The Impact of One Night of Sleep Deprivation on Social Decision-Making and the Neural Basis of this Relationship as Evidenced by Electroencephalographic (EEG) Indices

by

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Statement of Originality

I, LI, Cheng, hereby declare that I am the sole author of the thesis and the material presented in this thesis is my original work except those indicated in the acknowledgement. I further declare that I have followed the University's policies and regulations on Academic Honesty, Copyright and Plagiarism in writing the thesis and no material in this thesis has been submitted for a degree in this or other universities.

Abstract

Sleep loss is a prevalent phenomenon in many cities, such as Hong Kong. The effects of sleep loss on cognitive and emotional functions have been widely studied, but only a few studies have examined the impact of sleep loss on social functions. This thesis aimed to investigate the effect of one night of total sleep deprivation on social decision-making and its neural basis as evidenced by electroencephalographic (EEG) indices.

Study 1 examined the effect of one night of sleep deprivation on social decision-making using a between-subjects design. Forty-three healthy participants were randomly assigned to the sleep deprivation (SD) or sleep control (SC) group. After a week of habitual sleep at their own residences, participants in the SD group stayed awake in the laboratory for one night, while those in the SC group slept normally at home. In the morning after the sleep condition (SD/SC), all the participants underwent an 8-minute resting-state EEG recording and completed tasks related to sleepiness, vigilance and social decision-making. The following two EEG indices related to the emotional regulatory and cognitive process were calculated: frontal alpha asymmetry (the frontal alpha power difference between the right and left hemispheres) and the frontal theta/beta ratio (the power ratio of theta and beta bands over the frontal regions). The results showed marginal significance in the left-lateralized frontal alpha power following SD, suggesting a trend of poorer emotional regulation ability after sleep loss. However, there was no significant difference in the frontal theta/beta ratio between the SD and SC groups. Moreover, the effect of SD on trust was moderated by depressive symptoms. Compared to the controls, participants with a higher level of depressive symptoms showed fewer trusting behaviors after SD, while participants with a lower level of depressive symptoms showed more trusting

behavior after SD. However, there was no significant difference in rational decision-making performance between the SD and SC groups.

Considering individual differences in vulnerability to SD, Study 2 was conducted to examine the effect of one night of SD on social decision-making using a within-subjects design. Forty-eight participants completed a counterbalanced repeated-measures study design involving a night of SD and a night of normal sleep (NS), 7 days apart in a counterbalanced order. The participants completed an 8-minute resting-state EEG recording and measures of sleepiness, vigilance and social decision-making after each sleep condition (SD/NS). Contrary to the prediction, the trend of significant left-lateralized frontal alpha power after SD and the interaction effect between SD and depressive symptoms on trust found in Study 1 were not detected in Study 2, which showed no other significant effects, suggesting that 24 h of SD may not have robust effects on resting-state EEG indices and social decision-making.

Overall, this study provides the first evidence of the moderation effect of depressive symptoms on the relationship between SD and trust. The results show that people who have a higher level of depressive symptoms are more vulnerable to the adverse impact of SD; specifically, those who are more depressed showed less trust after a night of sleep loss. However, this moderation effect was not detected using a within-subjects study design. Moreover, the 24-h SD only had a marginally significant effect on resting-state EEG indices in Study 1 and had no significant effect on rational decision-making in both studies. In contrast to previous studies adopting longer durations of SD, our limited significant findings suggest that the social brain may be relatively resilient to the effects of one night of SD, at least in a well-controlled laboratory setting. Future

studies may compare different durations of SD and the potential moderating effects of individual differences variables, such as circadian preference, neuroticism, beliefs, and values on the relationship between SD and social decision-making behaviors.

Keywords: Sleep deprivation; Resting-state EEG; Social decision-making; Young adults

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

ADHD	Attention-Deficit/Hyperactivity Disorder
AHI	Apnea-hypopnea Index
ANOVA	Analysis of variance
ANCOVA	Analysis of covariance
APA	American Psychiatric Association
a.k.a	Also known as
b	Standardized coefficient
BMI	Body mass index
CI	Confidence interval
CSM	Composite Scale of Morningness
DASS	Depression Anxiety Stress Scale
DG	Dictator Game
EEG	Electroencephalographic
e.g.	For example
EI	Emotional intelligence
EMG	Electromyogram
EOG	Electro-oculogram
ERP	Event-related potential
ET	Evening type
fMRI	Functional magnetic resonance imaging
FFT	Fast Fourier transform
GEE	Generalized estimating equations

h	hour
Hz	hertz
i.e.	That is
ln	Natural logarithm
IQR	Interquartile range
MAO	Minimum acceptable offer
MEMORE	Mediation and moderation for repeated measures
mPFC	Medial-prefrontal cortex
MT	Morning type
n	Number of participants in a research study/task
NFC	Need for closure
NREM	NON-rapid-eye-movement sleep
NS	Normal sleep
OR	Odds ratio
PANAS	Positive and negative affect schedule
PcC	Paracingulate
PFC	Prefrontal cortex
Poor sleepers	Individuals with a global score greater than 5 on the Pittsburgh Sleep Quality Index
PSG	Polysomnography

PSQI	Pittsburgh Sleep Quality Index
PVT	Psychomotor vigilance task
REM	Rapid-eye-movement
rMEO	A short form of the morningness-eveningness questionnaire
RT	Reaction time
RW	Rested wakefulness
SA	Septal area
SE	Standard error
SC	Sleep control
SD	Sleep deprivation
SSS	Stanford Sleepiness Scale
SWS	Slow-wave sleep
TG	Trust Game
TSD	Total sleep deprivation
TST	Total sleep time
UG	Ultimatum Game
vmPFC	Ventromedial prefrontal cortex
η^2	Eta squared, an effect size measure

CHAPTER 1

General Introduction

In this thesis, I aimed to investigate the impact of 24-h sleep deprivation on social decision-making and resting-state emotion-related electroencephalography (EEG) indices using both between-subjects and within-subjects designs. I hypothesized that people would show fewer trusting behaviors and make more irrational decisions following 24-h sleep deprivation. In addition, sleep deprivation was hypothesized to bring neural changes to resting-state EEG indices related to emotional-regulatory and cognitive process.

I proposed that following 24-h sleep deprivation,

(a) participants would show fewer trusting behaviors;

(b) participants would make more irrational decisions; and

(c) participants would shower a lower frontal alpha asymmetry score and a higher theta/beta ratio, which may suggest a poorer emotional regulation ability and weaker cognitive control

1.1 Importance of Sleep

Everyone sleeps. Human beings spend almost one-third of their time sleeping (Aminoff et al., 2011). Sleep was long considered a passive process (i.e., the brain completely shuts down) by many researchers until the discovery of periods of rapid eye movement, i.e., the so-called REM phase, by Aserinsky and Kleitman in 1953. The discovery of REM stimulated physiological and clinical studies of sleep; subsequently, sleep has been considered a dynamic behavior (Stevens & Hening, 2007). EEG, electromyogram (EMG) and electro-oculogram (EOG) are tools that are often used to monitor brain activity, chin and muscle movements and eye movements during sleep, respectively. During wakefulness, the following two EEG activities are often observed in the EEG of a normal person: alpha activity and beta activity. Alpha activity consists of regular, medium-frequency brain waves of 8-12 Hz. When a person is quietly resting and not engaged in activities that require effort (e.g., problem solving), alpha activity is produced. Beta activity is another type of EEG pattern during wakefulness. Beta activity consists of irregular, low-amplitude waves of 13-30 Hz and is normally produced when a person is alert or is consciously thinking. Evidence from EEG has shown that sleep alternates between the following two distinct phases: REM and non-rapid eye movement (NREM). NREM can be divided into three stages according to the new guidelines of the American Academy of Sleep Medicine (AASM, Iber et al., 2007). N1, NREM stage 1, is regarded as light sleep. Stage N1 is the transition from wakefulness to sleep and is the lightest stage of sleep when people become drowsy and are ready to fall asleep. Theta activity, which consists of low-frequency brain waves of 3.5-7.5 Hz, occurs during this stage. Stage N1 accounts for approximately 2% to 5% of sleep time. Stage N2 is when sleepers become gradually harder to wake. The EEG frequencies during this stage are slow, and characterize a deeper stage of sleep. Abrupt neural activities such as sleep spindles and K complexes can be observed during this stage. Sleep spindles are brain waves of 12-14 Hz and K complexes are sudden sharp waveforms that normally only occur during stage N2 of sleep. Stage N2 accounts for approximately 45% to 55% of the total sleep time. Stages

N3 is regarded as deep sleep or slow wave sleep (SWS). During these deeper stages, EEG waves consist of low-frequency brain waves of 0.5-3.5 Hz characterizing delta activity. The arousal threshold in SWS is high. SWS accounts for approximately 10% to 20% of sleep time. In REM sleep, most muscles are paralyzed and the sleeper may dream. REM sleep accounts for approximately 20% to 25% of the total sleep time (Iber et al., 2007; Stevens & Hening, 2007; Abrams, 2015; Bettelheim, 1998).

Why do we need sleep? Researchers have attempted to answer this question for decades, but a large part of the answer remains unknown. It is well known that sleep plays an important role in not only resting the brain but also consolidating long-term memory. For example, SWS has been found to be important in consolidating declarative memory (a.k.a. explicit memory), while REM facilitates the consolidation of nondeclarative memory (a.k.a. implicit memory) (see the review in Carlson, 2014). Ample evidence has shown that sleep serves many different functions, such as biological survival functions (e.g., wound healing, Gümüstekin et al., 2004; muscle recovery and restoration of energy, Dattilo et al., 2011), cognitive functions (e.g., planning, Horne, 1988; inhibition, Harrison & Horne, 1998; academic performance, Wong et al., 2013), and emotional functions (e.g., mood, Baglioni et al., 2010; emotional regulation, Gruber & Cassoff, 2014). The importance of sleep is often characterized through studies investigating sleep deprivation (SD), which is further discussed in the following section.

1.2 Understanding the Functions of Sleep through Sleep Deprivation Studies

1.2.1 Impact of Sleep Deprivation on Cognitive and Emotional Functions

The first study involving SD was performed over 100 years ago (Patrick & Gilbert, 1896). SD (sleep deprivation) is defined as either the complete loss of sleep over a certain period or a less-than-optimal sleep duration over an extensive period (Orzeł-Gryglewska, 2010). The National Sleep Foundation has suggested that adults need an average of 7 to 9 hours of sleep (Hirshkowitz et al., 2015). However, inadequate sleep is becoming a worldwide phenomenon. The U.S. Centers for Disease Control and Prevention has described SD as a public health epidemic (Pinholster, 2014). American adults reported an average of 6.8 hours of sleep during weekdays in a 2005 poll (Banks et al., 2007), and there was an increase of 15% of U.S. adults who slept less than 6 hours from 2004 to 2017 (Sheehan et al., 2019). In a study involving college students in Hong Kong and Macau, students had an average of only 6.6 hours of sleep during weekdays (Wong et al., 2013). The impact of partial SD has been thoroughly examined (see the review in Orzeł-Gryglewska, 2010). Although total SD is less common than partial SD, it is important to study total SD as it may lead to catastrophic consequences (Dinges, 1995; Mitler et al., 1988). For example, in a prolonged SD study (i.e., four nights of SD), hallucinations, paranoid delusions and mumbling in speech were found in healthy participants following SD (Berger & Oswald, 1962). In addition, SD places people at risk of developing obesity. Greer et al. (2013) found a positive and significant correlation between sleepiness and the desire for high-calorie food among participants who were sleep deprived. After controlling for body mass index (BMI), this correlation remained significant. In addition, using functional MRI (fMRI), the study reported reduced activity in brain regions, such as the anterior insular cortex, lateral orbital frontal cortex and anterior cingulate cortex, which correspond to appetitive evaluation, following SD. Moreover, amplified activity was observed in the amygdala, which is a brain region known for processing emotional information, particularly aversive emotional stimuli (Davidson, 2002). These findings provide neural evidence explaining the increased food desire and possible weight gain following SD.

Unsurprisingly, SD affects basic cognitive functions, which has been studied for a long time. For instance, SD has been found to reduce word fluency, prompt a tendency to fixate on the same semantic category (Harrison and Horne, 1997), and affect the use of proper intonation in the voice, inhibition, word generation (Harrison and Horne, 1998), and planning (Horne, 1988). In a meta-analysis, Lim and Dinges (2010) concluded that one night of SD has a tremendous effect on cognitive functions. Among these cognitive functions, the effect size found in simple tasks measuring simple, sustained attention, such as the Psychomotor Vigilance Test, was larger than that found in more complex tasks.

Additionally, the effect of SD on emotional function has attracted increasing attention in recent years. For instance, a larger pupil diameter was observed in people after 24-h SD while viewing negative pictures, suggesting a stronger reaction to negative stimuli following sleep loss (Frazen, 2009). Regarding the identification of emotional faces, which can be regarded as social cues, studies have found that SD hampers the ability to accurately recognize human facial emotions. Van der Helm and colleagues (2010) reported an impairment in the ability to accurately identify facial emotion after 24-h SD. This impairment was specific to threat-related (anger) and reward-related (happy) emotional expressions and was most significantly observed among women.

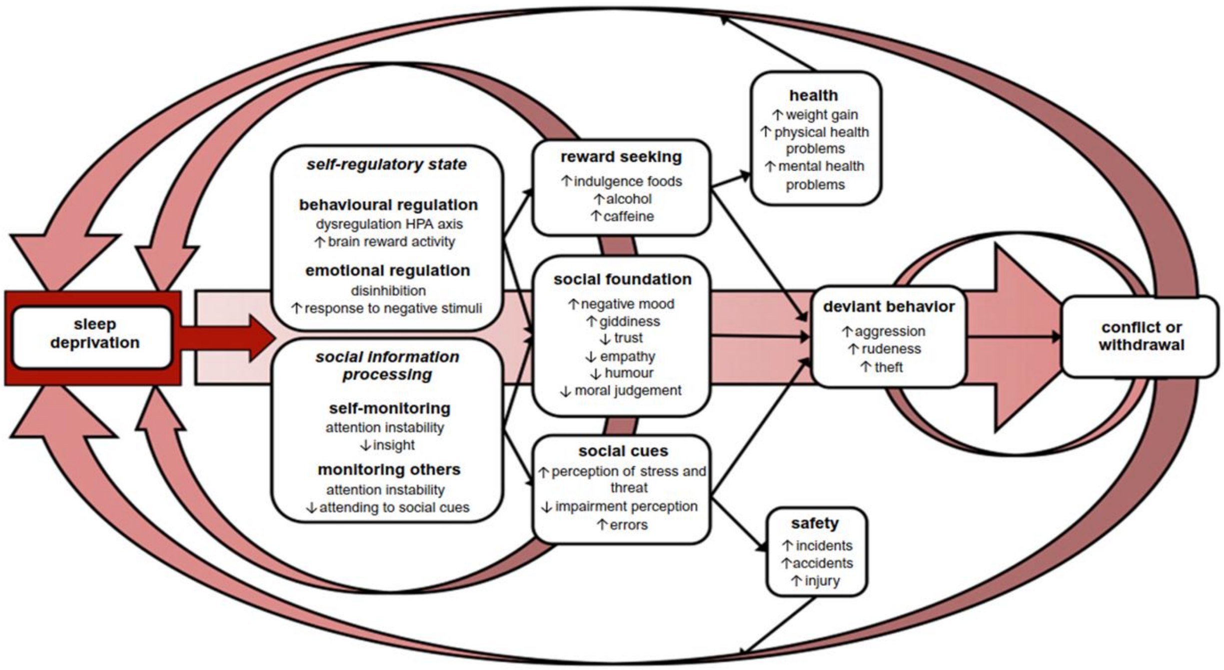
In addition to behavioral results, evidence from brain-imaging studies has also shown that SD can cause neural changes related to emotional regulation (Baum et al., 2014; Zhang et al., 2018b). Following SD, Yoo et al. (2007) found a disconnectivity between the amygdala and medial-prefrontal cortex (mPFC), a brain region known to have inhibitory top-down control over the amygdala in the regulation of emotion. Yoo et al. also found that the participants under the sleep-deprived condition showed a significant increase in activation in the amygdala when facing negative picture stimuli. Furthermore, using fMRI, Killgore (2013) discovered that the functional connectivity between the prefrontal cortex (PFC) and amygdala was directly related to Trait Emotional Intelligence (EI) scores; Trait EI involves self-perceived emotional functioning and self-awareness, reflecting one's ability to regulate emotion. Moreover, a recent study further indicated that SD adversely affected the effectiveness of using the emotional regulation strategy of cognitive reappraisal as evidenced by event-related potential (ERP) amplitudes (Zhang et al., 2018b). ERP evidence suggested that greater attention was allocated to negative stimuli following SD, which may be especially problematic for people who already have poor emotional regulation (Cote et al., 2015). While most studies have reported enhanced brain activity toward negative pictures, Gujar et al. (2011) found that sleep loss is also related to an increased neural and behavioral reactivity to positive stimuli. In their study, the participants underwent an fMRI scan while viewing 100 picture stimuli and made a binary response judgment of “pleasant” or “neutral” to the stimuli. The results showed that the participants were more likely to judge the stimuli as “pleasant” behaviorally after SD. Furthermore, neural reactivity in the mesolimbic reward networks was amplified toward the pleasant stimuli following SD.

