearson's *r*	−.14	−.01	.39	−.29	−.03	.10	−.31	−.06	.18	.16	.36	.22	−.34	.04	.09	.09
	P	.57	.96	.09	.21	.90	.69	.18	.81	.45	.49	.12	.35	.14	.87	.71	.70

MMSE = Mini-Mental State Examination; PSQI = Pittsburgh Sleep Quality Index; BDI = Beck Depression Inventory; BAI = Beck Anxiety Inventory; ESS = Epworth Sleepiness Scale.
*Correlation is significant at the .05 level (2-tailed).
†Correlation is significant at the .01 level (2-tailed).

subjects perform decision-making tasks under uncertainty.[82–84] Moreover, patients with dysfunction in the ventromedial prefrontal cortex, including regions of the OFC, fail to develop anticipatory electrodermal responses before making a choice. This, in turn, disrupts the ability to utilize emotional signals to guide decision-making, to learn from past experiences, and to avoid adverse choices.[85,86] Functional imaging studies have confirmed that PI can lead to structural changes in the prefrontal cortex,[38,71] decreased low-frequency fluctuations in the bilateral OFC,[87] and reduced functional connectivity to emotional circuits.[73,88] Our data suggested that participants with PI have similar deficits as patients with damage to the OFC. Although patients with PI show fewer global impairments than do patients with brain injuries, as seen in a clinical setting, they exhibit similar performance patterns as patients with OFC lesions.[85] This suggests that the functioning of similar prefrontal cortical regions may be adversely affected by PI; however, in the present study, we did not provide evidence for a direct reduction in prefrontal activity in the PI group during the IGT.

Apart from deficits in emotional memory and decision-making, we found that patients with PI exhibited widespread basic cognitive impairments, including deficits in working memory, and executive function. These results are in line with those of previous studies.[42,89] By using Pearson's correlation analysis, we also showed that sleep efficiency correlated with the results of the trail-making test, consistent with the results of a previous study that indicated that poorer sleep quality is associated with poorer executive function.[90] Moreover, the number of advantageous choices in the IGT correlated significantly with the BAI score. Previous studies have shown that patients with trait anxiety show a choice preference for deck 1 or 2 in the IGT,[91] suggesting that deficits in social decision-making ability may be due to exaggeration of emotional feelings or emotion regulation deficits.[92,93] Emotional changes are associated with punishment or reward signals for the past and potential occurrence of an outcome, thus guiding long-term behavior according to the "somatic-marker hypothesis".[85] In line with previous research reports,[94] our findings suggest that anxiety, caused by PI, can lead to impaired decision-making in terms of risk under ambiguous conditions.

This study had some limitations. In the absence of functional brain imaging data, we could not provide direct evidence to demonstrate whether deficits in emotional memory and decision-making in patients with PI are due to functional changes in the amygdala and prefrontal cortex. The PI and HC patients were not adequately matched at baseline, especially in terms of the psychological state of both groups, although analysis of covariance showed that the BDI and BAI score had no covariate effect on the accuracy (d′ values) for positive, neutral, or negative pictures or on the total number of advantageous choices in the IGT. Therefore, further neuropsychological and functional brain imaging studies are required to confirm the neural mechanisms underlying emotional memory and decision-making impairments in patients with PI.

Our findings suggest that insomnia had different effects on memory, depending on the emotional valence of the memory. Specifically, there was memory performance impairment for positive and neutral items, but the recognition of negative stimuli seemed to be more resistant to the effects of insomnia. Our results also suggested that decision-making, including decision-making under conditions of uncertainty, may be vulnerable to PI. However, elucidating the relationship between emotional memory and decision-making impairment in patients with PI and changes in prefrontal lobe function will require further functional brain imaging studies.

