# Discrepancy in Risky Decision Making of Insomniac Group and Correlated Neural Representations

**MC36424 Wang Ruisi; MC36425 Yuan Jingrui; MC36419, Miao He**

**University of Macau**

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## Abstract

This study investigated the impact of insomnia on risky decision-making in adolescents. The Cambridge Gambling Task (CGT) was used to evaluate the performance of an insomnia group and a control group on four measures: quality of decision-making, deliberation time, risk-taking, and risk adjustment. The results showed that the insomnia group had significantly longer deliberation times than the control group, suggesting that insomnia may lead to slower cognitive processing speed. However, there were no significant differences between the two groups in quality of decision-making, risk-taking, and risk adjustment. Correlation analyses revealed a negative correlation between deliberation time and quality of decision-making, and a near-significant positive correlation between subjective sleep quality scores and deliberation time. These findings indicate that while insomnia may slow down the decision-making process, it does not necessarily lead to increased risk-taking behavior, as participants may adjust their decision-making strategies due to self-awareness of cognitive deficits. Further research is needed to explore the longitudinal effects of insomnia on risky decision-making.

## Introduction

Insomnia is characterized by the persistent difficulty in initiating or maintaining sleep, or experiencing non-restorative sleep, is a prevalent sleep disorder with profound implications for cognitive and emotional well-being (American Psychiatric Association, 2013). The impact of insomnia is particularly significant during adolescence, a critical period marked by substantial developmental changes (de Zambotti et al., 2018). Adolescents already facing the challenges of growth and maturation with comorbidity of other disorders, are disproportionately affected by insomnia, which can lead to impaired decision-making and emotional regulation (Roberts et al., 2008; Johnson et al., 2006). The decision-making process, intricately linked to emotional and cognitive functions, is vulnerable to the effects of insomnia (Casement et al., 2016). Studies have shown that individuals with insomnia exhibit altered neural reward processing, which is crucial for emotional regulation and cognitive control (Xi et al., 2019). This relationship between insomnia and decision-making is of paramount importance, as it can lead to increased risk-taking behavior and impaired judgment, with potential long-term consequences for personal and social functioning (Telzer et al., 2013; Roberts et al., 2008). Given these serious implications, it is essential to explore the effects of insomnia on risky decision-making in adolescents to inform potential interventions and improve public health outcomes.

Previous studies have suggested that insomnia during adolescence is linked to an increased propensity for risk-taking behaviors, which can manifest in substance abuse, reckless driving, and other impulsive actions with severe consequences (Roberts et al., 2008; Alvaro et al., 2016). The relationship between insomnia and risk-taking behavior is mediated by the effects of sleep deprivation on cognitive control and decision-making processes, particularly in the context of reward sensitivity (Telzer et al., 2013; Casement et al., 2016). For example, research has shown that poor sleep quality in adolescents correlates with increased risk-taking related with reward processing (Telzer et al., 2013). Furthermore, studies indicate that adolescents with insomnia perform poorly on tasks requiring executive functioning, which is crucial for regulating complex behaviors and decision-making (Kuula et al., 2015; de Zambotti et al., 2018). The impact of insomnia on cognitive performance, including working memory and executive functioning, is suggested as a potential mechanism underlying the association between insomnia and risk-taking behavior (Dewald et al., 2010; Johnson et al., 2006). However, it is still unclear the specific effect of insomnia for risk-taking behaviors or if these behaviors contribute to the development or maintenance of insomnia, also the temporal sequence and the neurobiological processes that link insomnia with impaired decision-making and risk-taking behavior.

The neuroimaging result also demonstrates that individuals with insomnia exhibit distinct patterns of brain activation in regions associated with risk and decision-making compared to healthy individuals. Specifically, insomnia is linked to altered activity in the amygdala, a region correlated with processing emotional salience and risk assessment (Xi et al., 2019). Additionally, the prefrontal cortex, which plays a key role in executive functions and decision-making, shows differential activation in those with insomnia (Xi et al., 2019). These findings are particularly significant as they align with the results from the Cambridge Gambling Task (CGT), which highlight the involvement of the prefrontal cortex and the striatum—part of the brain's reward system—during decision-making under risk (Kurosch et al., 2018). The CGT also reveals increased activation in the anterior cingulate cortex when participants face choices with potential rewards or losses, suggesting a role in conflict monitoring and risk evaluation (Kurosch et al., 2018). The overlap in the neural substrates engaged during the CGT and those affected by insomnia underscores the potential impact of sleep disturbances on decision-making processes. So, the significance of these findings is that CGT could be used as a bridge between the realms of sleep and decision-making, offering insights into how insomnia may alter brain activity in decision-making tasks.