1.2.2 Impact of SD on Social Functions

Human beings are social animals, and most humans interact with other humans every day. While the impact of SD on basic cognitive and emotional functions has been greatly discussed, its impact of SD on more complex functions, such as social functions, is less understood. According to a recently proposed model on the integrated theory of SD on social cognition proposed by Dorrian et al. (2019), two critical aspects of social functions are negatively impacted by SD—self-regulation and social monitoring (see Figure 1 a). Self-regulation refers to behavioral or emotional regulation, which have been found to be negatively impacted by SD (as noted in section 1.2.1). Social monitoring refers to perceiving and interpreting cues regarding self and others. This model has proposed that SD would negatively affect social cognition through changes in self-regulation and social information processing. These changes will bring negative effects on health, safety and also increase deviant behaviors, which would lead to a cycle of conflict and/or withdrawal. All of these changes would act in a reciprocal way with sleep and can therefore exacerbate sleep loss, resulting in a self-reinforcing system. Although studies have increasingly examined the impact of sleep loss on social functions in recent years, the exact impact of SD on social functions remains unclear. In one study (Goldstein-Piekarski et al., 2015), participants were asked to discriminate between "threatening" or "not threatening" facial expressions after one night of SD and one night of normal sleep. The behavioral data showed that compared to the sleep-rested condition, people were more likely to rate a face as threatening after SD, as the reciprocal association between the central and peripheral emotional-signal systems was compromised after SD, resulting in increased subjective bias in rating threatening faces. Ben Simon and Walker (2018) conducted a laboratory experiment in which participants were approached by others after one night of SD or normal sleep. Participants were asked to indicate the distance that they would normally keep from a stranger. These authors also conducted another online survey in which 1033 independent judges were asked to view a “speak freely” interview of participants who underwent either a night of SD or normal sleep. The judges were asked to evaluate the participants regarding a range of socially relevant features. The laboratory study showed that following SD, people tended to keep a greater distance from others. In the online survey, the independent judges, who were blind to the study condition, rated the participants under the sleep-deprived condition as lonelier than those under the control condition. More interestingly, compared to those who watched videos of the participants under the control condition, those who watched videos of the participants under the SD condition felt lonelier. The authors concluded that SD could be deemed a social repellent that enforces greater separation between individuals. Furthermore, this asocial impact of SD can propagate, as indicated by feelings of loneliness after contact with sleep-deprived individuals. In another recent study (Holding, Sundelin, Lekander et al., 2019), 183 participants aged 18 to 45 years were randomly assigned to the one-night-of-SD group or the normal-sleep-at-home group. The participants completed two collaborative tasks during dyadic verbal communication. In the first task, participants in pairs were randomly assigned to the role of “describer” or “builder”. The “builder” needed to follow the instructions of the “describer” to build an identical model using bricks, which were given to the “describer”. Since the pair of participants did not sit face-to-face and the model could not be seen by the “builder”, the “describer” could only give instructions verbally. The accuracy of placement of the bricks and the time to complete the task were measured as performance outcomes in the task. The results showed that if the “builder” was sleep deprived, then the overall performance in this task was impaired. This finding suggests that after SD, verbal perception and linguistic comprehension are decreased. Interestingly, performance in the model-building task was improved if the “describer” was sleep deprived. Previous research has shown that SD elevates the stress level in response to psychosocial stressors (Minkel et al., 2014), and stress can improve cognitive performance, such as spatial processing. In another collaborative task, the participants were randomly assigned to the role of “speaker” and “guesser”. The “speaker” was asked to describe as many target words as possible to the “guesser” without saying the target words within 60 seconds. It was found that one night of SD did not have any noticeable effect on the performance of this task. This null result may be due to the brevity of the word-description tasks such that the participants’ attention was not divided or impaired. Holding and colleagues (2019) argued that one reason that these collaborative tasks were resilient to the effect of one night of SD was the short duration of the tasks. Lim and Dingers (2010) suggested that sustained attention was among the functions most strongly impaired by sleep loss. Given their brevity, communicative tasks are less susceptible to the effects of sleep loss. Another reason was that the participants in the tasks were not familiar with each other, and interactions with strangers may induce novelty and psychological arousal, which may override the effect of sleep loss.

Figure 1 a

Integrated Theory of the Impact of SD on Social Cognition



Note. This figure demonstrates an integrated theory of the effect of sleep deprivation (SD) on social cognition. From "Self-regulation and social behavior during sleep deprivation", by J. Dorrian et al., 2019, *Progress in Brain Research, 246,* p.96. Copyright 2019 by Elsevier B.V.

While a few studies have shown the potential negative effects of SD on social functions, some studies have found no such effect. In a recent study (Holding, Sundelin, Cairns, et al., 2019), one hundred eighty-one participants were randomly assigned to a night of SD or a night of normal sleep (8-9 hours) at home. After the experimental manipulation night, the participants' faces were photographed at approximately 14:00 on the test day. Their skin color, eye openness, and mouth curvature were also measured by machines. In another session, sixty-three additional participants were recruited to rate the photographs in terms of health, fatigue and paleness. Surprisingly, Holding and colleagues found that sleepiness was not associated with any face variable. Similarly, there was no difference in the subjective ratings between the groups. The field of SD and social function studies is still young, and the results obtained from limited studies remain controversial. It is of interest to explore what type of effect a night of SD could have on social functions, such as social interaction.

1.3 Introduction to Social Decision-making

Decision-making is defined as the cognitive process of making a choice among alternatives, which is challenging and often involves uncertainty and risk (Fitzgerald, 2002). Social decision-making refers to decision making that occurs in an interactive environment between two or more people (Lee, 2008). As human beings live in large social groups, studies of social decision-making, which forms the building blocks of human interaction, are important. There are two distinct features of social interaction. First, human behaviors frequently change as people seek to maximize their self-interest in a social interactive environment. Second, social interactions provide possibilities for competition and cooperation. In a world full of temptations, it is of interest to know the situations in which people make prosocial or antisocial and rational or irrational decisions while interacting with others (see the review in Lee, 2008).

Game theory is often a good starting point for understanding social decision-making (von Neumann & Morgenstern, 1944). Game theory was originally formulated to identify the strategies that a group of decision makers can use to maximize their own payoffs. Game theory can be applied to a wide range of situations as follows: "firms competing for business, political candidates competing for votes, jury members deciding on a verdict, animals fighting over prey, bidders competing in an auction, the evolution of siblings' behavior towards each other, competing experts' incentives to correctly diagnose a problem, legislators' voting behaviors under pressure from interest groups, and the role of threats and punishment in long-term relationships" (Osborne, 2004, p1). The Trust Game (TG), Ultimatum Game (UG) and Dictator Game (DG) are three widely adopted games that involve basic social interaction between two or more people. Prosocial behaviors (e.g., trust) in these games have been found to be simple signs of the social capital of the decision makers (Putnam, 1993). Researchers have found that increases in country-level trust, as measured in surveys, could encourage desirable macroeconomic outcomes, such as economic growth (Knack & Keefer, 2007) or a reduction in government corruption (La Porta et al., 1997). In a meta-analysis conducted by Oosterbeek et al. (2004), the responders' behavior in the UG significantly differed across geographic regions. Asian responders showed a higher rejection rate than responders in the US. However, no other difference was observed in the other games. Studies investigating cultural differences in social decision-making remain conflicting and inconsistent. Although no clear cultural difference has been found, occupations that rely on people working together cooperatively and making rational decisions (e.g., firefighters, trade union leaders, and military personnel, see Anderson & Dickinson, 2010) are commonly observed in different cultures. Therefore, it is essential to study this domain of decision-making, which may have direct or indirect effects on society and the economy.

In the TG (Berg et al., 1995), the trustor decides how much of an initial amount, such as $10, they would like to deliver to another player, i.e., the trustee, where the money will triple and be returned by the trustee. The TG is a non-zero-sum game (i.e., zero-sum indicates that one player's gain is necessarily the other player's loss) that allows an examination of trust and trustworthiness. The amount that the trustor delivers is considered a measure of trust, and the amount returned by the trustee is regarded as trustworthiness. Empirically, it has been found that the trustor tends to deliver approximately half of their money to the trustee. In the study by Berg et al. (1995), the average amount delivered by the trustor was $5.16, and after tripling, the average amount returned by the trustee was approximately $2.79 (18% of the tripled amount).

In the UG (Guth et al., 1982), participants decide how much of $X they will divide and deliver to the next participant (responder). The responder decides whether to accept or reject the division. If the responder rejects, then the game ends and both participants receive nothing, which is considered irrational decision-making in this game because it is more rational to accept every offer to maximize the total amount that one can obtain. However, according to previous studies, human beings are not always rational, and their decision-making is influenced by various factors (e.g., altruistic social preference and aversion to inequality). Offers from the first mover (proposer) of less than 20% of the total amount have a 50% chance of being rejected by the responder (Guth et al., 1921). This “irrational” rejection in the UG has been found to be correlated with feelings of anger (Pillutla & Murnighan, 1996), an increase in the skin conductance response (van’t Wout et al., 2006) and stronger activation in the anterior insula (Sanfey et al., 2003), which is a brain area often associated with negative emotional states, such as anger and disgust (Phillips et al., 1997). The DG is a deviation of the UG in which the responder has to accept all offers. This simplification is applied to distinguish whether offers in the UG are driven by the fairness of the offers or a simple fear of rejection (Forsythe et al., 1994). The average offer in the UG is approximately 40% of the total amount, which is significantly higher than the offer in the D G, indicating that participants are motivated to avoid potential rejection (Camerer, 2003).

The results of studies using the TG and UG provide evidence that humans are not entirely rational as suggested by most economic theories. These economic theories assume that people follow rationality principles for what they believe and choose, follow the rules of probability when processing information, resist temptation, etc. However, a newly emerging field called “behavioral economics”, which relies on psychology and neuroscience, proposes that emotional experience also plays a key role in these economic games. A dual-system approach hypothesizes that social interactive decision-making is guided by not only cognition but also emotion (see Camerer, 2003). For example, the first mover in the TG may feel fear of betrayal when deciding how much they want to deliver to their partners. In the UG, aversion to inequality and even anger may be induced in by the responder when receiving unfair offers from the proposer. Sanfey et al. (2003) reported that compared to playing with a computer, emotion-dominant brain regions are more active when playing the UG with a human player. The cognitive- and emotional-related neural basis of social decision-making games are discussed in the following text.

Socially interactive decision-making is a dynamic and complicated process, and many neuro-imaging studies have examined the neural basis of social decision-making and how features of social decision-making can be reflected in the functions of certain brain areas. A review of the neural basis of social decision-making (Lee, 2008) reports that the brain areas involved in reward evaluation and reinforcement learning, such as the striatum, insula and orbitofrontal cortex, are usually employed in social decision-making. For example, in a study using event-related hyperfMRI (Krueger et al., 2007), activation in the paracingulate (PcC) and septal area (SA) brain regions was correlated with decisions to trust in the TG. The former brain region is a unique region in humans that represents one’s thoughts, feelings and evaluations of the mental states of others (see the review in Krueger et al., 2007), and the latter brain region is a limbic region important for modulating various aspects of social behaviors, such as social memory and learning (Numan, 2005), and controlling the release of neuropeptides related to maternal care and bonding, such as oxytocin (Bartels & Zeki, 2003). In addition, Koenigs and Tranel (2007) reported that participants with damage to the ventromedial prefrontal cortex (vmPFC), brain area critical for emotional regulation, tend to exhibit exaggerated irrational decision-making (Barrash et al., 2000). Although knowledge regarding the neural mechanism underlying social decision-making is still limited, brain-imaging studies have provided evidence that social decision-making is associated with brain regions that are critical for cognitive and emotional processing. Therefore, it is possible that factors such as sleep loss that can disrupt these critical brain regions (e.g., weakened connectivity between the PFC and limbic region following 35-h SD, Yoo et al., 2007) may alter behavioral choices in social decision-making; relevant studies are reviewed in the following section.

1.4 Impact of SD on Social Decision-making

Decision-making forms the cognitive components of social decision-making, and the importance of sleep on decision-making has been explicitly studied. In a review of SD and decision-making, Harrison and Horne (2000) reported that simple decision-making tasks are sensitive to a night of SD, while complex tasks seem unaffected by a night of SD, possibly due to the complexity of and increased participant interest in the task. Nevertheless, these researchers believed that one night of SD still has effects on complex tasks involving the unexpected and innovation. Although many previous studies have examined the relationship between SD and decision-making, these studies solely focused on individual decision-making and did not include the social component or were conducted under in social context (e.g., Harrison & Horne, 2000; Killgore et al., 2006). The ability to regulate one’s emotions is important in any decision-making, particularly decision-making involving more emotion-based domains, such as social decision-making. As noted in the above sections, impairment in cognitive and emotion functioning has been observed after sleep loss. It is conceivable that the impairment in cognitive and emotional functions, which are important domains in social decision-making, after sleep loss could result in poorer performance (i.e., more irrational decision-making) in social decision-making.

It is important to study the impact of SD on social decision-making, as certain professions require working long hours or during the night, as well as making decisions. For example, in the medical sector, it is not uncommon to have an “on-call” system to provide emergency medical service. In Hong Kong, where the demand for medical services is high and staffs are in short supply (Schoeb, 2016), medical professionals face the challenge of continuous prolonged working hours and constant night shifts. Data collected in Hong Kong in September 2006 indicated that 18% of the Hospital Authority (HA) doctors worked more than 65 hours a week and approximately 8% of them worked overnight shift in HA hospitals almost every night (Hospital Authority, 2007). Being “on call” and working frequent night shifts may be stressful (Lindfors et al., 2006) and SD can cause many cognitive and emotional problems (as reviewed in section 1.2.1). Medical professionals are required to make quick decisions and judgments even when they are sleep deprived. It is important to investigate the impact of SD on social decision-making. The current study provides suggestions for professions that require night shifts and urges refinement of the “on-call” system in the medical sector.

Few studies have investigated the impact of SD on social decision-making. To the best of my knowledge, only one study investigated the effect of total sleep deprivation (TSD) on social decision-making (Anderson & Dickinson, 2010). Thirty-two participants were randomly assigned to the experimental group and control group, and both groups underwent a repeated-measures design. The experimental group (N = 16) was tested with social decision games twice at 19:00 h, once following a 36-hour SD (TSD condition) and again following a night of normal sleep (rested wakefulness: RW condition). Each test session was separated by a week. In this study, compared to the RW condition, the authors found a higher minimum acceptable offer (MAO) (i.e., the minimum X% of the total amount that the participants started to accept) in the UG following TSD, indicating that the participants were more resistant to offers that were deemed unfair following total SD. However, the offers from the proposers in the UG and DG did not significantly differ between the two groups and two conditions. Although the authors did not find a significant difference in the amount of money delivered by the first mover in the TG, an extreme level of trust (i.e., the first mover delivered at least 80% of the possible trust amount) was less likely following TSD. This study provided some evidence regarding the negative outcome of total SD on social decision-making, i.e., the participants displayed fewer trusting behaviors and made more irrational decisions. However, the result was only robust in the UG in which the participants were more likely to accept offers deemed fair and reject unfair offers following SD. The results of the TG were not robust and were only significant when the researchers used extreme trusting behaviors as the outcome measure. In a related study investigating sleep restriction and social decision-making, similar results were found following a week of chronic sleep restriction (Dickinson and McElroy, 2017). The participants completed a counterbalanced repeated-measures design with one week of 8-9 hours of sleep every night (SR treatment week), one week of 5-6 hours of sleep every night (WR treatment week), and an ad lib week (i.e., participants slept as much as they wanted) between the SR and WR weeks. Two laboratory sessions involving decision tasks were conducted after the WR week or the SR week. The participants were randomly assigned to a morning session (7:00 am) or an evening session (10:00 pm). In each laboratory session, half of the participants were identified as morning-type as measured by a short form of the morningness-eveningness questionnaire (rMEQ) prior to the experiment, and the other half were identified as evening-type. Robust results were found in the Dictator offer, showing lower amounts in the offer from the first movers in the DG. In addition, the participants showed reduced trusting behaviors as indicated by less trusting offers in the TG and less trustworthiness as indicated by lower amounts of money returned to the “deliverer” following sleep restriction. However, no significant change was found in the MAO (minimum acceptable offer) in the UG, indicating that the participants were not prone to making more irrational decisions after chronic sleep restriction. These two studies, which were conducted by the same team, were the only ones to have investigated the impact of sleep loss on social decision-making. The results of previous studies showed that the impact of sleep loss on social decision-making differed under various sleep protocols. For example, trusting behaviors in the TG were significantly reduced following a week of sleep restriction, while no similar result was found using a total SD protocol. It is interesting to explore how sleep loss impacts social decision-making. The TG, UG and DG were adopted in the current thesis; however, previous studies have indicated that the behaviors of the first mover (trustor) in the TG and second mover (proposer) in the UG are often of the greatest interest (Anderson & Dickinson, 2010). Therefore, the current study mainly aimed to examine the effect of SD on the trusting behaviors of the first mover in the TG and the irrational decision-making of the second mover in the UG.

As reviewed in section 1.3, a dual system hypothesized that social interactive decision-making is guided by not only cognition but also emotion (see Camerer, 2003) as evidenced in several neuroimaging studies. For example, Koenigs and Tranel (2007) found that patients with impairment in vmPFC tend to make more irrational decisions in UG. In another fMRI study, activation in the anterior medial prefrontal cortex (amPFC) was reported when participants decided to trust in the Trust Game (McCabe et al., 2001). From the evidence of fMRI studies, it is conceivable that PFC plays an important role in social decision-making. PFC has been reported as a brain region that represents affect in the absence of immediate rewards or punishments, as well as emotional regulation (see the review in Davidson, 2002). Studies have shown that baseline PFC activation could be a good predictor of the emotional regulation process (see review in Jackson et al., 2003). For example, Jackson et al. (2000) found that left-sided prefrontal activation is associated with the ability to suppress negative emotion voluntarily. An fMRI study showed that the right PFC was activated when participants were anticipating unpredictable negative stimuli, suggesting the important role of PFC in negative emotional processing (Dalton et al., 2002, as cited in Jackson et al., 2003). Another fMRI study suggested that the left PFC was activated when participants were asked to regulate their emotion when facing negative scenes (Ochsner et al., 2002). These studies provided evidence that emotion-related processing may be reliably indexed by PFC activation. This evidence was supported by brain lesion studies in which patients with damage to the PFC had problems regulating their emotions (Damasio, 1994; Robinson & Downhill, 1995). In addition to these neuro-imaging studies, two resting-state EEG indices (i.e., frontal alpha asymmetry and theta/beta ratio) have been widely studied in emotion-related processing. In a recent study, these two resting-state EEG indices have been found to be affected by a night of SD (Zhang et al., 2018a). The resting state is defined as a state in which there is no explicit input to or output from the brain (Fox & Raichle, 2007). In a resting state, the human brain is still highly functionally active without external stimuli and it even consumes more biological energy than the state of actively receiving external stimuli (Fox & Raichle, 2007; Raichle & Mintun, 2006). It is of interest to understand the impact of SD on the emotion- and cognition-related brain network in a resting state. In a resting-state fMRI study, Xu et al. (2018) found a significant change in the temporal properties of the dynamic functional connectivity following 36-h SD, and changes in these properties are related to certain symptoms of psychological disorders (e.g., schizophrenia, Damaraju et al., 2014; Alzheimer's disease, Jones et al., 2012). Frontal alpha asymmetry (ln [F4 alpha] – ln [F3 alpha]) and the frontal theta/beta ratio have been reported as two indices that are related to the emotional-regulatory process (see the review in Knyazev, 2007), which is discussed in the following sections.