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References

[1] Roth T, Roehrs T, Pies R. Insomnia: pathophysiology and implications for treatment. Sleep Med Rev 2007;11:71–9.
[2] Goldman-Mellor S, Gregory AM, Caspi A, et al. Mental health antecedents of early midlife insomnia: evidence from a four-decade longitudinal study. Sleep 2014;37:1767–75.
[3] Hasler BP, Martin CS, Wood DS, et al. A longitudinal study of insomnia and other sleep complaints in adolescents with and without alcohol use disorders. Alcohol Clin Exp Res 2014;38:2225–33.
[4] Fortier-Brochu E, Morin CM. Cognitive impairment in individuals with insomnia: clinical significance and correlates. Sleep 2014;37:1787–98.
[5] Liu H, Wang D, Li Y, et al. Examination of daytime sleepiness and cognitive performance testing in patients with primary insomnia. PloS One 2014;9:e100965.
[6] Li Y, Liu H, Weed JG, et al. Deficits in attention performance are associated with insufficiency of slow-wave sleep in insomnia. Sleep Med 2016;24:124–30.
[7] Baglioni C, Spiegelhalder K, Lombardo C, et al. Sleep and emotions: a focus on insomnia. Sleep Med Rev 2010;14:227–38.
[8] Stickgold R. Sleep-dependent memory consolidation. Nature 2005;437:1272–8.
[9] Walker MP, Stickgold R. Sleep-dependent learning and memory consolidation. Neuron 2004;44:121–33.
[10] Cipolli C, Mazzetti M, Plazzi G. Sleep-dependent memory consolidation in patients with sleep disorders. Sleep Med Rev 2013;17:91–103.
[11] Studte S, Bridger E, Mecklinger A. Nap sleep preserves associative but not item memory performance. Neurobiol Learn Mem 2015;120:84–93.
[12] Yaffe K, Falvey CM, Hoang T. Connections between sleep and cognition in older adults. Lancet Neurol 2014;13:1017–28.
[13] Koo DL, Shin JH, Lim JS, et al. Changes in subcortical shape and cognitive function in patients with chronic insomnia. Sleep Med 2017;35:23–6.
[14] Del Angel J, Cortez J, Juarez D, et al. Effects of sleep reduction on the phonological and visuospatial components of working memory. Sleep Sci 2015;8:68–74.
[15] Xie M, Yan J, He C, et al. Short-term sleep deprivation impairs spatial working memory and modulates expression levels of ionotropic glutamate receptor subunits in hippocampus. Behav Brain Res 2015;286:64–70.
[16] Alberca-Reina E, Cantero JL, Atienza M. Semantic congruence reverses effects of sleep restriction on associative encoding. Neurobiol Learn Mem 2014;110:27–34.
[17] Drummond SP, Walker M, Almklov E, et al. Neural correlates of working memory performance in primary insomnia. Sleep 2013;36:1307–16.
[18] Li Y, Liu L, Wang E, et al. Abnormal neural network of primary insomnia: evidence from spatial working memory task fMRI. Eur Neurol 2016;75:48–57.