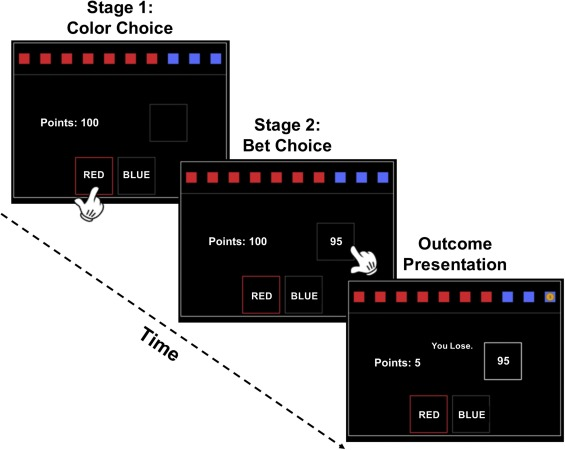
In this study, we wonder whether individuals with insomnia are more likely to make risky decisions compared to normal people, due to impaired decision-making abilities caused by insomnia. Our first hypothesis is that the insomnia group will underperform in the Cambridge Gambling Task (CGT), suggesting a diminished capacity for optimal decision-making under uncertainty. The second hypothesis is about the possibility that individuals with insomnia will exhibit a higher propensity for risk-taking in the CGT. Lastly, we hypothesized that people with insomnia might react more slowly during the CGT, which could suggest problems with thinking and focusing. By examining these hypotheses, our study seeks to shed light on the intricate relationship between insomnia and decision-making. This study’s result could help us find ways to improve decision-making in young people with sleep problems.

## Method

### Cambridge Gambling Task (CGT)

The Cambridge Gambling Task, or CGT, consists of three phases.  In the Color Determination Phase, each trial displays 10 cards of both red and blue colors. Each color varies from 1 to 9. The reward will appear in one of the colors. During the color decision phase, the participant clicks the left/right button to make selection. After the participant has chosen a color to bet on, the betting decision stage is reached. The bets appear randomly from small to large and from large to small (in proportions of 95%, 75%, 50%, 25% and 5% of the total prize). When the participant wants to place a bet at that bet amount, he/she presses the "Place" button. After placing the bet, the final stage was the results stage. If the participant guessed correctly, they would receive the appropriate amount; if the subject guessed incorrectly, they would lose the appropriate amount.

In the first phase, participants choose between two colors—red and blue. The probability of reward aligns with the color distribution shown. Participants select their choice by clicking left or right. In the second phase, following the color decision, the bet decision phase begins. Bets range from small to large, presented in varying ratios and in random order. using the Down button to select their bet amount. Finally, the outcome phase reveals whether the guess was correct.



**Figure 1 The Procedure of CGT**

### Classification of insomnia and non-insomnia groups

We posted the questionnaire collecting demographic variables and PSQI scores online to screen potential subjects based on the results(//www.qualtrics.com/). Regarding the method of recruitment and judgment of participants in the insomnia group, we chose the PSQI as the scale to measure insomnia, overall score over 7 will be treated as insomnia group. The PSQI is a self-report questionnaire that assesses the quality of sleep over a 1-month period. It is divided into seven sections related to sleep quality and consists of 19 individual items. A total score of more than 7 would be considered in the insomnia group.

### Data Analysis

Data preprocessing, we performed on matlab2022, and intergroup comparisons were performed using jamovi software(//www.jamovi.com/). We collect and analyze the following four main decision-making indicators: The first indicator is Quality of Decision Making (QDM): which is reflected in the total number of rational choices made by participants throughout the task. The second indicator is Deliberation Time (DT): which is the average amount of time a person takes to make decision and provides insight into their cognitive processing speed. And then the third indicator is Risk Taking (denoted as RT): which is the average amount of bet that participants are willing to put on the table. This variable is crucial for assessing their risk propensity. The last indicator is Risk Adjustment (RA): which is the average difference in bets placed relative to changing odds, shows how participants adjust their betting behavior to different probabilities.

## Result

### Demographic and clinical characteristics

A total of eight subjects were included and categorized into insomnia disorder n=4 and health control groups (HC n=4) matched for demographic variables such as age, gender, years of education, and history of psychiatric disorders according to the PSQI (>7) as a criterion.