Decades ago, the EEG frontal alpha asymmetry was historically employed as a psychophysiological metric to index affective style decades ago (Coan & Allen, 2004; Davison et al., 1979). Frontal EEG asymmetry is defined as "a measure of the difference in EEG alpha power between homologous right and left frontal electrodes" (p.2, Reznik & Allen, 2017). Previous EEG studies have shown that a higher alpha power demonstrates relatively lower neural activity, whereas a lower alpha power demonstrates heightened neural activity (Barry et al., 2007; Coan & Allen, 2004), suggesting that the alpha power is inversely related to neural activity. Multiple studies have examined the role of frontal asymmetry in emotional processing, and higher frontal alpha asymmetry (right lateralization in the alpha power) has been suggested to reflect success in emotional regulation (e.g., Jackson et al., 2003; Goodman et al., 2013; Zhang et al., 2018a). Furthermore, lower frontal alpha asymmetry (left lateralization in the alpha power) reflects poor emotional processing (Coan & Allen, 2004). The *dispositional model* (Davidson, 1998) proposes that individuals are predominantly different in their general tendency to approach or engage with a stimulus (as indexed by relatively greater left frontal activity) and to withdraw or disengage from a stimulus (as indexed by relatively greater right frontal activity) across all situations. Researchers found that individual differences in frontal alpha asymmetry were associated with differences in affective reactivity, which were sufficiently reliable and stable to be considered as a trait-like index. For example, Davidson and Fox (1989) found that in 10-month-old infants, those who cried when separated from their mothers were more likely to have greater right frontal activation in the resting baseline than those who did not cry in the same separation situation. However, this model of frontal alpha asymmetry has been challenged with claims that it "aims to measure individual approach versus withdrawal disposition regardless of situation" (p.198, Coan et al., 2006). Another recent model named the *"capacity model*" has proposed that individuals differ in their abilities to approach or withdraw from a stimulus, which is depending on the specific emotional context (Coan et al., 2006). In this model, frontal alpha asymmetry is regarded as a state-like index of emotional regulation ability. Papousek et al. (2011) have provided preliminary evidence that the frontal alpha asymmetry scores of participants who have better emotional regulation abilities return to the baseline scores when they are exposed to others' anxious voices, while those who have poorer emotional regulation abilities maintain the same asymmetry score. This evidence suggests that changes in frontal alpha asymmetry associated with emotional stimuli are adaptive and could reflect emotional regulation ability. In the current study, frontal alpha asymmetry changes could be deemed as state-like index of emotional regulation ability in response to the situation of SD.

The second resting-state EEG index is the frontal theta/beta ratio. The β (beta) band contains fast brain wave activity, while the θ (theta) band contains slow brain wave activity. Theta-wave activity has been found to be associated with subcortical affective processing and conduct problems among children (Mulert et al., 2007; Knyazev & Slobodskaya, 2003). From the developmental perspective, slow-wave activities (e.g., theta wave) contributes less to the EEG power spectrum with increasing of age (John et al., 1980). This change is considered a sign of maturation and, is accompanied by the development of inhibitory control (e.g., strength of inhibitory control increases during childhood, see the review in Knyazev, 2007). Empirical evidence also indicated that theta-wave activity is associated with emotional reactions and involved in discrimination among emotional stimuli. Nishiatni (2003) found that in a target discrimination task, an event-related synchronization of hippocampus theta activity was produced when participants were presented with unpleasant or pleasant pictures of human faces. Moreover, theta activity may be used to capture personality characteristics or individual differences. Theta activity in the orbitofrontal cortex and the default mode network (DMN) was found to be associated with the psychological process of a personality such as extroversion (Knyazev, 2012). Bresnahan et al. (1999) found that increased theta power may be associated with impulsivity when they investigated the developmental changes in EEG of individuals with Attention-Deficit/Hyperactivity Disorder (ADHD). While theta activity was consistently found to increase in individuals with ADHD, some studies also found a decrease of beta wave activity in ADHD patients (see the review in Arns et al., 2012). The fast frequency band (i.e., beta wave) was commonly associated with cortical arousal (Mendelson et al., 1986). In 1991, theta/beta-wave ratio was proposed by Lubar as a measure to distinguish children with ADHD from "normal" children. The theta/beta-wave ratio among individuals with ADHD is often found to be higher than that in controls (Arns et al., 2012), suggesting that a higher theta/beta ratio can indicate weaker cognitive control of behaviors and attention (Brennan & Arnsten, 2008). As noted above, PFC is a brain region that plays an important role in the emotional-regulatory process. The frontal theta/beta-wave ratio was suggested as a useful tool to study emotional-cognitive interactions (Putman et al., 2010). In a study (Putman et al., 2010) employing an emotional go/no go task, the theta/beta ratio in the frontal area was negatively correlated with inhibition control in reaction to fearful facial stimuli and self-reported attention control. This finding suggests that a higher theta/beta ratio indicates weaker inhibition and attention control in response to negative emotional stimuli. Therefore, the theta/beta ratio is considered an index of cognitive control and emotional regulation, and is hypothesized to change in response to SD.

1.5 Potential Moderators of the Relationship between SD and Social Decision-making

As noted in the above sections, SD has been found to have various effects across individuals on cognitive and emotional functions (e.g., memory recall, Taylor & McFactter, 2003); individual differences and personality factors could play roles as moderators in the relationship between SD and cognitive and emotional outcomes, and social decision-making is unlikely to be an exception. Thus, in the present study, how individual differences and personality factors might have different effects on the relationship between SD and social functions is examined in an exploratory analysis. After reviewing the literature, depressive symptoms, EI (emotional intelligence) and need for closure (NFC) are proposed to have moderating effects on the relationship between SD and social decision-making. The relevant literature is discussed in the subsequent sections.

Sleep and depression are closely correlated, and sleep problems are well known to be a key symptom of depression and a potential risk factor for depression (American Psychiatric Association, 2000). Previous studies have shown that depressive symptoms play a moderating role in the relationship between sleep quality and cognitive functions (Sutter et al., 2012). Sutter and colleagues found that poorer sleep quality was associated with worse performance in cognitive tasks, particularly among healthy participants reporting a higher level of depressive symptoms. It is of interest to investigate the differences in vulnerability to SD among healthy participants with different levels of depressive symptoms. The relationship between SD and depressive symptoms is rather inconsistent among different populations in the literature. Studies conducted decades ago found that SD could significantly decrease depressive symptoms in patients with depression (Schilgen & Tolle, 1980; Naylor et al., 1993). However, evidence obtained from more recent studies suggests that SD could increase depressive symptoms in healthy participants (Cadlwell et al., 2004). For example, a study examining the effect of SD on depressive mood in a healthy sample found that participants who had higher levels of sleepiness reported higher levels of depressive symptoms (Campo-Morales et al., 2005). On the other hand, negative mood and difficulty in making decisions are key symptoms of depression (American Psychiatric Association, 2000). It is plausible to hypothesize that people with higher levels of depressive symptoms are more likely to be influenced by the effect of SD on social decision-making.

EI is described as the "perception of one's ability to identify and regulate one's emotional state, involving abilities such as self-awareness, managing emotions, motivating one-self, empathy, and handling relationships" (Emert, et al., 2017, p.196). Killgore et al. (2007) found that people with high EI are less affected by sleep loss in emotionally charged moral judgment tasks than those with low EI. In another study, Killgore et al. (2008) found that EI also moderated the effect of SD on constructive thinking skills. Given that social decision-making contains both cognitive and emotional domains, it is plausible to assume that EI could play a role as a moderator in the relationship between SD and social decision-making. This study hypothesizes that people with high EI are less likely to be affected by SD on social decision-making.

NFC is another individual characteristic proposed to play a moderating role in the relationship between SD and social functions. NFC is defined as "the desire for an answer on a given topic, any answer…compared to confusion and ambiguity" (Kruglanski, 1990, p.337). NFC can be regarded as a trait, but its state can also be affected by factors such as fatigue (Webster et al., 1996). It has been reported that people with high NFC show less trust towards distant others and more trust towards close others (i.e., a polarization effect) when playing the Trust Game since they are averse to the unpredictability of that the other partners' behavior (Acar-Burkay et al., 2014). To date, no study has directly investigated the relationship among SD, NFC and trust. As fatigue and mental depletion are present following SD, it is predicted that people with high NFC would be particularly vulnerable to the effect of SD and would show less trust in social decision-making tasks since these tasks involve playing with anonymous partners in the current paradigm.

1.6 Overview of the Research Aims

Based on the content reviewed in this chapter, sleep loss is a prevalent problem, and its effects on daily social functioning and decision-making are important to investigate. Anderson and Dickinson (2010) examined the effect of total SD on social decision-making; however, these authors employed a 36-h total SD paradigm, which is less likely to occur in daily life. In Hong Kong, especially among adolescents and college students, SD is not uncommon. As reported by the Legislative Council Secretariat (2018), local students are sleep-deprived due to pressure to complete homework and electronic devices. Therefore, it is important to study whether a shorter (24-h vs. 36-h) but more common total SD duration could have a negative impact on social decision-making, as found in previous studies. In addition, a night of SD has been shown to affect emotional and cognitive functions as indicated by neural evidence, and the current thesis aimed to examine this effect through a resting-state EEG recording. Only one study has examined the impact of one night of SD on both resting-state EEG indices using a between-subjects design (Zhang et al., 2018a). Given that previous neural evidence has shown the emotion-based domain of social decision-making, it is conceivable to propose that SD will have an impact on the resting-state emotional-regulatory process, resulting in less altruistic/trusting and rational social decision-making. Both between-subjects and within-subjects designs were planned and employed in the current thesis to examine the effect of 24-h SD on social decision-making. Including both of the designs would provide a more comprehensive interpretation on the effect of SD on social decision-making, since each of the design has its advantage. On the one hand, within-subjects designs have the advantage of considering individual differences in vulnerability to SD. On the other hand, between-subjects designs have higher ecological validity (e.g. participant would make the decisions only once, which is more likely in reality) and would not be confounded by ordering or practice effects (Charness et al., 2012).

I proposed the following hypotheses:

Following 24-h SD, participants would exhibit

(a) fewer trusting behaviors and less trustworthiness (Hypothesis 1);

(b) more irrational social decision making (Hypothesis 2);

(c) left-lateralized alpha power in the frontal regions (Hypothesis 3a); and

(d) a higher theta/beta ratio in the frontal areas (Hypothesis 3b).

CHAPTER 2

Methods

The two studies were approved by the Human Research Ethics Committee of the Education University of Hong Kong. All the study protocols and designs adhered to the Declaration of Helsinki (World Medical Association, 2001). Written informed consent was obtained from all the participants prior to the experiment.

2.1 Participants

Study 1:

The participants in Study 1 completed a 9-day experiment. Based on a previous study using a similar experimental between-subjects design (Zhang et al., 2018a), fifty-one healthy young adults aged 18 to 30 years were recruited for Study 1 (*Mean*=21, *SD*=2.62). The participants were randomly assigned to the sleep deprivation (SD; n=25, 15 females) or control (SC; n=26, 19 females) group. Four participants (2 from the SD group and 2 from the SC group) dropped out in the middle of the experiment, and forty-seven participants remained. Four participants were excluded because they had less than 6 hours of sleep before the experiment; therefore, the final sample included forty-three healthy participants.

Study 2:

The participants in Study 2 completed a 14-day experiment. Before participating in Study 2, the participants were asked if they had participated in Study 1, and they were not invited to participate in Study 2 if they had participated in Study 1. Based on a previous study using a similar experimental within-subjects design (Anderson & Dickinson, 2010), fifty-six healthy young adults aged 18 to 30 years were recruited for Study 2 (*Mean*=21.88, *SD*=2.49). Four participants dropped out in the middle of the experiment, and fifty-two participants remained. Four participants slept less than 6 hours before either one or both experiment sessions and were excluded, resulting in forty-eight participants.

The inclusion and exclusion criteria were the same for both studies. Participants who were ethnically Chinese, read Chinese, were aged between 18 and 30 years, and were right-handed with normal or corrected-to-normal vision were included in the study. The participants were screened via a short online questionnaire and telephone interview. Participants were excluded if they had a current sleep disorder as indicated in the screening questionnaire; had a history of head trauma, a diagnosis of a sleep disorder or other psychiatric condition; had chronic or acute medical conditions; used medication or substances interfering with sleep or cognitive/affective functioning in general; currently used medication or substances, including tobacco; or had worked an overnight shift in the past two weeks.

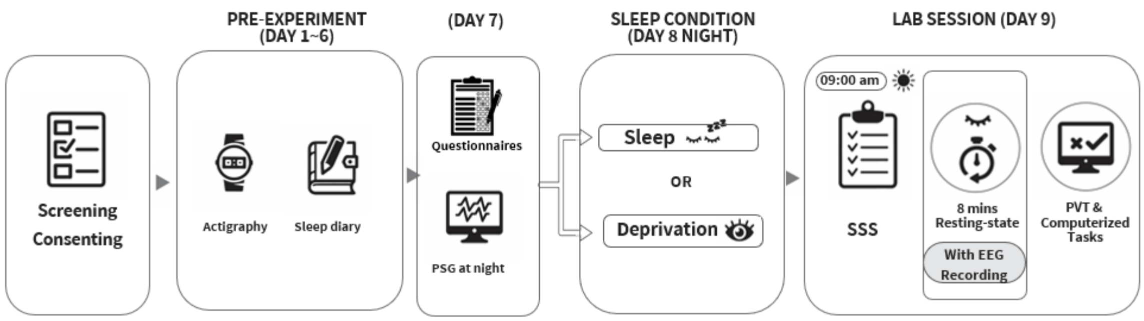
2.2 Procedures

Study 1:

This study adopted a between groups (SD vs. SC) experimental design with a pretest habitual sleep week and a 3-day experimental protocol (Figure 2a). Advertisements for the experiment were posted on campus or online and interested participants completed a short screening questionnaire. Participants who met the inclusion criteria were called for another telephone screening to confirm the information in the questionnaire they had completed. Then, the participants were invited to participate in the experiment and reserved dates to visit the laboratory. The group condition order was generated randomly by using Excel coding, and participants who arrived at the laboratory were randomly assigned to either the SD group or control group. After the screening and consent procedures, the recruited participants underwent a pretest sleep week while keeping a sleep diary and wearing an actigraph. On Day 1 of the experimental protocol, the participants completed a battery of questionnaires, which took approximately 30-45 minutes. The participants were asked to maintain their habitual sleep schedule at their residence on the night of Day 1 and were monitored by the actigraph (with at least 7 hours of time in bed and waking time no later than 10am). The participants could also wear a portable Polysomnography (PSG) on the night of Day 1, which was used to further screen for potential sleep disorders such as apnea (see details in the Measures section). On the morning of Day 2, the participants were informed of their random assignment to either the SC or the SD group. On the night of Day 2, the SC group had a normal night of sleep at their residence, while the participants in the SD group stayed awake performing solitary activities avoiding any emotional or physical arousal (e.g., watching horror movies or playing computer games) in the Sleep Lab of the Education University of Hong Kong. Snacks with calories lower than 100 kcal (e.g., small cake rolls with plain flavor) were provided at 1 am, 3 am and 5 am. On Day 3, the participants had breakfast at 08:00-08:45, followed by a series of outcome measurements from 09:00-11:00. Specifically, the participants underwent an EEG setup (approximately 20-30 minutes), the sleepiness and vigilance measures (approximately 10 minutes), the resting-state EEG recording and the social decision-making tasks (approximately 1-1.5 hours). All the measures were completed in the morning to control for circadian effects (e.g., Åkerstedt & Wright, 2009). The participants wore the acti-watch and abstained from caffeine, alcohol, and napping throughout the 3-day period and 24 hours before the laboratory session. Finally, the participants were debriefed and compensated with cash (HKD200 for SC group and HKD500 for SD group).

Figure 2 a

Study 1 Procedures

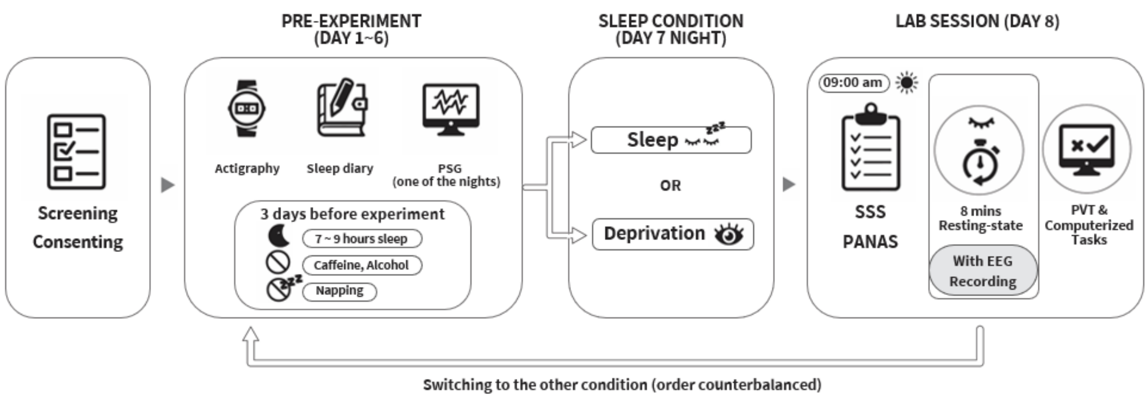


Study 2:

In Study 2, all the participants completed a counterbalanced, within-subjects repeated-measures study design involving two sleep conditions: **SD**, in which the participants stayed awake in the laboratory for the whole night, and **NS**, in which the participants stayed at home for a night of normal sleep (Figure 2b). The condition order was generated randomly by using Excel coding before the participants started the experiment, and the participants arriving at the laboratory were randomly assigned to undergo either the SD condition first or the NS condition first. As a result of the social movement and the outbreak of the pandemic in Hong Kong during the data-collection period, some participants who were supposed to undergo the SD condition first were changed to the NS condition due to the unstable and unpredictable traffic conditions and laboratory availability during these critical periods. Therefore, resulting in a final number of 32 participants underwent the NS condition first in Study 2, while 16 participants underwent the SD condition first. The recruiting and screening procedures were identical to those in Study 1. The participants wore an actigraph and kept a sleep diary throughout the two-week protocol and underwent one night of PSG-monitored sleep at home during the 6-day pretest week before the first sleep condition manipulation of SD or NS, which was separated by another pretest week. The morning of the laboratory session after each sleep condition, the participants completed the same set of tasks as described in Study 1 (i.e., the sleepiness and vigilance measures, resting-state EEG recording, and social decision-making tasks, see details in the Measures section). All the participants were compensated with cash (HKD800).

