Impaired emotional memory and decision-making following primary insomnia

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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 intermixed 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.\textsuperscript{[11]} 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.\textsuperscript{[2,3]} Moreover, insomnia can lead to impairments of many basic cognitive functions, including learning and memory,\textsuperscript{[4,5]} attention,\textsuperscript{[5,6]} as well as emotional impairments.\textsuperscript{[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.\textsuperscript{[8–10]} Taking a nap can improve memory, which supports the view that even short-term sleep is advantageous for memory consolidation.\textsuperscript{[11]} Memory impairment is thought to be the core symptom of the decline in cognitive function associated with sleep loss\textsuperscript{[12,13]} and may encompass deficits in working memory,\textsuperscript{[14,15]} as well as encoding of new memory information.\textsuperscript{[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.\textsuperscript{[17–20]}

In recent years, many studies on sleep disorders\textsuperscript{[21–23]} have implied that sleep is also important in emotional memory, and that sleep loss negatively influences emotional memory.\textsuperscript{[24]} but not the categorization of emotional perception.\textsuperscript{[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
memory, during sleep.\textsuperscript{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.\textsuperscript{29,30}

The formation of emotional memory depends on the activity in specific structures, such as the amygdala, insula, prefrontal cortex, and hippocampus.\textsuperscript{31} A study by Motomura et al.\textsuperscript{32} showed increased activity in the amygdala in sleep-deprived subjects when they were presented with aversive pictures. Baglioni et al.\textsuperscript{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.\textsuperscript{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.\textsuperscript{31,34} A study by Shao et al.\textsuperscript{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.\textsuperscript{35}

Another functional change includes the prefrontal lobe, which is more prone to be affected by sleep loss. A study by Thomas et al.\textsuperscript{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).\textsuperscript{37} Altena et al.\textsuperscript{38} also revealed that patients with PI exhibit smaller gray matter volumes in the left orbitofrontal region, 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.\textsuperscript{39–41} Moreover, several studies have reported that this neural circuitry maybe sensitive to insomnia.\textsuperscript{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.\textsuperscript{46,47} A recent study from Seeley et al.\textsuperscript{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,\textsuperscript{49,50} and decision-making ability has been shown to be impaired in participants with sleep deprivation.\textsuperscript{46,50} Previous studies have also confirmed functional abnormalities in the prefrontal cortex of patients with PI.\textsuperscript{18,45} 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.\textsuperscript{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)\textsuperscript{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 (EEG; C3, 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 distractor 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.[37] 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).
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 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      | X² = 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 ± 3.11 | 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.

### 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.

### Table 3
Background characteristics and neuropsychological test results for the Primary Insomnia and Healthy Control groups (mean ± standard deviation).

### 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 test revealed that the HC group selected a greater number of advantageous cards than those of other groups (block 3: t(43) = 2.09, P = .042), block 4 (t(43) = 2.06, P = .045), block 5 (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).
3.6. Correlations of \( \Delta \) values and decision-making with background characteristics, PSG sleep parameters, and neuropsychological indexes in the P and HC groups

Pearson correlations among \( \Delta \) 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 \( \Delta \) values and PSG sleep parameters, background characteristics, or neuropsychological test scores. The number of advantageous choices in the IGT significantly correlated with BAI scores \((r = -0.447, P = 0.025)\); sleep efficiency significantly correlated with the trail-making test result (part B–part A) \((r = -0.49, P = 0.01)\); and there was no correlation between any of the neuropsychological indexes and the other \( \Delta \) values and IGT results \((all \ P > 0.05)\) (Table 4).

Moreover, there were no significant correlations of \( \Delta \) values and performance on the IGT with PSG sleep parameters, background characteristics, and neuropsychological test scores in the HC group \((all \ P > 0.05)\) (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 \( \Delta \) values for positive, neutral, or negative pictures \((P = 0.57, P = 0.99, and P = 0.67, respectively)\) or on the total number of advantageous choices in the IGT \((P = 0.53)\) between the 2 groups. Similarly, the BAI score had no covariate effect on the accuracy of positive, neutral, or negative pictures \((P = 0.81, P = 0.89, P = 0.69, respectively)\), or on the number of advantageous choices in the IGT \((P = 0.27)\) 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.\(^{59}\) 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\(^{22,59}\) or have included only HC subjects.\(^{61,62}\) Although many studies have shown that emotion\(^{53}\) 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

| 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 | \(t = 0.46\) | \(t = 0.09\) | \(t = 0.06\) | \(t = 2.28\) | \(t = 3.47\) |
| \(P\) value | \(P = .65\) | \(P = .042\) | \(P = .045\) | \(P = .03\) | \(P = .001\) |

\(PI = \) Primary Insomnia; HC = Healthy Control.
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. A study by Tempesta et al. 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, which seems to be mediated by the amygdala. Moreover, previous studies have shown that negative stimuli increase activity in the amygdala during sleep loss. This indicates that the greater stability of negative stimulus memory may be attributed to the increased reactivity to negative pictures, induced by insomnia, and the heightened amygdala responses to negative stimuli. Our results are similar to those of previous studies on individuals with sleep deprivation. Previous studies have suggested that emotional memory relies on many brain regions, including the hippocampus, prefrontal cortex, and amygdala, and that sleep loss negatively affects the functionality of these regions. 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. Changes due to PI include decreased connectivity in the frontoparietal network and emotional circuits. 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, as well as the decreased functional connectivity of the amygdala with the prefrontal cortex.