[19] Li S, Tian J, Li M, et al. Altered resting state connectivity in right side frontoparietal network in primary insomnia patients. Eur Radiol 2018;28:664–72.
[20] Drummond SP, Brown GG, Gillin JC, et al. Altered brain response to verbal learning following sleep deprivation. Nature 2000;403:655–7.
[21] Tempesta D, Socci V, Coppo M, et al. The effect of sleep deprivation on the encoding of contextual and non-contextual aspects of emotional memory. Neurobiol Learn Mem 2016;131:9–17.
[22] Tempesta D, Socci V, Dello Ioio G, et al. The effect of sleep deprivation on retrieval of emotional memory: a behavioural study using film stimuli. Exp Brain Res 2017;235:3059–67.
[23] Rosales-Lagarde A, Armony JL, Del Rio-Portilla Y, et al. Enhanced emotional reactivity after selective REM sleep deprivation in humans: an fMRI study. Front Behav Neurosci 2012;6:25.
[24] Kaida K, Niki K, Born J. Role of sleep for encoding of emotional memory. Neurobiol Learn Mem 2015;121:72–9.
[25] Kyle SD, Beattie L, Spiegelhalder K, et al. Altered emotion perception in insomnia disorder. Sleep 2014;37:775–83.
[26] Payne JD, Chambers AM, Kensinger EA. Sleep promotes lasting changes in selective memory for emotional scenes. Front Integr Neurosci 2012;6:108.
[27] Cunningham TJ, Crowell CR, Alger SE, et al. Psychophysiological arousal at encoding leads to reduced reactivity but enhanced emotional memory following sleep. Neurobiol Learn Mem 2014;114:155–64.
[28] Cellini N, Torre J, Stegagno L, et al. Sleep before and after learning promotes the consolidation of both neutral and emotional information regardless of REM presence. Neurobiol Learn Mem 2016;133:136–44.
[29] Tempesta D, De Gennaro L, Presaghi F, et al. Emotional working memory during sustained wakefulness. J Sleep Res 2014;23:646–56.
[30] Pilcher JJ, Callan C, Posey JL. Sleep deprivation affects reactivity to positive but not negative stimuli. J Psychosom Res 2015;79:657–62.
[31] Altena E, Micoulaud-Franchi JA, Geoffroy PA, et al. The bidirectional relation between emotional reactivity and sleep: from disruption to recovery. Behav Neurosci 2016;130:336–50.
[32] Motomura Y, Kitamura S, Oba K, et al. Sleep debt elicits negative emotional reaction through diminished amygdala-anterior cingulate functional connectivity. PloS One 2013;8:e56578.
[33] Baglioni C, Spiegelhalder K, Regen W, et al. Insomnia disorder is associated with increased amygdala reactivity to insomnia-related stimuli. Sleep 2014;37:1907–17.
[34] Pessoa L. On the relationship between emotion and cognition. Nat Rev Neurosci 2008;9:148–58.
[35] Shao Y, Lei Y, Wang L, et al. Altered resting-state amygdala functional connectivity after 36 hours of total sleep deprivation. PloS One 2014;9: e112222.
[36] Thomas M, Sing H, Belenky G, et al. Neural basis of alertness and cognitive performance impairments during sleepiness. I. Effects of 24 h of sleep deprivation on waking human regional brain activity. J Sleep Res 2000;9:335–52.
[37] Seeley CJ, Smith CT, MacDonald KJ, et al. Ventromedial prefrontal theta activity during rapid eye movement sleep is associated with improved decision-making on the Iowa Gambling Task. Behav Neurosci 2016;130:271–80.
[38] Altena E, Vrenken H, Van Der Werf YD, et al. Reduced orbitofrontal and parietal gray matter in chronic insomnia: a voxel-based morphometric study. Biol Psychiatry 2010;67:182–5.
[39] Bechara A, Damasio H, Damasio AR. Emotion decision making and the orbitofrontal cortex. Cereb Cortex 2000;10:295–307.
[40] Padoa-Schioppa C, Conen KE. Orbitofrontal cortex: a neural circuit for economic decisions. Neuron 2017;96:736–54.
[41] Wallis JD. Orbitofrontal cortex and its contribution to decision-making. Annu Rev Neurosci 2007;30:31–56.
[42] Perrier J, Chavoix C, Bocca ML. Functioning of the three attentional networks and vigilance in primary insomnia. Sleep Med 2015;16:1569–75.
[43] Li Y, Wang E, Zhang H, et al. Functional connectivity changes between parietal and prefrontal cortices in primary insomnia patients: evidence from resting-state fMRI. Eur J Med Res 2014;19:32.
[44] Perrier J, Clochon P, Bertran F, et al. Specific EEG sleep pattern in the prefrontal cortex in primary insomnia. PloS One 2015;10:e0116864.
[45] Sun JJ, Liu XM, Shen CY, et al. Reduced prefrontal activation during verbal fluency task in chronic insomnia disorder: a multichannel near-infrared spectroscopy study. Neuropsychiatr Dis Treat 2017;13: 1723–31.