Figure 2 b

Study 2 Procedures



2.3 Measures

Sleep Diary: The participants were required to keep a sleep diary (Carney et al., 2012) during the pretest period. The participants were instructed to complete the diary to record the time they went to bed, their sleep time, their wake time, the time they got out of bed, their daily positive and negative affect and their napping behaviors. The average sleep duration across the six days before the laboratory session was calculated as the average of the nocturnal sleep duration in Study 1. In Study 2, the participants were instructed to keep a regular sleep pattern three nights before the laboratory session. The participants were asked to sleep at least 7 to 9 hours and wake up no later than 10 am (to ensure a 24-h SD before the laboratory session). The average sleep duration across the three days before the laboratory session was calculated as the average of the nocturnal sleep duration. Ten items related to positive and negative affect were extracted from the sleep diary as a baseline measure of affect.

Actigraphy: Continuous activity recordings were obtained by using an AMI Motionlogger Micro Watch in the Zero Crossing Mode (ZCM) for the data acquisition (Ambulatory Monitoring, Inc.). This accelerometer-based device resembles a wrist-watch and can noninvasively acquire activity data that are moderately correlated with PSG measures of sleep and waking and provide information regarding activity levels and patterns during the day. The participants were asked to wear the actigraph watch throughout the experiment. All the actigraphy was preset at the ZCM, and the data were scored using ActionW 2.7 (Ambulatory Monitoring, Inc.) using a validated algorithm

(Cole and Kripke, 1992). The total sleep time (TST) was extracted and compared with the sleep diary. Each participant's final actigraphy-verified sleep diary sleep duration was calculated.

Nocturnal Polysomnography (PSG): Portable PSG (Esprit Nova ™, also adopted in Abumuamar et al., 2018) was used as an additional screening procedure to exclude participants with potential sleep apnea and test the application of portable PSG in sleep studies. The participants were instructed regarding how to use the machine in the laboratory and wear it at home for one night of sleep. The following parameters were measured using PSG: electroencephalogram (EEG), left and right electrooculogram (EOG), electromyogram (EMG) (chin and bilateral anterior tibialis muscle), electrocardiogram (ECG), airflow, snoring, respiratory effort, body position, limb movement, oxygen saturation, pulse rate, and pulse waveform. All the computerized sleep data were automatically scored and verified manually by registered PSG technologists according to the standard American Academy of Sleep Medicine (AASM) criteria (see the review in Abumuamar et al., 2018). A sleep report was generated for each participant. An apnea-hypopnea index (AHI) score higher than 5 in the report would be regarded as potential sleep apnea. As all the participants were screened for sleep apnea using the Berlin questionnaire before they participated in the experiment (Netzer et al., 1999), PSG only worked as an objective measure for additional screening. None of the participants in the current study reached the threshold of AHI for diagnosis of sleep apnea.

Daytime Electroencephalography: EEG signals were recorded using a 64-channel Brain Products EEG cap system with actiCap electrodes according to the international 10-20 system at a sampling rate of 500Hz per channel. The signals were referenced to the average of all channels with a ground at AFz. The impedance of all the channels was kept below 20 km. The participants were instructed to sit with their back upright, face the computer screen, attempt not to blink their eyes and sit still; 8 alternating one-min eyes-open and eyes-closed resting-state EEG data were recorded. Although an increase of alpha power was reported as an index of sleepiness in the eyes-closed condition, an explorative analysis separating the eyes-closed and eyes-open condition did not find any significant difference compared to collapsing both conditions. Therefore, the data in the eyes-closed and eyes-open conditions were collapsed together for the calculation (Putman et al., 2010; Zhang et al., 2018a). The EEG data were filtered with a high-pass filter at 0.1 Hz and a low-pass filter at 30 Hz. Artifact rejection was performed in all the channels using a peak-to-peak threshold of 100 uV within a moving window of 500 ms and a 250-ms window step. After the automatic artifact rejection, obvious eye-movement artifacts were also removed by the eye-balling method. A fast Fourier transform (FFT) was used to estimate the spectral power density in the delta (1–3 Hz), theta (4-7 Hz), alpha (8-13 Hz) and beta (13–30 Hz) bands. The following two emotion-related EEG indices were calculated: frontal alpha asymmetry and theta/beta ratio. Frontal alpha asymmetry was calculated as the difference in the natural log-transformed alpha power density at F4 and F3 (i.e., ln(F4 alpha)-ln(F3 alpha)). The theta/beta ratio was calculated as the averaged ratios of the theta power density over the beta power density in the frontal area (F3, Fz, and F4). EEG data with valid data less than 240s were not included for analysis (Zhang et al., 2018a).

Pittsburgh Sleep Quality Index (PSQI): The Chinese PSQI was used to assess sleep quality over the past month retrospectively (Tsai et al., 2005). The PSQI includes the following seven components of sleep quality: subjective sleep quality, sleep onset latency, actual sleep time, habitual sleep efficiency, sleep disturbance, use of sleep medication and daytime dysfunction. The total score ranges from 0 to 21, and we adopted a cutoff score of 5/6 to identify good/poor sleepers (Buysse et al., 1989). The total score represents the overall sleep quality, which was the main interest in the current study, and an overall score over 5 suggests that the individual is a “poor sleeper”.

Composite Scale of Morningness (CSM): The CSM (Smith et al., 1989) is a 13-item scale assessing circadian preference in behavioral terms. Scoring high on the CSM represents high morningness. A Chinese adapted version of the CSM (Lau et al., 2013; Wong et al., 2012) was employed to measure circadian preference as a baseline/control variable. A score of 23 or below indicates an evening type, while a score of 40 or above indicates a morning type. A score between 23 and 40 indicates an intermediate type.

Depression Anxiety Stress Scales (DASS). The 21-item DASS was used to assess negative depressive and anxious emotions and stress over the past week. The DASS was developed by Lovibond & Lovibond (1995). The scale includes three subscales and each subscale includes 7 items. The items were scored on a 4-point Likert scale ranging from 0 (never) to 3(always). The sum of each subscale was calculated and used in the current study.

Emotional Intelligence: Wong’s Emotional Intelligence Scale (WEIS) is a self-reported measure developed by Wong and Law (2004) to measure EI among Chinese respondents. The scale consists of 20 forced-choice questions; the participants have to choose one of two abilities that best describe them. The total score was calculated, and the scores ranged from 0 to 20. A higher total score suggests higher EI.

Need for Closure: NFC was measured by the 15-item shortened scale developed by Roets (2011). The participants rated their responses using a 6-point Likert scale ranging from 1 (*strongly disagree)* to 6 (*strongly agree)*. The scores can range from 15 to 90. A higher total score indicates a higher NFC.

Stanford Sleepiness Scale (SSS): The SSS (Chinese version) is a self-reported scale used to assess participants' perceived sleepiness (Hoddes et al., 1973). The SSS was translated to Chinese with back translation. The participants were asked to rate their current sleepiness on a scale ranging from 1 (*very alert)* to 7 (*extremely sleepy)*.

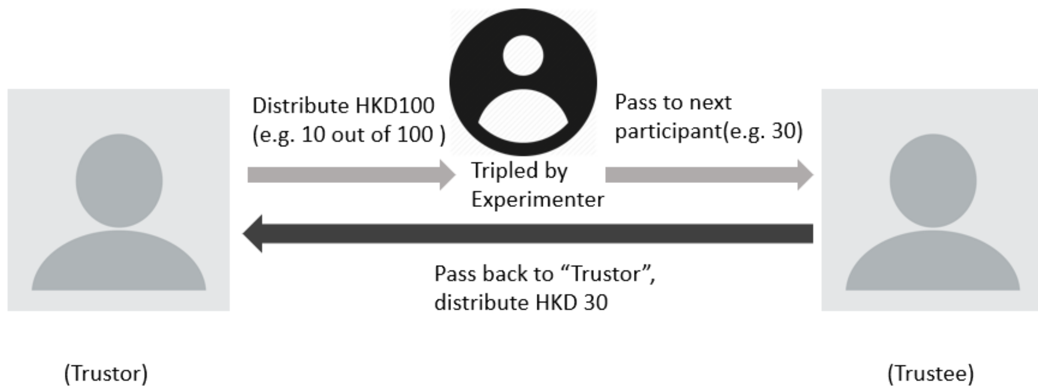
Psychomotor Vigilance Test (PVT): On the 10-min computerized PVT, the participants were required to press a button as quickly as possible once a target appeared on the screen (Belenky et al., 2003). The average response time (with a press of the "SPACE" bar) during each trial and the number of lapses (>1000 ms) were recorded.

Positive and Negative Affect Schedule (PANAS): The PANAS is a 20-item scale with 10 words related to positive affect and 10 words related to negative affect. The participants were asked to rate the extent to which they felt their affect was positive or negative at the time. The positive affect and negative affect scores were added separately. A higher score indicates a higher level of each affect (Watson et a., 1988). The PANAS was applied in Study 2 during the day following a night of SD or normal sleep.

Social Decision-making Tasks*:* The social decision-making tasks applied in the current study included the following three games: TG, UG, and DG. The participants were informed in advance that they would take part in a drawing after the full experiment and obtain an extra reward based on their performance in one of the three games and that they would be debriefed at the end. The TG (Berg et al., 1995) examines trust and trustworthiness in an environment that is not zero-sum (zero-sum being where one player's gain is necessarily the other's loss). There are two parts in the TG: the first part measures trust and the second part measures trustworthiness. In the TG (see Figure 2 c and Appendix 1 for the instruction script), the participant who played the role of "trustor" decided how much of HKD100 to deliver to the next participant (the "trustee"). The money was then tripled by the experimenters and the trustee needed to decide how much of the money they would return to the trustor. The participants were informed that they would deliver the money to the next participant and that they would receive the final payoff after all the experiment sessions when all the payoffs were calculated for both the trustor and trustee. The amount of money that the trustor delivered was regarded as a measure of trust. Following the first part of the TG, the participants were told that they were paired with a previous participant and would play the role of "trustee" in the second part of the TG. Then, all the participants were given half of the tripled amount of money ($150=50% * 100*3) and needed to decide how much they wanted to return to the previous participant. The amount returned by the trustee was regarded as a measure of trustworthiness. However, there were no "next participants" or "previous participants" in reality, and all offers were pre-set (HKD150) by the experimenter before the experiment.

Figure 2 c

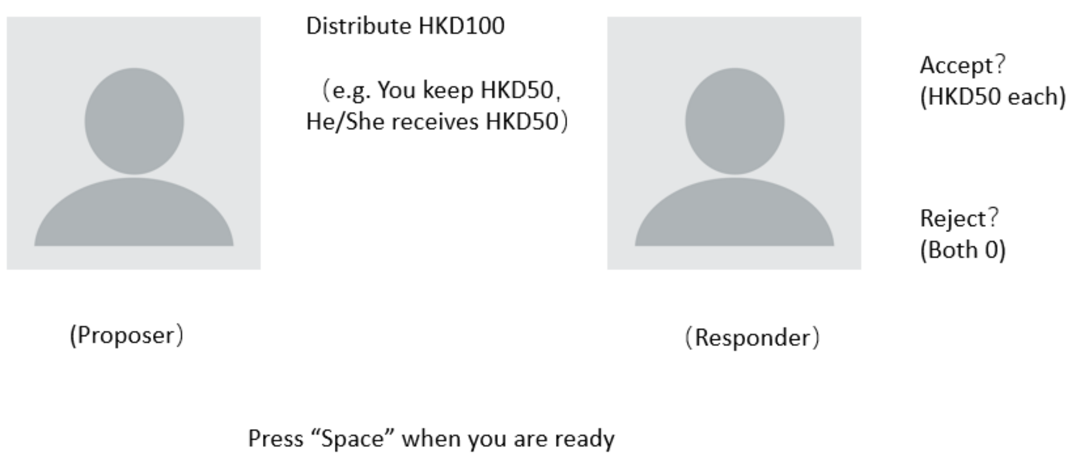
Trust Game Demonstration



The UG (Güth et al., 1982) is a simple bargaining game measuring rational decision-making when facing unfairness. In this game, the participants were introduced to 10 subjects (confederates) by introducing their participant numbers and told that they would be playing a game with each of these ten people. The "proposer" decided how much of HKD10 they would give to the "responder". The responder had the choice to accept or reject the offer. If the responder rejected the offer, both of the individuals receive nothing (see Figure 2 d). The participants were informed that they were randomly assigned to the role of proposer or responder; however, all participants were assigned to the role of responder. All offers were predetermined such that all the participants received the same set of offers. Half of these 10 offers were fair, i.e., a proposal to divide the $10 evenly ($5:$5), while the remaining half were unfair (two offers of $9:$1, two offers of $8:$2, and one offer of $7:$3). The participants were expected to receive a payoff no greater than $34 (if they accepted all the offers). The acceptance rate was calculated and compared among the different offer conditions.

Figure 2 d

Ultimatum Game Demonstration



Study 1 was conducted before Study 2, to increase the authenticity of the procedure and eliminate any possible confounding factors (i.e., the participants knew precisely how their choices affected the outcome), a strategy method was used instead of a game method in Study 2 in both the TG and UG. In Study 2, the “trustee” part of the game was administered via the strategy method, and the participants were asked to make decisions regarding all the possible offers that the trustor might make. In the UG, the participants played both the roles of proposer and responder. The proposer decided how much of HKD100 instead of HKD10 they would offer to the “responder” to increase the ecological validity of the task in Study 2 (HKD10 is a trivial amount in Hong Kong). The “responder” part of the game was administered via the strategy method, and the participants were asked to make decisions regarding all the possible offers that the proposer might make. The amount distributed by the proposer is usually not of interest, but it was still included in this study as a measure of generosity. The minimum acceptable offer (MAO), i.e., the minimum offer amount distributed by the proposer when the responder decided to accept, is regarded as a measure of rational decision-making. The rational decision is to accept all offers, regardless of how small the amount. The DG is a simplification of the UG (Forsythe et al., 1994), in which the responder's rejection option is eliminated. The DG was only played in Study 2, and all the participants played the role of the proposer. The participants were asked to decide how much of HKD100 they wanted to deliver to the next participant and they were informed that the responder could not reject the offer (see the instruction script in Appendix I). The DG was applied to help distinguish whether the proposers made decisions due to a sense of fairness or only a fear of rejection. A previous study showed that the offers made by a proposer in the DG were much lower than those offered in the UG; however, the offers were still above zero (Forsythe et al., 1994). The DG was added in the current study as a validation check for the offers in the UG.

2.4 Analytic Plan

The data were analyzed using SPSS 26. In Study 1, one participant did not complete the questionnaire; thus, the demographic information of the participants only includes 42 participants. Only thirty-one participants completed both the TG and UG using the game method as the strategic method was introduced, and the simple 10-trial UG was no longer used. Thirty-six participants have validated resting-state EEG data and were included in the analysis. Due to errors made in saving the computerized tasks (e.g., SSS and PVT), some data were accidentally replaced with new data and are thus missing. Only 30 participants completed the social decision-making games in Study 2 as the current thesis is part of a larger study, and other tasks were performed instead of social decision-making in a later stage. Thirty-five participants have validated resting-state EEG data under each condition in Study 2 and were included in the analysis.

Table 1 a

Number of Participants Included in Each Task

	Study 1 (Total N = 43)	Study 2 (Total N = 48)
Number of participants included in preliminary analysis (N)	42	48
Number of participants included in social decision-making (N)	31	30
Number of participants included in EEG analysis (N)	36	35

Data Analysis in Study 1:

Independent-sample t-tests and chi-square tests were used to compare the group differences in the demographic variables, sleep characteristics, sleepiness and vigilance. Given that the DASS scores significantly differed between the SD and SC groups and their potential correlation with social decision-making outcomes, the DASS subscale scores were entered as covariates while testing Hypotheses 1 and 2. An analysis of covariance (ANCOVA) was used to compare the group differences in trust and trustworthiness. A generalized estimating equations (GEE) model was used to explore the differences in the probability of accepting the offers (1: accept; 0: reject) between the SD and SC groups under four different conditions. A logistic regression fitted with the GEE method is a nonparametric test of the response probability for the same individual with a given offer amount (Hanley et al., 2003). This analysis generates an estimate of the odds ratio, 95% confidence interval (CI), and p value. Regarding Hypotheses 3a and 3b, an independent-sample t-test was conducted. As suggested by a previous study (Zhang et al., 2018a), PSQI and CSM are potential covariates that may affect the relationship between SD and resting-state EEG indices. Therefore, the PSQI, CSM and DASS subscale scores were tested as covariates using an ANCOVA. If Mauchly's Test of Sphericity was violated, the Greenhouse-Geisser adjustment was adopted. The potential moderators were explored using PROCESS 3.5(Hayes, 2012).

Data Analysis in Study 2:

The differences between the SD condition and control condition in sleepiness and vigilance were examined using paired-sample t-tests. A paired-sample t-test was applied to investigate differences in the social decision-making tasks (i.e., TG, UG and DG) and resting-state EEG markers between the two conditions. The PSQI and CSM were used as covariates in the repeated-measures ANCOVA. If Mauchly's Test of Sphericity was violated, the Greenhouse-Geisser adjustment was adopted. An SPSS macro (MEMORE) developed by Montoya (2018) for moderation analyses in repeated-measures designs was used in Study 2. MEMORE is a statistical tool similar to PROCESS (Hayes, 2012) that was developed by the same team for moderation analyses with one or multiple between-subjects moderators in a repeated-measures study design.

CHAPTER 3

Results

3.1 Study 1 – Between-subjects Data Analyses

3.1.1 Psychometric Properties of the Questionnaires

The psychometric properties of the assessment tools are shown in Table 2 a. All the scales, except for the PSQI, had acceptable (Cronbach's alpha > 0.6) internal consistency. The relatively low Cronbach's alpha of the PSQI has been consistently reported in Chinese samples (Chung & Wong, 2014).