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. 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. The results suggested that sleep loss affects risk-taking behavior due to reduced individual responses to negative feedback stimuli. Both Pace-Schott et al. and Seeley et al. 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. 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 \( \Delta \) 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          | 0.26              | -0.13              | 0.04                | 0.17            |
| \( P \)           | 0.86 | 0.82      | 0.43 | 0.37              | 0.93 | 0.20 | 0.89 | 0.13 | 0.89              | 0.17             | 0.13             | 0.34              | 0.93          | 0.20              | 0.26                | 0.04                | 0.17            |
| **d' value (neutral)** |     |           |      |                   |      |     |     |     |                   |                  |                  |                   |              |                   |                     |                          |                        |
| Pearson’s \( r \)  | -0.31| 0.26      | 0.20 | -0.24             | 0.33 | -0.06| 0.04 | 0.20 | 0.13              | -0.03            | -0.32            | -0.22             | -0.22        | 0.54              | 0.21                | 0.55                | 0.95            |
| \( P \)           | 0.14 | 0.30      | 0.33 | 0.26              | 0.11 | 0.57 | 0.99 | 0.84 | 0.17              | 0.11             | 0.13             | 0.28              | 0.98          | 0.12              | 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 | 0.09              | -0.13            | -0.10            | -0.05             | -0.15        | 0.22              | 0.35                | 0.25                | -0.16           |
| \( P \)           | 0.76 | 0.40      | 0.83 | 0.81              | 0.72 | 0.92 | 0.69 | 0.55 | 0.95              | 0.62             | 0.82             | 0.47              | 0.23          | 0.45              | 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| -4.77| -0.16| 0.21              | 0.02             | 0.17             | -0.11            | -0.27        | -0.34             | 0.29                | 0.26                |                 |
| \( P \)           | 0.72 | 0.42      | 0.19 | 0.32              | 0.13 | 0.48 | 0.25 | 0.45 | 0.31              | 0.93             | 0.43             | 0.30             | 0.59          | 0.20              | 0.10                | 0.15                | 0.21            |

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 \( \Delta \) 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 symbol substitution |
|------------------|-----|-----------|------|------|-----|-----|-----|-------------------|------------------|------------------|-------------------|--------------|-------------------|---------------------|--------------------------|------------------------|
| **d' value (positive)** |     |           |      |      |     |     |     |                   |                  |                  |                   |              |                   |                     |                          |                        |
| Pearson’s \( r \)  | -0.31| -0.11    | -0.15| -0.18| -0.11| -0.01| -0.06| -0.08             | -0.02            | -0.24            | -0.24             | 0.08          | 0.03              | -0.07               | -0.25                | 0.11            |
| \( P \)           | 0.19 | 0.65      | 0.67 | 0.54 | 0.45 | 0.63 | 0.98 | 0.82              | 0.73             | 0.15             | 0.52              | 0.73          | 0.91              | 0.79                | 0.29                | 0.65            |
| **d' value (neutral)** |     |           |      |      |     |     |     |                   |                  |                  |                   |              |                   |                     |                          |                        |
| Pearson’s \( r \)  | -0.06| 0.06      | -0.21| -0.14| -0.02| 0.14 | -0.03| -0.28             | -0.09            | -0.04            | -0.36             | 0.16          | 0.37              | 0.08                | 0.08                | 0.02            |
| \( P \)           | 0.80 | 0.37      | 0.96 | 0.96 | 0.89 | 0.99 | 0.70 | 0.86              | 0.52             | 0.97             | 0.52              | 0.74          | 0.74              | 0.74                | 0.74                | 0.95            |
| **d' value (negative)** |    |           |      |      |     |     |     |                   |                  |                  |                   |              |                   |                     |                          |                        |
| Pearson’s \( r \)  | -0.20| -0.35    | 0.06 | 0.09 | 0.26 | -0.12| -0.23| -0.19             | -0.10            | 0.36             | 0.42              | 0.48          | 0.48              | 0.76                | 0.30                | 0.15            |
| \( P \)           | 0.39 | 0.13      | 0.82 | 0.72 | 0.32 | 0.61 | 0.36 | 0.42              | 0.67             | 0.62             | 0.48              | 0.74          | 0.74              | 0.70                | 0.09                | 0.09            |
| Total number of advantageous cards selected |     |           |      |      |     |     |     |                   |                  |                  |                   |              |                   |                     |                          |                        |
| Pearson’s \( r \)  | -0.14| -0.01    | -0.29| -0.03| -0.10| -0.31| -0.06| -0.18             | -0.16            | -0.36            | -0.22             | 0.22          | 0.04              | -0.09               | 0.09                |                 |
| \( P \)           | 0.57 | 0.96      | 0.21 | 0.90 | 0.69 | 0.18 | 0.81 | 0.45              | 0.49             | 0.12             | 0.35              | 0.87          | 0.71              | 0.70                |                      |                 |

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. 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. Functional imaging studies have confirmed that PI can lead to structural changes in the prefrontal cortex and reduced functional connectivity to emotional circuits. 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. 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. 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. 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, suggesting that deficits in social decision-making ability may be due to exaggeration of emotional feelings or emotion regulation deficits. 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”. In line with previous research reports, 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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