First, to ensure subgroup validity, we performed one-sided t-tests on the total PSQI scores and the seven subscales to compare the scores of two groups. And the insomnia group scored (10.5±4.04), significantly higher than the HC (5.25±0.957;t=-2.53,P<0.05\*).Comparison of the seven subscale scores between ID and HC groups（Tab.1）showed that ID had later bedtimes compare to HC(t=-4.90,P<0.001\*\*).At the same time, in comparisons of sleep quality, sleep duration, sleep efficiency, sleep disorders, and medications scores , the ID group all showed higher scores, implying worse sleep, and the results were statistically close to borderline significant so the results of clinical indicators fully demonstrated the effectiveness of grouping. Interestingly, in the daytime dysfunction subscale, all of eight subjects, reported that they often felt daytime fatigue, and the results were completely homogeneous between the two groups. This may be since our sample of subjects came from a group of graduate students at a university, all of whom were under heavy stress during finals week and all felt daytime fatigue.

| **Table1** Comparison of PSQI Scale Differences Between HC and ID Groups | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | |  | | **T** | | **df** | | **P Value** | |
| PSQI (total) |  | Student's |  | -2.53 |  | 6.00 |  | 0.022\* |  |
| PSQI1\_SleepQauilty |  | Student's t |  | -1.85 |  | 6.00 |  | 0.057 |  |
| PSQI2\_SleepingTime |  | Student's t |  | -4.90 |  | 6.00 |  | 0.001\* |  |
| PSQI3\_SleepDuration |  | Student's t |  | -1.41 |  | 6.00 |  | 0.104 |  |
| PSQI4\_SleepEfficiency |  | Student's t |  | -1.00 | ᵃ | 6.00 |  | 0.178 |  |
| PSQI5\_SleepDisorders |  | Student's t |  | -1.41 |  | 6.00 |  | 0.104 |  |
| PSQI6\_HypnoticMedications |  | Student's t |  | -1.00 | ᵃ | 6.00 |  | 0.178 |  |
| PSQI7\_Daytime dysfunction |  | Student's t |  | NaN |  |  |  |  |  |
| Hₐ μ HC < μ ID | | | | | | | | | |

**Figure 2** Comparison of the ID VS HC group's performance on four indicators in the CGT.

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### Comparative results between groups

Following the precedents set by previous research and considering the unique characteristics of our insomnia patient sample (Zois et al, 2014), we selected four decision-making indicators from CGT. These indicators include the Quality of Decision Making (QDM), which measures the overall rationality of choices; the Deliberation Times (DTs), signifying the time taken to deliberate before selecting; the Response Times (RT), indicating the mean amount of bet; and the Risk-Taking Ratio (RT-ratio), which assesses the percentage of the bet that owns the principal.

Tab. 2 presents the descriptive statistical results. The table outlines key variables measured through the Cambridge Gambling Task (CGT), including the Deliberation Time (DT), Quality of Decision Making (QDM), Risk Taking (RT), and the Risk-Taking Ratio (RT-Ratio). The mean and standard deviation (SD) for each variable is provided.

In terms of DT, it is crucial for understanding cognitive processing speeds and the decision-making process. Based on reports in previous articles about insomniacs having low prefrontal activation (Wu et al,2020) due to sleep deprivation, making them slower to respond (Brownlow et al, 2020), we hypothesized that insomniacs have longer DTs because they need more time to gather information, process it, and make decisions. HC exhibited a mean DT of 1.02 seconds, whereas the ID demonstrated a longer mean DT of 2.04 seconds (Tab.2, Fig2.a), the borderline significant results of the independent samples t-test also indicates that the ID a longer DT (t=-2.09, P<0.081). Given that we are a small study, this matches our hypotheses.

There was no significant difference in the comparison of QDM (t=0.278, p=0.79). Although we predicted that ID with impaired prefrontal decision-making function, might show poorer quality of decision-making (Delazer et al., 2012), this was not reflected in the results of this study. This may be due to the specificity of our sample (graduate student), whose decision quality is moderated by educational attainment. A large-sample CGT performance study of a substance-addicted group also reported that QDM in alcohol-addicted people did not differ from normal (Zois et al., 2014) for which the QDM does not have sufficient external validity and sensitivity observations. However, based on Fig 2.b, the QDM variance is greater in the ID group and HC is more convergent.

In addition, HC demonstrated a mean RT of 97.6 and a mean RT-ratio of 0.526, whereas the ID group showed a RT mean of 116 and a mean RT-ratio of 0.454（Fig2.c, Fig2. d. Both RT and RT-ratio were no statistically significant difference (t=-0.32, P=0.75; t=0.653, P=0.53). We hypothesized that an insomniac population with impaired inhibition and a higher risk preference would have a significantly higher RT & RT-ratio, but the results did not support it.