Table 2 a

Psychometric Properties of the Questionnaires Used in Study 1

	Cronbach's alpha
Composite Scale of Morningness	.845
Pittsburgh Sleep Quality Index	.584
DASS-Depression scale	.810
DASS-Anxiety scale	.681
DASS-Stress scale	.807
Need for Closure	.804
Emotional Intelligence	.785

3.1.2 Participant Characteristics

An independent t-test was used to compare the participants' characteristics (Table 2 b) between the SD and SC groups, and the p value is reported based on the assumption of equal variance between the groups. Sex was compared using chi-square analysis. The participants in the SD group and SC groups did not significantly differ in most demographic characteristics and study variables at baseline, indicating that the two groups of participants were similar at baseline in terms of their individual characteristics. However, the scores on all three subscales of the DASS in the SD group were significantly higher than those in the SC group. Therefore, the depression, anxiety and stress scores in the DASS were controlled as covariates in the following analysis. In the DASS, the percentage of participants who scored normal to mild was 85.7% (N=36) on the depression subscale, 81% (N=34) on the anxiety subscale and 88.1% (N=37) on the stress subscale. The box plot analysis showed that there were no extreme cases of outliers in the outcome variables (i.e., >3 IQR, Hoaglin & Iglewicz, 1987); thus, no outliers were excluded.

Table 2 b

Demographic Characteristics of the Participants

	SD group (n=22)	SC group (n=20)	
	Mean (SD)	Mean (SD)	*p-value*
Age	20.64(1.65)	21.40(3.39)	.352
Sex (% female)	56.52%	65.00%	.756
DASS-Depression scale	4.36(3.57)	2.35(2.23)	.036
DASS-Anxiety scale	4.09(3.02)	2.25(1.92)	.028
DASS-Stress scale	6.86(2.98)	4.00(3.08)	.004
NFC (total score)	63.82(7.92)	58.00(7.39)	.019
EI	13.18(4.38)	13.75(3.91)	.661

Baseline Affect			
Positive	2.44(0.42)	2.42(0.31)	.871
Negative	1.72(0.49)	1.53(0.28)	.141

Note: EI: Emotional Intelligence; NFC: Need for Closure

3.1.3 Sleep Characteristics

The two groups of participants did not significantly differ in terms of sleep characteristics at baseline (Table 2 c). The average sleep duration as measured by the sleep diary (verified by actigraph) was more than 7 hours in both groups. The chi-square test indicated that there was no significant difference in sleep quality (good vs. poor) or circadian preference between the two groups. In total, 79% of the participants were the intermediate type of circadian preference, 12%were the evening type, and 9% were the morning type. This is consistent with the fact that most people fall somewhere between these two types and represent the intermediate type (Selvi et al., 2007). The PSQI scores ranged from 2 to 12, and approximately 39% of the participants had a score over 5.

Table 2 c

Sleep Characteristics

	SD group(n=22)	SC group(n=20)	
	Mean (SD)	Mean (SD)	*p-value*
Averaged sleep duration(h)	7.53(1.04)	7.66(.87)	.666
CSM score	31.27(5.85)	30.95(6.45)	.866

PSQI global score	5.43(2.11)	5.00(2.58)	.563

Note: CSM: Composite Scale of Morningness; PSQI: Pittsburgh Sleep Quality Index

3.1.4 Correlation between the Baseline Variables and Outcome Variables

Pearson's correlation analysis of the baseline variables and outcome variables was conducted (Table 2 d). Trust was found to be closely related to personality traits such as EI (r = -.341, p=.027). Similarly, trustworthiness was correlated with circadian preference (r = .360, p = .043) such that a higher CSM score indicated an inclination toward morningness. However, with a corrected p value (p = .005), there was no significant correlation between the baseline variables and the social decision-making outcome variables. A further correlation analysis was conducted separately for the two groups (see Appendix II). In the SD group, the DASS-depression score was negatively correlated with trust (r = -.490, p = .021) and trustworthiness (r = -.475, p = .046). In the control group, only trust was positively correlated with DASS-depression (r = .478, p = .033).

Table 2 d

Correlation between the Baseline Variables and Outcome Variables

	1	2	3	4	5	6	7	8	9	10
1. Trust	-									
2.Trustworthi-ness	.519**	-								
3. Acceptance rate (unfair)	.228	-.050	-							
4. PSQI	-.068	-.203	-.047	-						
5. CSM	.226	.360*	.200	-.345*	-					
6. DepScore	-.123	-.251	.006	.333*	-.388*	-				
7. AnxScore	-.025	.055	-.021	.481**	-.069	.601**	-			
8. StrScore	-.04	.153	-.008	.435**	-.221	.682**	.683**	-		
9. TotalNFC	.037	.179	.055	-.173	-.023	.068	.041	.190	-	
10. EI	-.341*	-.164	-.059	-.250	-.071	-.342*	.444**	-.266	.045	-

Note: PSQI: Pittsburgh Sleep Quality Index; CSM: Composite Scale of Morningness; DepScore: Depression subscale score in Depression, Anxiety, Stress Scale; AnxScore: Anxiety subscale score in Depression, Anxiety, Stress Scale; StrScore: Stress subscale score in Depression, Anxiety, Stress Scale; EI: Emotional Intelligence; NFC: Need for Closure

*p < .05, two-tailed. **p < .01, two-tailed.

3.1.5 Impact of SD on SSS and PVT

An independent-sample t-test was conducted to compare the SSS and PVT data between the two groups and revealed the well-established effect of SD (Table 2 e). On the morning of experiment Day 3, the participants in the SD group were significantly sleepier than those in the SC group ($t(31.305) = 6.558$, $p < .001$). During the PVT, the participants in the SD group missed significantly more targets than those in the SC group ($t(22.903) = 2.854$, $p = .010$). In addition, the response time (RT) in the SD group was significantly longer than that in the SC group ($t(41) = 4.458$, $p < .001$). After controlling for the effect of the DASS, there were significant differences in the SSS ($F(1,37)=26.5$, $p < .001$, partial $\eta^2 = .417$), PVT reaction time ($F(1,37) = 24.485$, $p < .001$, partial $\eta^2 = .398$), and PVT lapses ($F(1,37) = 7.649$, $p = .009$, partial $\eta^2 = .171$) between the SD and SC groups.

Table 2 e

Independent Sample t-test Comparing SD and SC Groups on PVT and SSS

	SD group(n=22)	SC group(n=20)	
	Mean (SD)	Mean (SD)	*p-value*
PVT-RT	395.98(51.08)	334.34(37.32)	< .001
PVT-lapses	4.70(7.06)	.45(.94)	<.010
SSS	4.43(1.34)	2.40(0.60)	< .001

Note: PVT: Psychomotor Vigilance Test; RT: Response Time; SSS: Stanford Sleepiness Scale

3.1.6 Impact of SD on Social Decision-making

The average trust amount delivered by the first mover in the TG was HKD42.44 of HKD100. The average amount returned by the trustees was HKD63.12 of HKD150. To test Hypothesis 1, the independent t-test showed that there was no significant difference between the SD group (M = 42.14, SD = 21.13) and the SC group (M = 43.25, SD = 22.08) in trust offers ($t(41) = 0.456$, $p = .816$) and trustworthiness ($t(30) = 1.578$, $p = .125$ (Table 2 f). ANCOVA was used to control for the covariate effect of the DASS, and the results of the trust offers ($F(1,37) = .004$, $p = .953$, partial $\eta^2 = .000$) and trustworthiness ($F(1,27) = 2.952$, $p = .097$, partial $\eta^2 = .099$) remained nonsignificant.

Table 2 f

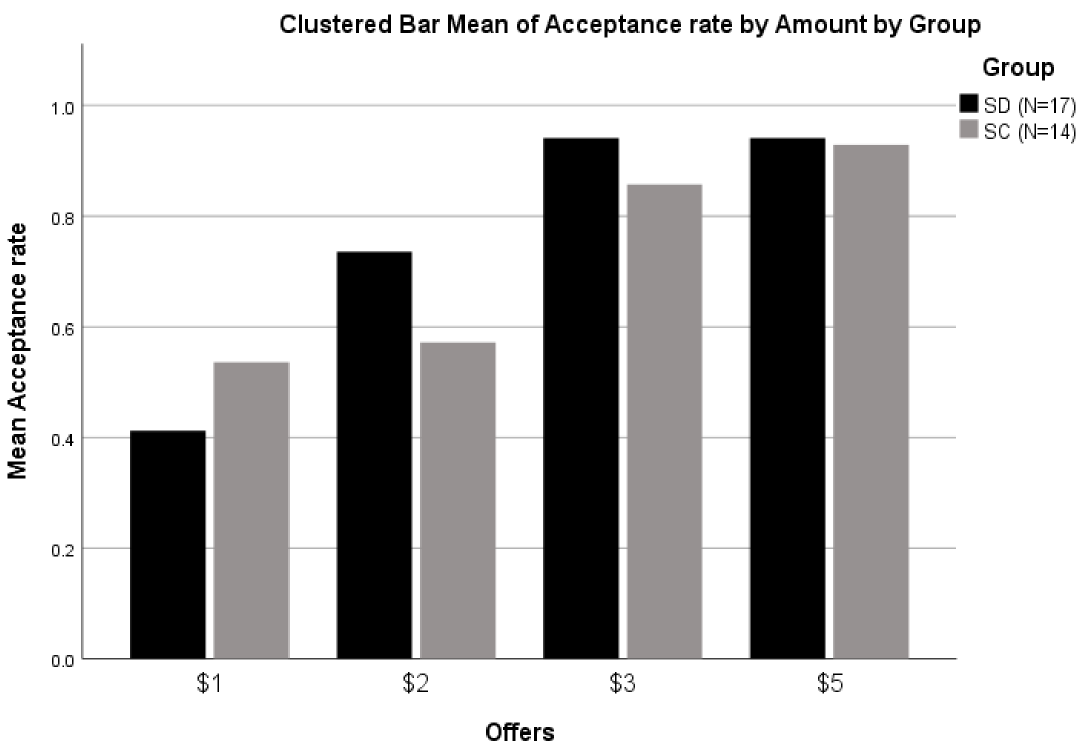
Independent Sample t-test Comparing SD and SC Groups on Trust and Trustworthiness

	SD group	SC group		
	Mean (SD)	Mean (SD)	*t*	*p-value*
Trust	41.74(20.20)	43.25(22.08)	0.234	.82
Trustworthiness	0.47(0.20)	0.36(0.16)	1.578	.13

Given that only thirty-one participants completed the 10-trial Ultimatum Game, the baseline differences of the demographic characteristics and sleep characteristics were compared between the SD and SC groups (Supplementary Tables 3&4, Appendix III). To test hypothesis 2, a Generalized Estimating Equations (GEE) model was used to compare the acceptance rates between the two groups under four different offer conditions. Group (SD vs. SC) and offer were entered in the GEE model as predictors, and choice (accept vs. reject) was the binary dependent variable. As expected, a high acceptance rate under the fair offer condition, i.e., \$5: \$5 (SD:93%; SC:88%), was revealed, while an offer of \$9: \$1 ($b = -2.334$, $p < .001$, $OR = .097$, 95%CI = .044, .215) or \$8: \$2 ($b = -2.259$, $p < .01$, $OR = .104$, 95%CI = .028, .394) was less likely to be accepted than the fair offers. However, there was no significant main effect of group (SD vs. SC) in accepting the offer under the four conditions ($b = .231$, $p = .775$, $OR = 1.259$, 95%CI = .259, 6.117), and no significant interaction between group and condition was observed, with all *ps* > .05 (see Figure 3 a). The results remained the same ($b = .231$, $p = .775$, $OR = 1.259$, 95%CI = .259, 6.117) after controlling for the effect of the covariates (i.e., DASS and NFC).

Figure 3 a

Group Acceptance Rate of Ultimatum Game Offers.



3.1.7 SD Effect on Resting-state EEG Indices

Scores of the alpha power density in F3 and F4 and the frontal alpha asymmetry are summarized in Table 2 g. To test hypothesis 3a, an independent t-test showed marginally significant lower frontal alpha asymmetry score in the SD group (M=-0.05, SD = 0.18) than in the SC group (*M*=0.08, *SD* = 0.24); *t* (34) = -1.826, *p* = .077). The group difference was significant in a one-tailed t-test given the hypothesized direction. The effect became nonsignificant after controlling for the potential effects of negative mood (DASS), habitual sleep quality (PSQI) and circadian preference (CSM); the ANCOVA results did not show a significant difference in frontal alpha asymmetry between the two groups ($F(1,30) = 2.690$, $p = .113$, $\eta^2 = .091$). Dividing the alpha power (Figure 3 b) into different frequencies showed that the marginal group difference was mainly driven by the upper alpha frequency, especially at 12 Hz ($t(34) = -2.147$, $p = .039$). When the effect of SD on frontal alpha asymmetry score was analyzed separately in eye-closed and eye-open condition, there was no significant difference of asymmetry scores between SD and SC group for both conditions.

Table 2 g

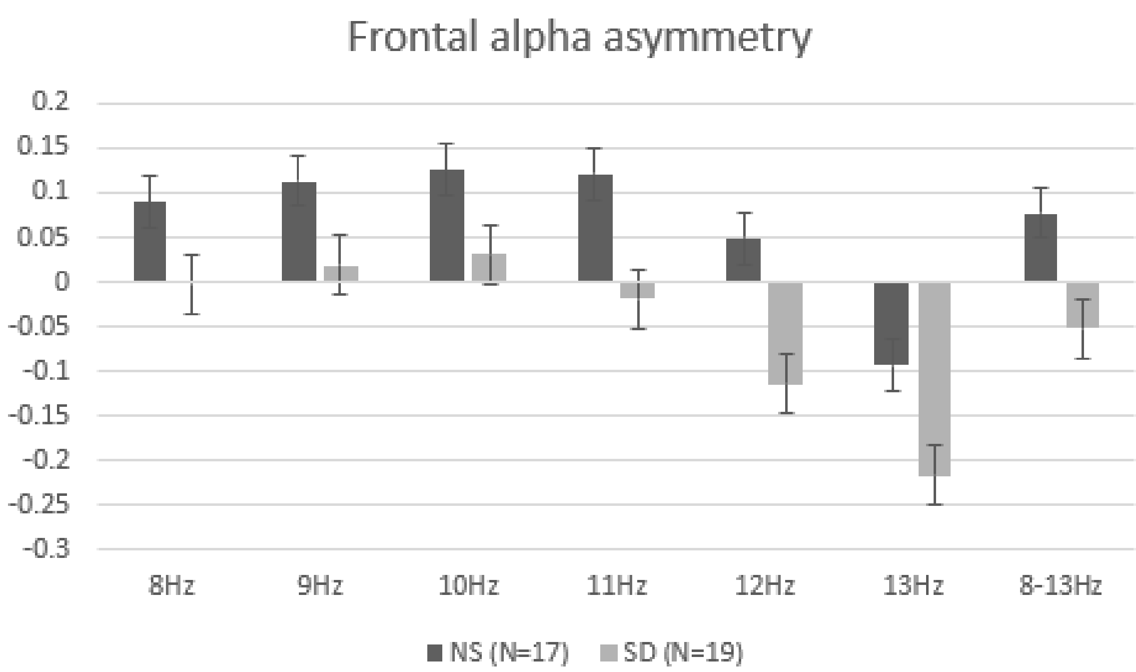
Independent Sample t-test Comparing SD and SC Groups on Frontal α Asymmetry

	SD group (n=19)		SC group (n=17)		
	Mean	SD	Mean	SD	*p-value*
In (α at F3)	0.56	0.54	0.65	0.8	-

In (α at F4)	0.51	0.57	0.73	0.8	-
Frontal α asymmetry	-0.05	0.18	0.08	0.24	0.077

Figure 3 b

Distribution of Frontal Alpha Asymmetry in Different Power Band



To test the Hypothesis 3b, a 2 (group: SC group vs. SD group) x 3 (site: F3 vs. Fz vs. F4) repeated-measures ANOVA was performed to compare the differences in the theta/beta ratios between the two groups across three frontal sites. The analyses revealed a significant main effect of site ($F(2,66)=14.77$, $p<.001$, partial $\eta^2 =.309$) on the theta/beta ratio but no significant main effect of group ($F(1,33)=.102$, $p=.751$, partial $\eta^2 =.003$).

There was also no significant interaction effect between group and site (F(2,66) = .536, p = .588, partial η^2 = .016). After controlling for the potential effect of PSQI, CSM and DASS, the main effect of site became nonsignificant between the two groups (F(2,54) = .128, p = .880, partial η^2 = .005) while the main effect of group remained nonsignificant (F(1,27) = .043, p = .837, partial η^2 = .002). There was also no significant interaction effect between group and site (F(2,54) = 1.735, p = .186, partial η^2 = .060). The post hoc pairwise comparison showed that the overall frontal theta/beta ratio in F4 was significantly higher than in F3 and Fz, *ps* <.05. The theta and beta power densities, and theta/beta ratios at F3, Fz, and F4 in the two groups are presented in Table 2 h.

Table 2 h

Power Densities of the θ/β Ratios at F3, Fz and F4

	SD group (N=18)	SC group (N=17)		
	Mean (SD)	Mean (SD)	*t*	*p-value*
θ				
F3	1.78(0.75)	1.70(1.36)	.214	.832
Fz	1.76(1.15)	1.53(0.99)	.707	.529
F4	1.77(0.69)	1.68(1.17)	.276	.784
β				
F3	0.39(0.67)	0.23(0.18)	.993	.328
Fz	0.21(0.18)	0.16(0.08)	1.142	.262
F4	0.15(0.07)	0.14(0.05)	.845	.404
ln(θ/β)				
F3	1.88(0.67)	2.02(0.41)	-.723	.475

Fz	2.18(0.56)	2.23(0.60)	-.276	.784
F4	2.44(0.39)	2.40(0.60)	.249	.805

3.1.8 Potential Moderation Effects of Individual Characteristics

The proposed moderators (i.e., DASS-depression, EI, and NFC) were entered separately using the PROCESS (Hayes, 2012) in SPSS as potential moderators of the relationship between SD and social decision-making. Since there were only 6 participants in the category of mild to severe in DASS-depression score versus 36 participants in the category of normal to mild, depression score was entered in the moderation model as a continuous variable. Since the moderation analysis was conducted for three potential moderators of the relationship between SD and trust/trustworthiness, the p value for significance was adjusted for increased type-I error ($p < .008$). Among all the variables, the depression score on the DASS was the only variable that was found to significantly interact with SD in predicting trust ($b = -6.45$, $t = -3.299$, $R^2 = .23$, $p = .002$, Table 2 i).