[46] Killgore WD, Balkin TJ, Wesensten NJ. Impaired decision making following 49 h of sleep deprivation. J Sleep Res 2006;15:7–13.
[47] Venkatraman V, Chuah YM, Huettel SA, et al. Sleep deprivation elevates expectation of gains and attenuates response to losses following risky decisions. Sleep 2007;30:603–9.
[48] Seeley CJ, Beninger RJ, Smith CT. Post learning sleep improves cognitive-emotional decision-making: evidence for a 'deck B sleep effect' in the Iowa Gambling Task. PloS One 2014;9:e112056.
[49] Hebscher M, Barkan-Abramski M, Goldsmith M, et al. Memory, decision-making and the ventromedial prefrontal cortex (vmPFC): the roles of subcallosal and posterior orbitofrontal cortices in monitoring and control processes. Cereb Cortex 2016;26:4590–601.
[50] Liu L, Zhou R. Effect of 72 h of sleep deprivation on the Iowa gambling task. Noro Psikiyatr Ars 2016;53:357–60.
[51] Buysse DJ, Reynolds CF3rd , Monk TH, et al. The Pittsburgh sleep quality index: a new instrument for psychiatric practice and research. Psychiatry Res 1989;28:193–213.
[52] Zhang MY. The application of scales in diagnosis of dementia. J Applied Med (in Chinese) 1992;13:337–40.
[53] Lezak MD, Howieson DB, Loring DW. Neuropsychological Assessment. 4th edn. USA: New York: Oxford University Press; 2004.
[54] Tombaugh TN. Trail making test A and B: normative data stratified by age and education. Arch Clin Neuropsychol 2004;19:203–14.
[55] Gong YX. Wechsler adult intelligence scale-revised in China Version. 1992. Changsha, Hunan/China. Hunan Medical College.
[56] Bai L, Ma H, Huang Y, et al. The development of native Chinese affective picture system–a pretest in 46 college students. Chin Mental Health J 2005;19:719–22.
[57] Kim HW, Kang JI, Namkoong K, et al. Further evidence of a dissociation between decision-making under ambiguity and decision-making under risk in obsessive-compulsive disorder. J Affect Disord 2015;176:118–24.
[58] Xi C, Zhu Y, Mu Y, et al. Theory of mind and decision-making processes are impaired in Parkinson's disease. Behav Brain Res 2015;279:226–33.
[59] Tempesta D, De Gennaro L, Natale V, et al. Emotional memory processing is influenced by sleep quality. Sleep Med 2015;16:862–70.
[60] Wiesner CD, Pulst J, Krause F, et al. The effect of selective REM-sleep deprivation on the consolidation and affective evaluation of emotional memories. Neurobiol Learn Mem 2015;122:131–41.
[61] Lehmann M, Schreiner T, Seifritz E, et al. Emotional arousal modulates oscillatory correlates of targeted memory reactivation during NREM, but not REM sleep. Sci Rep 2016;6:39229.
[62] Ashton JE, Cairney SA, Gaskell MG. No effect of targeted memory reactivation during slow-wave sleep on emotional recognition memory. J Sleep Res 2018;27:129–37.
[63] Palagini L, Petri E, Novi M, et al. Adult insecure attachment plays a role in hyperarousal and emotion dysregulation in insomnia disorder. Psychiatry Res 2018;262:162–7.
[64] Guo H, Wei M, Ding W. Changes in cognitive function in patients with primary insomnia. Shanghai Arch Psychiatry 2017;29:137–45.
[65] Hamilton JP, Gotlib IH. Neural substrates of increased memory sensitivity for negative stimuli in major depression. Biol Psychiatry 2008;63:1155–62.
[66] Morgenthaler J, Wiesner CD, Hinze K, et al. Selective REM-sleep deprivation does not diminish emotional memory consolidation in young healthy subjects. PloS One 2014;9:e89849.
[67] Watts S, Buratto LG, Brotherhood EV, et al. The neural fate of neutral information in emotion-enhanced memory. Psychophysiology 2014;51:673–84.
[68] Park BY, Hong J, Park H. Neuroimaging biomarkers to associate obesity and negative emotions. Sci Rep 2017;7:7664.
[69] Sterpenich V, Albouy G, Boly M, et al. Sleep-related hippocampo-cortical interplay during emotional memory recollection. PLoS Biol 2007;5:e282.
[70] Krause AJ, Simon EB, Mander BA, et al. The sleep-deprived human brain. Nat Rev Neurosci 2017;18:404–18.
[71] Joo EY, Noh HJ, Kim JS, et al. Brain gray matter deficits in patients with chronic primary insomnia. Sleep 2013;36:999–1007.
[72] Li M, Yan J, Li S, et al. Altered gray matter volume in primary insomnia patients: a DARTEL-VBM study. Brain Imaging Behav 2018;12:1759–67doi: 10.1007/s11682-018-9844-x.
[73] Huang Z, Liang P, Jia X, et al. Abnormal amygdala connectivity in patients with primary insomnia: evidence from resting state fMRI. Eur J Radiol 2012;81:1288–95.
[74] Yoo SS, Gujar N, Hu P, et al. The human emotional brain without sleep–a prefrontal amygdala disconnect. Curr Biol 2007;17:R877–8.