**Figure 3** Correlation between QDM and DT; correlation between time to sleep and DT.

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| **Table3** The Correlation Matrix Between the PSQI Scores and the Four CGT Decision indicators | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | |  | | **RT-ratio** | | **RT** | | **QDM** | | **DT(s)** | | **PSQI (total)** | |
| **RT-ratio** |  | Pearson's r |  | — |  |  |  |  |  |  |  |  |  |
|  |  | df |  | — |  |  |  |  |  |  |  |  |  |
|  |  | p |  | — |  |  |  |  |  |  |  |  |  |
| **RT** |  | Pearson's r |  | 0.731 |  | — |  |  |  |  |  |  |  |
|  |  | df |  | 6 |  | — |  |  |  |  |  |  |  |
|  |  | p |  | 0.039\* |  | — |  |  |  |  |  |  |  |
| **QDM** |  | Pearson's r |  | 0.576 |  | 0.035 |  | — |  |  |  |  |  |
|  |  | df |  | 6 |  | 6 |  | — |  |  |  |  |  |
|  |  | p |  | 0.135 |  | 0.934 |  | — |  |  |  |  |  |
| **DT(s)** |  | Pearson's r |  | -0.633 |  | -0.113 |  | -0.729 |  | — |  |  |  |
|  |  | df |  | 6 |  | 6 |  | 6 |  | — |  |  |  |
|  |  | p值\ |  | 0.092 |  | 0.790 |  | 0.040\* |  | — |  |  |  |
| **PSQI (total)** |  | Pearson's r |  | -0.140 |  | -0.007 |  | 0.013 |  | 0.270 |  | — |  |
|  |  | df |  | 6 |  | 6 |  | 6 |  | 6 |  | — |  |
|  |  | p |  | 0.740 |  | 0.986 |  | 0.975 |  | 0.519 |  | — |  |
|  | | | | | | | | | | | | | |

### Regression analysis

According to previous studies, Pittsburgh scale scores can be converted into continuous variables (Liu et al, 2021), so we also calculated the correlation between the PSQI scores of the eight subjects and their performance in the CGT decision indicator. The 5\*5 correlations we all report through Tab.3 correlation matrix。

The relationships within the four decision-making indicators are discussed first. As for the significant positive correlation between RT and RT-ratio（r=0.731, p<0.05\*）, it is reasonable because RT is the absolute value and RT-ratio is the value of the ratio to the principal when the subject bets. The other group is that DT shows a significant negative correlation with QDM（r=0.-729, p<0.05\*）, indicating that the longer the time, the lower the quality of the decision. Fig3.b Shows a scatter plot of the data for the 8 participant DT vs. QDM. While this is not consistent with the inference that the longer the decision time, the higher the quality of the decision, there may be other mediating effects, such as higher arousal and alertness (Shahid et al, 2011).

As for the relationship between PSQI score and decision index, we did not find significant in the direct correlation analysis, but for the PSQI sub-scale score mining at a higher level, we found that sleeping time was close significantly correlated with DT (r=0.59, p=0.10). As Fig 3.b, with the delay in falling asleep, the reaction time will be longer the next day. This suggests that the busy time state of the final week, combined with the special group of our subjects as graduate students, the delayed sleep time led to the delayed daytime response.

## Discussion

The findings from this study provide valuable insights into the relationship between insomnia and decision-making in adolescents. Our results indicate that individuals with insomnia demonstrate a distinct pattern in their decision-making processes, particularly when it comes to risky choices. The insomnia group exhibited longer deliberation times during the CGT may suggest a slower cognitive processing speed or a heightened need for caution when making decisions (Wu et al., 2020). The lack of significant difference in the quality of decision-making between the insomnia and control groups was expected, because CGT’s reward probability is directly demonstrated in each trial, no need for further complex cognitive processing to detect.

The response times and risk-taking ratios between the groups shows no significance, this result is predictable because of the sample size. It is possible that the adolescents with insomnia in our sample were more aware of their cognitive vulnerabilities and adjusted their decision-making strategies accordingly (Delazer et al., 2012). This self-awareness and adaptation could be a factor that mitigates the impact of insomnia on risk-taking behavior. Interestingly, our correlation analysis revealed a significant positive correlation between deliberation times and quality of decision-making, contradicting the common assumption that longer deliberation times result in higher quality decisions (Dewald et al., 2010). Finally. The close significant correlation between PSQI scores and decision-making indicators suggests that the subjective experience of sleep quality might directly affect to observable cognitive impairments in the context of decision-making.

The results underscore the need for a comprehensive understanding of the mechanisms underlying the link between insomnia and decision-making. Future research should aim to explore the longitudinal effects of insomnia on decision-making and risk-taking behavior, as well as the potential interventions that could improve cognitive outcomes in this population.

## Conclusion

This study used the CGT to examine how insomnia impacts risky decision-making in graduate students. The main finding was the insomnia group took longer to think before deciding, indicating impaired thinking ability. But there were no significant group differences in decision quality, risk-taking, or risk adjustment. Longer thinking times related to poorer decisions. Sleep quality was close to significantly predicting longer thinking. This suggests insomnia may slow decisions but not increase risks, as participants may adjust strategies due to self-awareness of deficits. Future long-term studies should explore insomnia's effects on risky decisions and potential interventions to improve cognition for insomniacs.

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