Table 2 i

Linear Model of the Predictors of Trust

	b	*SE*	*t*	*p-value*
Constant	48.24	4.76	10.13	0
	[38.60, 57.88]			
Group (dummy)	-3.48	6.37	-0.55	0.588
	[-13.09, 10.24]			

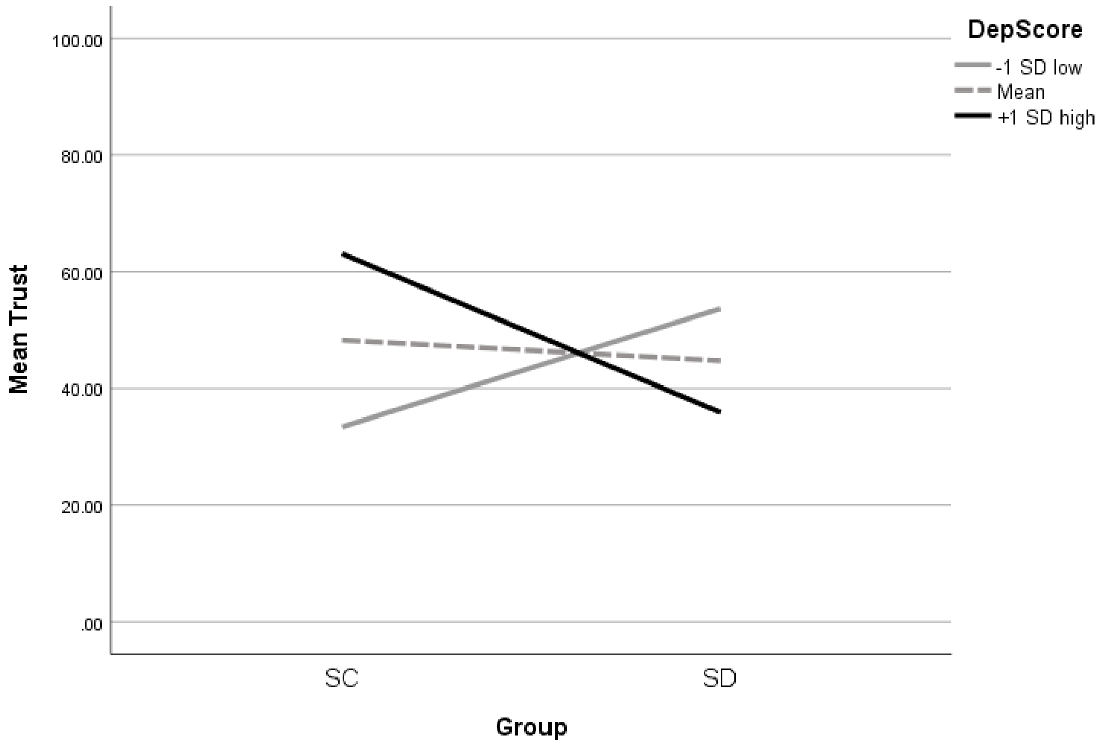
DepScore (centered)	4.73	1.97	2.4	0.021
	[0.74, 8.72]			
Group X DepScore	-7.56	2.29	-3.29	0.002
	[-12.20, -2.92]			

Note: R^2 = .23. SE = standard error. The 95% CI is provided in the table.

Simple slope analysis showed that the effect of SD on trust depended on the depression level. The values of the quantitative moderators were calculated using the mean plus/minus one SD from the mean, and the conditional effect is shown in Figure 3 c. Participants with more depressive symptoms (1 SD above the mean) showed fewer trusting behaviors after SD, while participants with a low level of depression symptoms (1 SD below the mean) showed more trusting behavior after SD than the controls.

Figure 3 c

Moderation Effect of Depression on Trust



3.2 Study 2 - Within-subjects Data Analyses

3.2.1 Psychometric Properties of the Questionnaires

The psychometric properties of the assessment tools are shown in Table 3 a. All the scales, except for the PSQI, had acceptable (Cronbach's alpha > 0.6) internal consistency. As described in Study 1, the Cronbach's alpha of the PSQI was relatively low, as consistently reported in Chinese samples (Chung & Wong, 2014).

Table 3 a

Psychometric Properties of the Questionnaires Used in Study 2

	Cronbach's alpha
Composite Scale of Morningness	.830
Pittsburgh Sleep Quality Index	.404
DASS-Depression scale	.750
DASS-Anxiety scale	.676
DASS-Stress scale	.787
Need for Closure	.861
Emotional Intelligence	.732

3.2.2 Participant Characteristics

Table 3 b shows the demographic characteristics of the participants in Study 2. The mean age of the participants in Study 2 was 21.88 years (*SD* = 2.49). There were 28 females and 20 males. In the DASS, the percentage of participants who scored normal to mild was 85.4% (N=41) on the depression subscale, 85.4% (N=41) on the anxiety subscale and 93.8% (N=45) on the stress subscale. The box plot analysis showed that there were no extreme cases of outliers in the outcome variables (i.e., >3 IQR, Hoaglin & Iglewicz, 1986); therefore, no outliers were excluded.

Table 3 b

Demographic Characteristic of the Participants

	n	Mean	SD
Age		21.88	2.49
Sex (% female)	28(58.3%)		
DASS-Depression scale		3.71	2.71
DASS-Anxiety scale		2.85	2.52
DASS-Stress scale		4.54	3.23
NFC (total score)		57.58	9.99
EI		14.35	2.72
Baseline Affect			
Positive		2.49	.54
Negative		1.66	.51

Note: NFC: Need for closure total score; EI: Emotional intelligence

3.2.3 Sleep Characteristics

The average sleep duration according to the habitual sleep week diary was 7.38 hours, which was within the suggested daily sleep duration range for young adults (i.e., 7-9 hours, National Sleep Foundation, 2015). In total, 81% of the participants were the intermediate chronotype, 15% were the evening type and 4% were the morning type. The PSQI scores ranged from 3 to 9, and approximately 23% of the participants scored over 5 (see Table 3 c).

Table 3 c

Sleep Characteristics

	Mean	SD
Averaged three-night sleep before NS lab day (h)	7.49	0.87
Averaged three-night sleep before SD lab day (h)	7.77	0.81
CSM score	30	6.15
PSQI global score	4.65	1.67

Note: CSM: Composite Scale of Morningness; PSQI: Pittsburgh Sleep Quality Index

3.2.4 Impacts of SD on the SSS, PVT and PANAS

A paired-sample t-test showed that there was a significant condition difference in the SSS ($t(43) = -10.717$, $p < .001$), PVT reaction time (RT) ($t(43) = -7.631$, $p < .001$) and PVT lapses ($t(43) = -3.842$, $p < .001$). This finding suggests that the manipulation of SD was successful and that the participants were less vigilant and sleepier after one night of SD. The participants also had significantly less positive affect ($t(43) = 8.325$, $p < .001$) and more negative affect ($t(43) = -2.462$, $p = .018$) after a night of SD.

Table 3 d

Paired-sample t-tests Comparing SDand NS Conditions on PVT, SSS, and PANAS

	NS condition	SD condition	
	Mean (SD)	Mean (SD)	*p-value*
PVT-RT	341.32(43.03)	381.80(45.99)	< .001
PVT-lapses	0.48(1.7)	3.49(6.31)	< .001
SSS	2.18(0.54)	4.29(1.32)	< .001
Lab day positive affect	2.90(0.52)	1.99(0.64)	< .001
Lab day negative affect	1.60(0.49)	1.80(0.64)	0.018

Note: PVT: Psychomotor Vigilance Test; RT: Response Time; SSS: Stanford Sleepiness Scale

3.2.5 Impact of SD on Social Decision-making

To test hypotheses 1 and 2, a paired-sample t-test was conducted to compare the amounts delivered by the trustors (i.e., trust), the amount returned by the trustees (i.e., trustworthiness), the amounts delivered by the first mover in the UG, the MAO (minimum accepting offer), and the amounts delivered by the first mover in the DG between the two conditions. Table 3 e shows that there was no significant difference in trust ($t(29) = -1.413$, $p = .168$), trustworthiness ($t(28) = 1.049$, $p = .303$), the UG ($t(28) = -0.583$, $p = .565$, the MAO ($t(28) = 0.192$, $p = .849$) or the DG ($t(28) = 1.506$, $p = .143$) between the two conditions, indicating that one night of SD did not have a significant impact on performance in these games. As an exploratory analysis, there was a marginally significant difference in trust between the SD and NS conditions when only participants with intermediate circadian preference were included in the analysis ($t(25) = -2.056$, $p = .050$).

Table 3 e

Paired-sample t-tests Comparing SD and NS Conditions on Social Decision Outcomes

	Condition	Mean (SD)	*t*	*p-value*
Trust	SD	50.83(28.27)	-1.413	.168
	NS	59.16(29.99)		
Trustworthiness	SD	.49(.22)	1.049	.303
	NS	.44(.17)		
UG (as deliverer)	SD	51.72(14.22)	-0.583	.565
	NS	53.10(17.90)		
MAO	SD	19.48(18.77)	0.192	.849
	NS	18.79(19.07)		
DG (as deliverer)	SD	48.45(25.00)	1.506	.143
	NS	39.31(24.41)		

3.2.6 Impact of SD on Resting-state EEG Indices

Scores of the alpha power density at F3 and F4 and the frontal alpha asymmetry are summarized in Table 3 f. To test Hypothesis 3a, a paired-sample t-test indicated that there was no significant difference in frontal alpha asymmetry between the two conditions ($t(34) = -1.698$, $p = .099$). The effect remained nonsignificant after controlling for the potential effects of habitual sleep quality (PSQI) and circadian preference (CSM).

Table 3 f

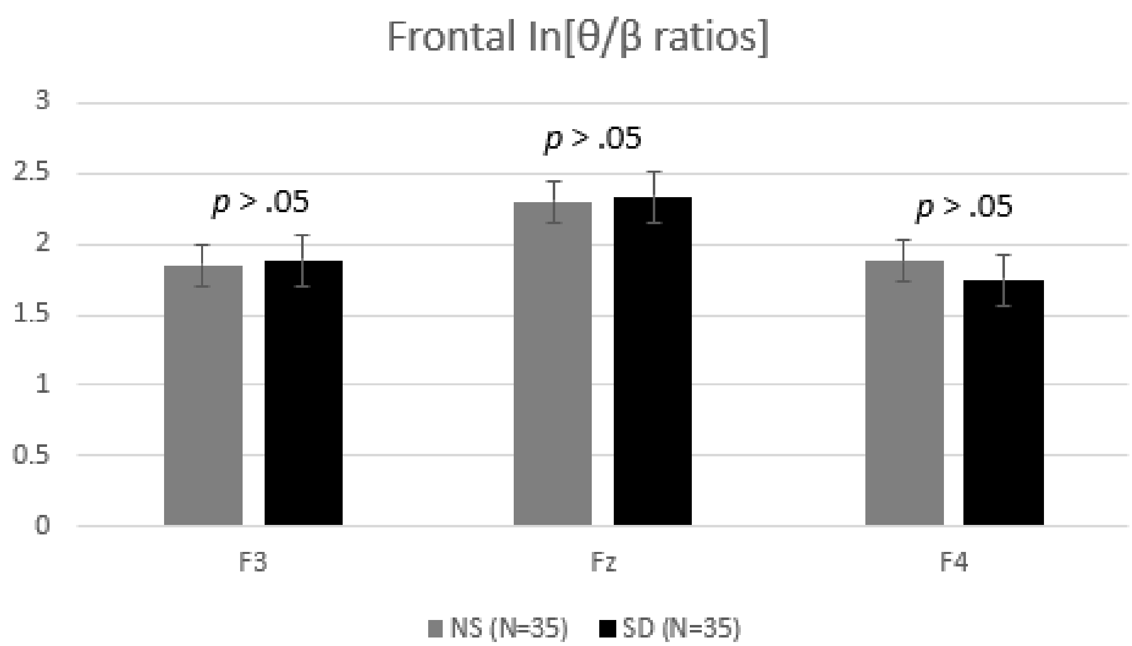
Paired-sample t-tests Comparing SD and NS Conditions on Frontal α Asymmetry

		NS condition		SD condition			
	N	Mean	SD	Mean	SD	*t*	*p-value*
In (α at F3)		0.58	0.88	0.27	0.85	3.672	-
In (α at F4)	35	0.53	0.9	0.29	0.92	3.383	-
Frontal α asymmetry		-0.05	0.2	0.01	0.15	-0.668	0.51

Two (condition: NS condition vs. SD condition) x three (site: F3 vs. Fz vs. F4) repeated-measures ANOVA was performed to test Hypothesis 3b. The analyses showed a significant main effect of site ($F(2,68) = 51.725$, $p < .001$, partial $\eta^2 = .758$) on the theta/beta ratio but no significant main effect of condition ($F(1,34) = .078$, $p = .782$, partial $\eta^2 = .002$). There was a marginally significant interaction effect between condition and site ($F(1.698, 57.746) = 3.340$, $p = .050$, partial $\eta^2 = .089$), indicating that there was a potential difference in the theta/beta ratio among the three sites between the two conditions. Post hoc tests with Bonferroni adjustment were conducted. Under the NS condition, the theta/beta ratio at Fz ($M = 2.299$, $SD = .557$) was significantly higher than that at F3 ($M = 1.850$, $SD = .704$) and F4 ($M = 1.877$, $SD = .593$) with all *ps* <.001. Under the SD condition, the theta/beta ratio at Fz ($M = 2.336$, $SD = .433$) was significantly higher than that at F3 ($M = 1.885$, $SD = .480$) and F4 ($M = 1.746$, $SD = .605$) with all *ps* <.001. However, the pairwise comparisons showed that there was no difference between the two conditions in the theta/beta ratio at all three sites; all *ps* > .05. After controlling for the potential effect of the PSQI and CSM, the results revealed similar patterns. The distribution of the frontal theta/beta ratios is presented in Figure 4 a.

Figure 4 a

Frontal Theta/beta Ratio Distribution



3.2.7 Potential Moderation Effects of Individual Characteristics

MEMORE was used to test whether individual differences or personality factors played a role as moderators in the effects of SD on social decision-making. The DASS-depression, NFC and EI scores were entered as moderators separately in the model. The outcome variables of social decision-making were entered as the dependent variable in each model. However, no interaction effect was found between any of the proposed moderators and social decision-making outcomes, and all *ps* > .05.

In addition, as the participants in Study 2 underwent the SD condition and NS condition in different order (counterbalancing), the order of the experiment was entered as a covariate in the ANCOVA of the effect of SD on social decision-making (i.e., trust and irrational decision-making). However, after controlling for the effect of order, there was no effect of SD on trust ($F(1,28) = .004$, $p = .952$, partial $\eta^2 = .000$) and MAO ($F(1,27) = .014$, $p = .908$, partial $\eta^2 = .001$).

CHAPTER 4

Discussion

4.1 Summary of Findings

4.1.1 Findings of Study 1

Study 1 examined the impact of 24-h SD on social decision-making and the resting-state EEG indices using a between-subjects design. Partially consistent with Hypothesis 1, depressive symptoms moderated the effect of SD on trust. After one night of SD, participants with a higher level of depressive symptoms showed less trust than the control group. In contrast, participants with a lower level of less depressive symptoms showed more trust after SD compared to those who had a night of normal sleep. However, there was no significant difference between the acceptance rates of the unfair offers between the two groups as proposed by Hypothesis 2. Partially consistent with Hypothesis 3a, there was a trend of lower frontal alpha asymmetry score (left-lateralized asymmetry) in the SD group than in the SC group, indicating poorer ability to regulate emotion. However, after controlling for covariates, there was no significant difference in the frontal alpha asymmetry between the two groups. Moreover, the theta-beta ratio did not differ significantly between the two groups as hypothesized (hypothesis 3b). In summary, in Study 1, one night of SD did not show any significant effect on social decision-making or the emotional-regulatory process evidenced by resting-state EEG indices. Depressive symptoms moderated the effect of SD on trust, and people with a higher level of depressive symptoms showed significantly less trust in the TG after SD.

4.1.2 Findings of Study 2

Study 2 examined the impact of one night of SD on social decision-making and the resting-state EEG indices using a repeated-measures design. Consistent with the previous literature, the ultimatum offer was not affected by sleep loss (Anderson & Dickinson, 2010; Dickinson & McElroy, 2017). The MAO in the Ultimatum Game did not significantly differ between the two conditions. In the TG, the trustors under the two conditions delivered similar amounts of money and the trustees returned similar amounts of money. One night of SD did not have an impact on these social decision-making tasks in the current study. However, there was a significant difference in trust between the SD and NS conditions among participants with the intermediate type of circadian preference. Following a night of SD, I type participants showed significant less trust than after a night of normal sleep. Individual characteristics were analyzed as moderators in the exploratory analysis of the effect of SD on social decision-making. However, no significant moderation effect was found. Moreover, consistent with Study 1, there was no significant effect of one-night SD on the resting-state EEG indices. In conclusion, the results of Study 2 did not support the hypotheses (hypotheses 1, 2, 3a and 3b).