[75] Suardi A, Sotgiu I, Costa T, et al. The neural correlates of happiness: a review of PET and fMRI studies using autobiographical recall methods. Cogn Affect Behav Neurosci 2016;16:383–92.
[76] Vanderhasselt MA, De Raedt R, Brunoni AR, et al. tDCS over the left prefrontal cortex enhances cognitive control for positive affective stimuli. PloS One 2013;8:e62219.
[77] Killgore WD, Lipizzi EL, Kamimori GH, et al. Caffeine effects on risky decision making after 75 hours of sleep deprivation. Aviat Space Environ Med 2007;78:957–62.
[78] Pace-Schott EF, Nave G, Morgan A, et al. Sleep-dependent modulation of affectively guided decision-making. J Sleep Res 2012;21:30–9.
[79] Eggen C, Huber O, Bar A, et al. Impairments in an early stage of the decision-making process in patients with ventromedial prefrontal damage: preliminary results. Neurocase 2015;21:509–19.
[80] Manes F, Sahakian B, Clark L, et al. Decision-making processes following damage to the prefrontal cortex. Brain 2002;125:624–39.
[81] Bechara A, Damasio H, Tranel D, et al. Dissociation of working memory from decision making within the human prefrontal cortex. J Neurosci 1998;18:428–37.
[82] Fukui H, Murai T, Fukuyama H, et al. Functional activity related to risk anticipation during performance of the Iowa Gambling Task. Neuro-Image 2005;24:253–9.
[83] Lin CH, Chiu YC, Cheng CM, et al. Brain maps of Iowa gambling task. BMC Neurosci 2008;9:72.
[84] Halfmann K, Hedgcock W, Bechara A, et al. Functional neuroimaging of the Iowa Gambling Task in older adults. Neuropsychology 2014;28:870–80.
[85] Bechara A. The role of emotion in decision-making: evidence from neurological patients with orbitofrontal damage. Brain Cogn 2004;55:30–40.
[86] Bechara A, Damasio AR, Damasio H, et al. Insensitivity to future consequences following damage to human prefrontal cortex. Cognition 1994;50:7–15.
[87] Li C, Ma X, Dong M, et al. Abnormal spontaneous regional brain activity in primary insomnia: a resting-state functional magnetic resonance imaging study. Neuropsychiatr Dis Treat 2016;12:1371–8.
[88] Wang T, Yan J, Li S, et al. Increased insular connectivity with emotional regions in primary insomnia patients: a resting-state fMRI study. Eur Radiol 2017;27:3703–9.
[89] Noh HJ, Joo EY, Kim ST, et al. The relationship between hippocampal volume and cognition in patients with chronic primary insomnia. J Clin Neurol 2012;8:130–8.
[90] Kuula L, Pesonen AK, Martikainen S, et al. Poor sleep and neuro-cognitive function in early adolescence. Sleep Med 2015;16:1207–12.
[91] Zhang L, Wang K, Zhu C, et al. Trait anxiety has effect on decision making under ambiguity but not decision making under risk. PloS One 2015;10:e0127189.
[92] Zhang D, Gu R. Behavioral preference in sequential decision-making and its association with anxiety. Hum Brain Mapp 2018;39:2482–99.
[93] Wu T, Luo Y, Broster LS, et al. The impact of anxiety on social decision-making: behavioral and electrodermal findings. Soc Neurosci 2013;8:11–21.
[94] Miu AC, Heilman RM, Houser D. Anxiety impairs decision-making: psychophysiological evidence from an Iowa Gambling Task. Biol Psychiatry 2008;77:353–8.