4.2 Impact of a Night of SD on Social Decision-making

The current study provides the first evidence that depressive symptoms moderate the effect of 24-h SD on trust. People with a higher level of depressive symptoms would exhibit fewer trusting behaviors after a night of SD, while people with a lower level of depressive symptoms showed more trust after SD. In a study conducted in the United States, interpersonal trust was found to have a protective effect on major depression (Fujiwara & Kawachi, 2007). However, the effect became non-significant when only mentally healthy participants were included in the analysis. It could be that participants who are mentally healthy are less likely to develop depression regardless of their level of trust. The same pattern was observed in another sample of Koreans in which lower interpersonal trust was a risk factor for long-term depression, but the effect was attenuated after excluding participants who had pre-existing disabilities, poor health, and chronic disease (Kim et al., 2012). Consistent with the previous literature, depressive symptoms were negatively correlated with trust in the SD group and positively correlated with trust in the control group in the current study. More interestingly, in the normal sleep condition, individuals with a higher level of depressive symptoms showed more trust than those low in depressive symptoms. A recent review of psychiatric disorders and economic games suggested that abnormalities in social interaction are commonly seen in psychiatric disorders. Making social decisions (as implicated in economic games) involves a complicated process that requires not only substantial cognitive capacity but also inferring others' emotions and understanding the motivations for and consequences of one's action (Robson et al., 2020). Ong et al. (2017) recruited participants with a history of major depressive disorder and healthy controls to play an economic TG and found that participants with psychiatric disorders showed more reciprocal behaviors than healthy controls. This result somewhat contradicts the common notion that people with depression are often found to have compromised social functions. One possible explanation is that economic games simplify social interaction and that depressed patients are able to respond to the clear social signals. However, in a complex real-life social interaction, mood disorders may hamper the ability to understand complex social cues. In a study investigating the role of gender in the effect of depression on prosocial behaviors using a modified TG, depressed men showed more prosocial behaviors than the control men, while there was no difference in women. The authors suggested that behaving in a prosocial way might help reduce social stress. In another study using fMRI to study compliant and cheating behaviors in a modified TG (Shao et al., 2014), researchers found that depressed individuals were less likely to cheat (returning less than the amount requested by the trustor) than the healthy controls even when the risk of being caught is low. Neuro-imaging evidence also suggested a reduction in the BOLD response in the left dorsal putamen and anterior insula, which are brain regions involved in risky behaviors and evaluation of situations. This result demonstrated that reduced cognitive and affective processing may be associated with the limited ability of depressed patients to deal with the cognitive load in social interaction. However, a night of SD could change the tendency to trust among participants. Participants with a lower level of depressive symptoms seemed to mimic the tendency of more depressed participants in normal sleep conditions in their trusting behaviors following a night of SD. It is likely that a night of sleep loss limited the cognitive capacity in the less depressed participants and resulted in more prosocial behaviors as detected in the more depressed participants in normal sleep condition (Robson et al., 2020). Participants with a higher level of depressive symptoms showed a more severe loss in trust in the TG following SD, indicating that SD had a more negative impact on those with a higher level of depressive symptoms than the less depressed individuals. Although previous studies have shown that SD can have antidepressant effects on patients with depression (Schilgen & Tolle, 1980; Naylor et al., 1993), the results of the current study are consistent with the findings among healthy participants (Campo-Morales et al., 2005) in which sleepiness is correlated with more depressive symptoms. The finding of the moderation effect of depressive symptoms in the relationship between sleep loss and trust has several implications. Firstly, it provides guidance for when professionals such police, medical or military personnel are recruiting individuals for shift work or prolonged working periods. Since individuals in these professions often work under the condition of sleep loss and are required to make important decisions involving trust, those who are less vulnerable to the effect of sleep loss may perform better in these jobs. Specifically, in professions in which a high level of trust is appreciated (e.g., investors), people with have a lower level of depressive symptoms or negative mood may be differentially affected by sleep loss, thus maintaining their trust level after SD. Secondly, this finding may help mental health professionals in identifying individuals with depression who are prone to the effects of sleep loss or other sleep problems on social functions. Depressed individuals should be treated with extra care regarding their sleep conditions, and treatment for disrupted sleep should be provided if needed, to alleviate the impact of sleep problems on their social functions.

The results of the exploratory analysis in the current study provide an idea of the possible moderation effect of circadian preference in the relationship between SD and trust. People who are intermediate type of circadian preference show marginally significantly less trust after a night of SD. Circadian preference refers to one’s preferred sleep and waking schedule and healthy individuals often show distinct differences in circadian preferences (Dagys et al., 2012). Studies have provided evidence that people with different circadian preferences are different in their susceptibility to SD effects. In one study (Selvi et al., 2007), 60 healthy participants (30 morning types and 30 evening types) were randomly assigned to a TSD group or partial SD group and their mood states were recorded before and after SD. The results suggested that circadian preference moderated the effect of SD on mood changes. There was a significant increase in depressive mood among the morning types and a significant decrease in depressive mood among the evening types following TSD. However, partial SD did not have the same effect of modifying mood. The authors suggested that evening types have a greater tolerance for SD as they are more adjusted to a delayed circadian rhythm (Costa, 1997). Selvi et al.'s finding was consistent with an experiment conducted by Hildebrandt and Stratmann (1979), in which six nurses were invited to the laboratory for a 24-h investigation immediately after their night shift and after a 10-day recovery. The nurses who were morning types were much less vigilant after night work than after the recovery period while nurses who were evening types showed no difference in vigilance between the two conditions. It is conceivable that people who are evening types are more adapted to shift work and SD than the morning types. However, most of the participants in the current study were intermediate types, so a moderation effect of circadian preference could not be detected. Future studies are needed to examine the role of circadian preference in the relationship between SD and social decision-making, which could provide useful guidance for professions that require shift work.

The true effect of SD on social decision-making remains underexplored and with conflicting findings in the literature. In the only previous study examining SD and social decision-making (see Dickinson & McElroy, 2017 for sleep restriction and social decision-making), Anderson and Dickinson (2010) employed a 36-h SD protocol, which was 12 hours longer than that used in the current protocol. Anderson and Dickinson found that the MAO (minimum acceptable offer) was significantly increased following total SD, indicating that participants were more resistant to unfair offers. However, in their study, the trusting offers (the amounts delivered by the first movers) in the TG were not significantly affected after 36 h of SD. Extreme trust offers, which delivered all the money to the counterpart, were more likely to be seen in the restful condition than in the SD condition. In another sleep restriction study conducted by the same team (Dickinson & McElroy, 2017), trust and trustworthiness were significantly decreased following a week of sleep restriction. However, the MAO was not found to be significantly affected by sleep restriction in this study. The differences between these two studies (Anderson & Dickinson, 2010 vs. Dickinson & McElroy, 2017) suggest that different sleep-loss protocols may have distinct effects on social decision-making tasks. In the current study, the offer delivered by the trustor was approximately half of the total offer (e.g., HKD42.44 of HKD100 in Study 1) regardless of the sleep condition of the participants. A similar trust offer amount has been consistently reported in previous studies (e.g., $5.16 of $10 in Berg et al., 1995; Camerer, 2003). Consistent with the literature, under both conditions, the participants accepted significantly more fair offers (e.g., $5: $5) than unfair offers (e.g., $9: $1) in the UG (Sanfey et al., 2003; Koenigs & Tranel, 2007), indicating the validity of the tasks. No other studies have investigated the effect of sleep loss on social decision-making; thus, it important for future studies to replicate these effects. Several possible explanations for the limited significant effects of SD on social decision-making in the current study will be discussed in the following sections.

One explanation for the limited significant impact of SD on social decision-making may be that the testing of the tasks occurred in a different circadian phase than in previous studies. Anderson and Dickinson (2010) conducted the social decision-making tasks at approximately 7:00 pm, when the day was ending and the sunlight was out (Carlson, 2014). In the current study design, the social decision-making tasks were conducted in the morning, when the circadian process was on the rise. Although the participants showed significant impairment of their vigilance level and sleepiness after one night of SD, their performance on social decision-making tasks may have been affected by the circadian increase due to more light from the external world. It is possible that basic cognitive functions, such as vigilance and attention are easily affected by sleep loss while social functions are not. Future studies could explore the extent to which testing in different circadian phase can affect social decision-making tasks. Studies could also compare the effects of longer SD on social decision-making tasks completed in the morning and the effects of shorter SD on social decision-making tasks completed in the afternoon to determine whether the circadian effect or the length of SD is important. Furthermore, studies could examine whether sleep has an impact on social decision-making by asking participants to sleep longer than necessary.

Another possible explanation could be differences in the participants' characteristics. In Anderson and Dickinson's study (2010), only good sleepers were included while the current study did not exclude poor sleepers as categorized by the PSQI. Although there was no evidence in the current study suggesting that poor sleepers and good sleepers significantly differ in their vulnerability to SD in social decision-making, future studies should compare individual differences in vulnerability to SD between good sleepers and poor sleepers with larger differences in PSQI scores. Furthermore, in the current study, the participants mainly included college students from the same university, while this information was not provided in Anderson and Dickinson's study. On the one hand, it is well known that people tend to trust those who belong to their ingroup more than those who belong to an out-group (e.g., Tanis & Postmes, 2005). People tend to have negative attitudes or evaluations towards others who do not belong to their in-group, especially when the people are cognitively tired or rushed (e.g., Hewstone et al., 2002; Hilton & von Hippel, 1996). Alkozei et al. (2018) found that participants had more negative impressions of those with stereotypically negative appearances following chronic sleep restriction. On the other hand, it has also been found that people are more likely to trust others in some cases (see the review in Sundelin & Holding, 2019). In a study in which the participants were either sleep deprived or slept normally for a night, they were asked to estimate the distances between several European cities. The sleep-deprived participants were more likely to follow an estimation from an adviser than the controls (Hausser et al., 2016). This finding suggests that people show more trust in others in some cases when they are sleepy and might need help. Concluding from the above studies, people may tend to trust and seek help from others who belong to their ingroup. In the current study, the participants were told that they would be randomly paired with other participants in the social decision-making tasks. Before the experiment started, all the participants were briefed and informed that college students were the subjects of the study. It is possible that the participants considered their counterparts to belong to their ingroup (i.e., college students). Even while in a cognitively tired and sleepy state after a night of SD, the participants did not have any negative attitudes toward their ingroup counterparts. Therefore, no significant difference was found in their trusting behaviors following SD compared to a night of normal sleep. Future studies should be cautious in briefing participants about the subject pool, and follow-up questions regarding awareness of the identity of their counterparts could be added.

In summary, depressive symptoms moderated the effect of SD on trust but this effect was not seen in Study 2 using a within-subject design. Moreover, there was no significant impact of SD on irrational decision-making. Sleep loss has been shown to have negative impacts on cognitive and emotional functions. However, evidence regarding the effect of sleep loss on other functions, such as social functions, has been inconsistent and controversial. In a recent study (Sundelin et al., 2019), 25 participants were invited to complete a gambling task using a within-subjects design following either two nights of 8-h sleep opportunities or two nights of 4-h sleep opportunities in a counterbalanced order. The study showed that two nights of sleep restriction did not have a significant impact on the tendency to gamble. The authors suggested that sleep loss has a modest or no effect on the tendency to gamble, at least when a safe option is provided, which is consistent with several previous studies (Maric et al., 2017; Mullette-Gillman et al., 2015; Libedinsky et al., 2013). A night of SD was not found to be associated with how healthy or fatigued individuals were perceived to be by others (Holding, Sundelin, Cairns, et al., 2019). A similar finding was made in a study in which the participants were asked to negotiate the sale price of selling books following a night of SD or normal sleep. The price reached after negotiation did not significantly differ between the SD group and control group (Sundelin, 2019).

Although numerous studies have identified impacts of SD on some cognitive and emotional functions, social functions, which are higher-order functions, may be more resilient to the effect of SD than simple and basic cognitive functions. According to the integrated theory proposed by Dorrian et al. (2019), SD could affect social cognition through self-regulation and social monitoring. The model hypothesized that SD will alter brain activity in prefrontal cortex implicated in inhibition, emotional regulation and decision-making. These cognitive changes could lead to increased reward seeking and behaviors that are related with negative health outcomes. These changes could also result in reductions in trust, empathy and moral judgment, which may promote deviant behaviors. Research concerning sleep loss and social functions is still in its infancy. More studies are needed to examine the effect of 24-h SD on social functions and how the effect of SD on social functions depends on individual differences (e.g., circadian preference, personality, values) and the underlying mechanism Most of the previous studies have been conducted in a laboratory setting with participants performing tasks in front of a computer or camera, which is not an optimal design for studying social effects. Field study involving real human interactions should be considered to study social effects and increase the ecological validity in future studies.

4.3 Impact of a Night of SD on Resting-state Emotion-related EEG Indices

Consistent with the previous literature, a marginally significant difference was observed in the frontal alpha asymmetry between the SD group and SC group in Study 1 (Zhang et al., 2008a). Following a night of SD, the frontal alpha power was left lateralized in the SD group and right lateralized in the SC group. As the frontal alpha power is inversely related to its neural activation (Barry et al., 2007; Coan &Allen, 2004), the left lateralization in the frontal alpha asymmetry indicated a relatively higher cortical activation in the right hemisphere. Therefore, the marginally lower frontal alpha asymmetry in the SD group in Study 1 suggests that the participants were in a negative mood during the resting-state after one night of SD, which is consistent with previous studies reporting that SD-related negative mood is associated with a lower frontal alpha asymmetry (Ferreira, et al., 2006). However, the marginally significant difference in the frontal alpha asymmetry between the SD and SC groups could no longer be observed after controlling negative mood (DASS), sleep quality (PSQI) and circadian preference (CSM). In the only two known previous studies investigating frontal alpha asymmetry following a night of SD, participants' negative mood was not measured at baseline or after the experiment (Ferreira, et al., 2006; Zhang et al., 2018a). Therefore, whether individuals' baseline negative mood states could play a role in their sensitivity to the impact of SD is unknown.

A heightened theta/beta ratio has been found to be associated with poorer emotional inhibition and ADHD symptoms (Lubar, 1991). However, in a meta-analysis by Arnes (2012) analyzing nine studies involving theta/beta ratio comparisons between ADHD children and controls, the effect size of these studies was found to be large in the earlier studies but increasingly smaller in the recent studies. Clark et al. (2011) attempted to replicate their study in 2001, but the prevalence of a heightened theta/beta ratio among ADHD children decreased from 80% to 35% ten years later. To date, a heightened theta/beta ratio in response to SD has been reported in only one previous study (Zhang et al., 2018a). One potential explanation for the nonsignificant theta/beta ratio difference after SD in the current study could be the short sleep duration on average among Hong Kong young adults and increased drowsiness. Although the participants in the current study reported a sleep duration of more than 7 hours (but less than 8 hours) before the experiment, this sleep duration is on the low end of the suggested sleep duration of 7 to 9 hours for young adults recommended by the National Sleep Foundation (2015). In addition, since the control participants had a night of normal sleep at their own residence, they needed to travel to the university campus (the traveling time was controlled within 30 minutes), while the SD participants stayed a night in the laboratory without travelling. Both the short sleep duration and 30-minute traveling time may have increased the tiredness and drowsiness of the participants. Previous studies have suggested that theta-wave signatures of fatigue and drowsiness (Strijkstra et al., 2003) and an increase in the theta wave could result in an increased theta/beta wave ratio in the control group. Although SD participants reported significantly more sleepiness than the controls before the EEG recording, it is possible that there is a “ceiling effect” on the theta/beta-wave ratio which contributed to the non-significant difference in the theta/beta wave between the sleep-deprived participants and well-rested participants. Specifically, a heightened theta/beta-wave ratio driven by an increase in the theta wave and a heightened theta/beta-wave ratio driven by both an increase in the theta wave and a decrease in the beta wave (i.e., consequences of sleep loss, Zhang et al., 2018a) may not mathematically and statistically differ. Another conceivable explanation for differences in the current findings and Zhang and colleagues' findings is the difference in the EEG equipment and methods used. The current study attempted to be consistent with the previous study in terms of the filtering method, analysis software, artifact rejection methods and parameters used (Zhang et al., 2018a). However, the EEG system differed between the two laboratories (Brain Product vs. ANT), and manual rejection of the eye-movement data was used in the current study in addition to the automatic artifact rejection performed using software in Zhang et al.'s study.

In conclusion, one night of SD was only found to have a marginal impact on the frontal alpha asymmetry and no impact on the theta/beta ratio in the current study. In one study, Pilcher and colleagues (2015) found that total SD affects emotional reactivity to positive but not negative stimuli. Another study found no effect of SD on the evaluation of positive and negative stimuli (Tempesta et al., 2010). Nevertheless, the effects of SD on emotion-related outcomes are conflicting in the literature, and it is still unclear how SD affects emotion-related outcomes, especially the negative emotional outcomes examined in the current study. Further investigation of how SD affects emotional regulation toward negative stimuli is warranted. In summary, a night of SD and a testing time in the morning (as noted in section 4.2) may not cause detectable changes behaviorally and neurologically, especially among healthy participants. A review of neuro-imaging studies investigating SD (Gillin et al., 2001) provided evidence that SD has a beneficial antidepressant effect. Although the antidepressant effect disappeared after follow-up sleep recovery, it is conceivable that SD provides some beneficial effects, especially among people with depression (although the symptoms may rebound after the recovery of sleep). Gillin et al. (2001) reported that following a night of SD, the elevated metabolism in the orbital mPFC normally found in patients with depression could be lowered to a level comparable to that in controls. Another study showed that although the hippocampo-neocortical network is enhanced during sleep and inhibited during SD, the brain appears to provide an alternate amygdalo-neocortical network that is employed during the recollection of negative memories (Sterpenich et al., 2007). Evidence from these brain studies has suggested that the human brain is adaptive to SD, allowing us to keep track of potentially dangerous environment. It is possible that the ability to regulate our emotions and social cognitions as social beings has been well developed in a well-controlled interactive environment. Future studies are needed to investigate the potential underlying mechanisms linking the effect of SD and social functions.

4.5 Limitations and Future Directions

The current study is not without limitations.

First, there was no real interaction between two human subjects in the social decision-making tasks compared to the real pairing-up of the participants in Anderson and Dickinson's study (2010). In previous studies, participants were told that they were paired with other participants by showing pictures of fictitious participants in the UG (Sanfey et al. 2003; Koenigs & Tranel, 2007). The results indicated that, participants reacted more strongly to unfair offers made by human counterparts than by computer counterparts. In the current study, the participants were only informed that they were paired with other participants; they were not shown a face picture but rather only a participant number or code. Shelley et al. (2007) found that an emotional face stimulus could change people's motivation in social interaction tasks. For example, a facial expression that was deemed as smiling could motivate people to be more cooperative. Therefore, to eliminate the effect of nonverbal cues on social interaction tasks, the face of a counterpart was not added. Nevertheless, the distribution tendency in the TG was consistent with that in the previous literature, and the acceptance rate significantly differed between the fair and unfair offers, highlighting the validity of the tests.

Second, the current study did not explicitly exclude participants who had mood disorders. Although the participants were asked whether they had any chronic sleep disorders, and depression is strongly associated with poor sleep, we did not explicitly ask whether they had a depressive disorder. Moreover, the participants significantly differed in the DASS scores at baseline between the SD group and control group in Study 1. The group condition order was randomly generated by using Excel coding and participants arriving at the laboratory were randomly assigned to either the SD group or the control group. However, individual differences may not explain the non-significant impact of SD on social decision-making and EEG markers in Study 2 as a repeated-measures design was employed to minimize individual differences. In a previous study, Dickinson and McElroy (2017) screened participants with anxiety or depressive disorders in their study of chronic sleep restriction and social decision-making, while mood disorders were not mentioned in the screening criteria in Anderson and Dickinson's (2010) study investigating 36-h SD and social decision-making. Although the DASS is not a diagnostic tool and has normally been applied in a non-clinical population, it measures the negative emotional states of depression, anxiety and stress and can be used to screen normal adults and adolescents

(Lovibond & Lovibond, 1995). Future studies could examine whether mood disorder or depressive/anxious symptoms can play a role in the relationship between SD and social decision-making.

Third, in the current study, only Hong Kong college students were recruited and the result should be generalized with caution. In a previous study involving Hong Kong college students, the average sleep duration was 6.6 hours on school days (Wong et al., 2013). It is not uncommon for hall and community activities to be held late in the evenings at colleges and for students to routinely deprive themselves of sleep to engage in activities or schoolwork. Although the current study attempted to recruit healthy participants with good sleep habits and required them to sleep 7 to 9 hours at least one to three days before the experiments, it is possible that they had irregular sleep patterns other than during the experiment period. Nevertheless, the average sleep duration before the experiment was approximately 7 hours which meets the requirement of 7-9 hours of sleep for the whole sample, and those who slept less than 6 hours were excluded. One explanation for the non-significant impact of SD is that college students in Hong Kong may adapt well to the short sleep duration pattern and occasional SD conditions. Therefore, the experimental design involving 24-h SD did not result in significant changes in their social and emotional functions. However, the current study lasted one year-long and did not control for the effect of examination weeks or holidays as participants may have had different sleep habits during these periods. Thus, future studies should conduct experiments during normal school weeks to avoid any confounding effect of examination periods and holidays. Moreover, future studies could examine the effect of a night of SD in other populations (e.g., older populations) with better and more regular sleep habits.

Last but not the least, some data were lost for several reasons (e.g., machine malfunction and overriding of data); therefore, the final sample size was medium, and the sample size differed in different tasks. However, compared to a sample size of 18 participants in the experimental group in Anderson and Dickinson's study (2010), the sample size of 31 participants in the repeated-measures design in the current study was expected to detect the effect of SD on social decision-making. The current study did not control for the circadian effect on SD among the participants, and the time when the experiment was conducted differed from previous studies (morning vs. afternoon/evening, Anderson & Dickinson, 2010; Dickinson & McEloy, 2017). Future studies are needed to control for the circadian effect on SD and social decision-making. Moreover, in the current study, the control groups slept at home, but the SD group stayed awake in the laboratory. Due to the limitations of the laboratory facility at the university, this study could not provide sleep opportunities at the laboratory. Future studies with this capability should ask participants to both sleep and stay awake at the laboratory to control for any potential environmental effects. As the current study is the first to explore the effect of one night of SD on social decision-making in an Asian culture, it is possible that cultural differences contributed to the null effect found in the current study. A previous meta-analysis of cultural differences in social decision-making found that in countries with higher levels of economic development, people cared less about fairness (Tisserand et al., 2017). However, studies investigating cultural differences in social decision-making have reported inconsistent and contradicting findings. Therefore, a comparison of the effect of SD on social decision-making across different cultures is warranted in future studies. While the current study only recorded the EEG signals during the resting state, further studies could record the EEG signals when participants are conducting the social decision-making tasks, which could provide more information about the underlying neural changes after a night of SD.

4.6 Conclusions

The current study employed both between-subjects (Study 1) and within-subjects (Study 2) research designs to investigate the effect of 24-h SD on social decision-making and resting-state EEG indices. Study 1 reported that participants with a higher level of depressive symptoms showed less trust after SD. However, this moderation effect was not found in Study 2, and there was no the adverse influence of SD on other social decision-making performance. Moreover, there was no significant difference regarding the resting-state EEG indices. This resilience to sleep loss contradicts the impairments identified in two previous studies with longer duration of sleep loss (i.e., 36-h SD) coupled with testing in a different circadian phase. Moreover, the research field investigating sleep and social decision-making can be considered as young; therefore, the results are likely to be affected by positive publication bias, especially when the true effect size and sample size are small (Ioannidis, 2007). Future studies with a higher power will have to illustrate which, if any, aspects of social decision-making are affected by sleep loss and the effects of SD in populations other than college students, who may be accustomed to chronic sleep restriction and occasional TSD.

Reference

Abrams, R. M. (2015). Sleep Deprivation. *Obstetrics and Gynecology Clinics of North America*, *42*(3), 493–506. https://doi.org/10.1016/j.ogc.2015.05.013

Abumuamar, A. M., Dorian, P., Newman, D., & Shapiro, C. M. (2018). The prevalence of obstructive sleep apnea in patients with atrial fibrillation. *Clinical Cardiology*, *41*(5), 601–607. https://doi.org/10.1002/clc.22933

Acar-Burkay, S., Fennis, B. M., & Warlop, L. (2014). Trusting others: The polarization effect of need for closure. *Journal of Personality and Social Psychology*, *107*(4), 719–735. https://doi.org/10.1037/a0037022

Åkerstedt, T., & Wright, K. P. (2009). Sleep Loss and Fatigue in Shift Work and Shift Work Disorder. *Sleep Medicine Clinics*, *4*(2), 257–271. https://doi.org/10.1016/j.jsmc.2009.03.001

Alkozei, A., Haack, M., Skalamera, J., Smith, R., Satterfield, B. C., Raikes, A. C., & Killgore, W. D. S. (2018). Chronic sleep restriction affects the association between implicit bias and explicit social decision making. *Sleep Health*, *4*(5), 456–462. https://doi.org/10.1016/j.sleh.2018.07.003

American Psychiatric Association. (2000). *Practice Guidelines for the Treatment of Psychiatric Disorders (American Psychiatric Association Practice Guidelines)* (2nd ed.). American Psychiatric Association.

Aminoff, M. J., Boller, F., & Swaab, D. F. (2011). Foreword. *Handbook of Clinical Neurology*, vii. https://doi.org/10.1016/b978-0-444-52006-7.00047-2

Anderson, C., & Dickinson, D. L. (2010). Bargaining and trust: the effects of 36-h total sleep deprivation on socially interactive decisions. *Journal of Sleep Research*, *19*(1-Part-I), 54–63. https://doi.org/10.1111/j.1365-2869.2009.00767.x

Arns, M., Conners, C. K., & Kraemer, H. C. (2012). A Decade of EEG Theta/Beta Ratio Research in ADHD. *Journal of Attention Disorders*, *17*(5), 374–383. https://doi.org/10.1177/1087054712460087

Baglioni, C., Battagliese, G., Feige, B., Spiegelhalder, K., Nissen, C., Voderholzer, U., Lombardo, C., & Riemann, D. (2011). Insomnia as a predictor of depression: A meta-analytic evaluation of longitudinal epidemiological studies. *Journal of Affective Disorders*, *135*(1–3), 10–19. https://doi.org/10.1016/j.jad.2011.01.011

Banks, S., & Dinges, D. F. (2007). Behavioral and Physiological Consequences of Sleep Restriction. *Journal of Clinical Sleep Medicine*, *03*(05), 519–528. https://doi.org/10.5664/jcsm.26918

Barrash, J., Tranel, D., & Anderson, S. W. (2000). Acquired Personality Disturbances Associated With Bilateral Damage to the Ventromedial Prefrontal Region. *Developmental Neuropsychology*, *18*(3), 355–381. https://doi.org/10.1207/s1532694205barrash

Barry, R. J., Clarke, A. R., Johnstone, S. J., Magee, C. A., & Rushby, J. A. (2007). EEG differences between eyes-closed and eyes-open resting conditions. *Clinical Neurophysiology*, *118*(12), 2765–2773. https://doi.org/10.1016/j.clinph.2007.07.028

Bartels, A., & Zeki, S. (2004). The neural correlates of maternal and romantic love. *NeuroImage*, *21*(3), 1155–1166. https://doi.org/10.1016/j.neuroimage.2003.11.003

Baum, K. T., Desai, A., Field, J., Miller, L. E., Rausch, J., & Beebe, D. W. (2013). Sleep restriction worsens mood and emotion regulation in adolescents. *Journal of Child Psychology and Psychiatry*, *55*(2), 180–190. https://doi.org/10.1111/jcpp.12125

Belenky, G., Wesensten, N. J., Thorne, D. R., Thomas, M. L., Sing, H. C., Redmond, D. P., Russo, M. B., & Balkin, T. J. (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. *Journal of Sleep Research*, *12*(1), 1–12. https://doi.org/10.1046/j.1365-2869.2003.00337.x

Ben Simon, E., & Walker, M. P. (2018). Sleep loss causes social withdrawal and loneliness. *Nature Communications*, *9*(1), 3146. https://doi.org/10.1038/s41467-018-05377-0

Berg, J., Dickhaut, J., & McCabe, K. (1995). Trust, Reciprocity, and Social History. *Games and Economic Behavior*, *10*(1), 122–142. https://doi.org/10.1006/game.1995.1027

Berger, R. J., & Oswald, I. (1962). Effects of Sleep Deprivation on Behaviour, Subsequent Sleep, and Dreaming. *Journal of Mental Science*, *108*(455), 457–465. https://doi.org/10.1192/bjp.108.455.457

Berry, R. B., Brooks, R., Gamaldo, C. E., Harding, S. M., Lloyd, R. M., Marcus, C. L., & Vaughn, B. V. (2015). *AASM Manual for the Scoring of Sleep and Associated Events.* (2.2 ed.). American Academy of Sleep Medicine.

Bettelheim, A., & Congressional Quarterly, inc. (1998). *Sleep deprivation : What's keeping Americans up at night?* (Vol. 8). Congressional Quarterly.

Brennan, A. R., & Arnsten, A. F. T. (2008). Neuronal Mechanisms Underlying Attention Deficit Hyperactivity Disorder. *Annals of the New York Academy of Sciences*, *1129*(1), 236–245. https://doi.org/10.1196/annals.1417.007

Bresnahan, S. M., Anderson, J. W., & Barry, R. J. (1999). Age-related changes in quantitative EEG in attention- deficit/hyperactivity disorder. *Biological Psychiatry*, *46*(12), 1690–1697. https://doi.org/10.1016/s0006-3223(99)00042-6

Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh sleep quality index: A new instrument for psychiatric practice and research. *Psychiatry Research*, *28*(2), 193–213. https://doi.org/10.1016/0165-1781(89)90047-4

Caldwell, J. A., Caldwell, J. L., Brown, D. L., & Smith, J. K. (2004). The Effects of 37 Hours of Continuous Wakefulness On the Physiological Arousal, Cognitive Performance, Self-Reported Mood, and Simulator Flight Performance of F-117A Pilots. *Military Psychology*, *16*(3), 163–181. https://doi.org/10.1207/s15327876mp1603_2

Camerer, C. F. (2003). *Behavioral Game Theory: Experiments in Strategic Interaction (The Roundtable Series in Behavioral Economics)*. Princeton University Press.

Campos-Morales, R. M., Valencia-Flores, M., Castaño-Meneses, A., Castañeda-Figueiras, S., & Martínez-Guerrero, J. (2005). Sleepiness, performance and mood state in a group of Mexican undergraduate students. *Biological Rhythm Research*, *36*(1–2), 9–13. https://doi.org/10.1080/09291010400028484

Carlson, N. (2020). *Foundations of Behavioral Neuroscience: Pearson New International Edition* (9th edition). Neil R. Carlson.

Carney, C. E., Buysse, D. J., Ancoli-Israel, S., Edinger, J. D., Krystal, A. D., Lichstein, K. L., & Morin, C. M. (2012). The Consensus Sleep Diary: Standardizing Prospective Sleep Self-Monitoring. *Sleep*, *35*(2), 287–302. https://doi.org/10.5665/sleep.1642

Charness, G., Gneezy, U., & Kuhn, M. A. (2012). Experimental methods: Between-subject and within-subject design. *Journal of Economic Behavior & Organization*, *81*(1), 1–8. https://doi.org/10.1016/j.jebo.2011.08.009

Chung, Y.-S., & Wong, J.-T. (2014). Investigating Heterogeneous Factor Effects on Stress and Burnout of Commercial Drivers: A Case in Taiwan. *Asian Transport Studies*, *3*(2), 234–249. https://doi.org/10.11175/eastsats.3.234

Clarke, A. R., Barry, R. J., Dupuy, F. E., Heckel, L. D., McCarthy, R., Selikowitz, M., & Johnstone, S. J. (2011). Behavioural differences between EEG-defined subgroups of children with Attention-Deficit/Hyperactivity Disorder. *Clinical Neurophysiology*, *122*(7), 1333–1341. https://doi.org/10.1016/j.clinph.2010.12.038

Coan, J. A., & Allen, J. J. B. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biological Psychology*, *67*(1–2), 7–50. https://doi.org/10.1016/j.biopsycho.2004.03.002

Coan, J. A., Allen, J. J. B., & McKnight, P. E. (2006). A capability model of individual differences in frontal EEG asymmetry. *Biological Psychology*, *72*(2), 198–207. https://doi.org/10.1016/j.biopsycho.2005.10.003

Cole, R. J., Kripke, D. F., Gruen, W., Mullaney, D. J., & Gillin, J. C. (1992). Automatic Sleep/Wake Identification From Wrist Activity. *Sleep*, *15*(5), 461–469. https://doi.org/10.1093/sleep/15.5.461

Cote, K., Jancsar, C., & Hunt, B. (2015). Event-related neural response to emotional picture stimuli following sleep deprivation. *Psychology & Neuroscience*, *8*(1), 102–113. https://doi.org/10.1037/h0100354

Dagys, N., McGlinchey, E. L., Talbot, L. S., Kaplan, K. A., Dahl, R. E., & Harvey, A. G. (2012). Double trouble? The effects of sleep deprivation and chronotype on adolescent affect. *Journal of Child Psychology and Psychiatry*, *53*(6), 660–667. https://doi.org/10.1111/j.1469-7610.2011.02502.x

Dalton, K. M., Kalin, N. H., & Davidson, R. J. (2002). Brain and cardiac activation and interactions during fear-related emotional processing: A functional brain and cardiac MRI study. *Unpublished manuscript, University of Wisconsin-Madison*.

Damaraju, E., Allen, E. A., Belger, A., Ford, J. M., McEwen, S., Mathalon, D. H., Mueller, B. A., Pearlson, G. D., Potkin, S. G., Preda, A., Turner, J. A., Vaidya, J. G., van Erp, T. G., & Calhoun, V. D. (2014). Dynamic functional connectivity analysis reveals transient states of dysconnectivity in schizophrenia. *NeuroImage: Clinical*, *5*, 298–308. https://doi.org/10.1016/j.nicl.2014.07.003

Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. Avon Books.

Dattilo, M., Antunes, H. K. M., Medeiros, A., Mônico Neto, M., Souza, H. S., Tufik, S., & de Mello, M. T. (2011). Sleep and muscle recovery: Endocrinological and molecular basis for a new and promising hypothesis. *Medical Hypotheses*, *77*(2), 220–222. https://doi.org/10.1016/j.mehy.2011.04.017

Davidson, R. J. (1998). Affective Style and Affective Disorders: Perspectives from Affective Neuroscience. *Cognition & Emotion*, *12*(3), 307–330. https://doi.org/10.1080/026999398379628

Davidson, R. J. S. G. (1979). Frontal versus parietal EEG asymmetry during positive and negative affect. *Psychophysiology*, *16*(2), 202-203.

Davidson, R. J. (2002). Anxiety and affective style: role of prefrontal cortex and amygdala. *Biological Psychiatry*, *51*(1), 68–80. https://doi.org/10.1016/s0006-3223(01)01328-2

Davidson, R. J., & Fox, N. A. (1989). Frontal brain asymmetry predicts infants' response to maternal separation. *Journal of Abnormal Psychology*, *98*(2), 127–131. https://doi.org/10.1037/0021-843x.98.2.127

Davidson, R. J., & Irwin, W. (1999). The functional neuroanatomy of emotion and affective style. *Trends in Cognitive Sciences*, *3*(1), 11–21. https://doi.org/10.1016/s1364-6613(98)01265-0

Dickinson, D. L., & McElroy, T. (2017). Sleep restriction and circadian effects on social decisions. *European Economic Review*, *97*, 57–71. https://doi.org/10.1016/j.euroecorev.2017.05.002

Dinges, D. F. (1995). An overview of sleepiness and accidents. *Journal of Sleep Research*, *4*, 4–14. https://doi.org/10.1111/j.1365-2869.1995.tb00220.x

Dorrian, J., Centofanti, S., Smith, A., & McDermott, K. D. (2019). Self-regulation and social behavior during sleep deprivation. In *Progress in brain research* (Vol. 246, pp. 73-110). Elsevier.

Emert, S. E., Tutek, J., & Lichstein, K. L. (2017). Associations between sleep disturbances, personality, and trait emotional intelligence. *Personality and Individual Differences*, *107*, 195–200. https://doi.org/10.1016/j.paid.2016.11.050

Fitzgerald, S. P. (2002). *Decision Making: Leading 08.07 (Express Exec)* (1st ed.). Capstone.

Forsythe, R., Horowitz, J. L., Savin, N. E., & Sefton, M. (1994). Fairness in Simple Bargaining Experiments. *Games and Economic Behavior*, *6*(3), 347–369. https://doi.org/10.1006/game.1994.1021

Fox, M. D., & Raichle, M. E. (2007). Spontaneous fluctuations in brain activity observed with functional magnetic resonance imaging. *Nature Reviews Neuroscience*, *8*(9), 700–711. https://doi.org/10.1038/nrn2201

Franzen, P. L., Buysse, D. J., Dahl, R. E., Thompson, W., & Siegle, G. J. (2009). Sleep deprivation alters pupillary reactivity to emotional stimuli in healthy young adults. *Biological Psychology*, *80*(3), 300–305. https://doi.org/10.1016/j.biopsycho.2008.10.010

Fujiwara, T., & Kawachi, I. (2008). A prospective study of individual-level social capital and major depression in the United States. *Journal of Epidemiology & Community Health*, *62*(7), 627–633. https://doi.org/10.1136/jech.2007.064261

Gillin, J. C., Buchsbaum, M., Wu, J., Clark, C., & Bunney, W. (2001). Sleep deprivation as a model experimental antidepressant treatment: Findings from functional brain imaging. *Depression and Anxiety*, *14*(1), 37–49. https://doi.org/10.1002/da.1045

Goldstein-Piekarski, A. N., Greer, S. M., Saletin, J. M., & Walker, M. P. (2015). Sleep Deprivation Impairs the Human Central and Peripheral Nervous System Discrimination of Social Threat. *Journal of Neuroscience*, *35*(28), 10135–10145. https://doi.org/10.1523/jneurosci.5254-14.2015

Goodman, R. N., Rietschel, J. C., Lo, L.-C., Costanzo, M. E., & Hatfield, B. D. (2013). Stress, emotion regulation and cognitive performance: The predictive contributions of trait and state relative frontal EEG alpha asymmetry. *International Journal of Psychophysiology*, *87*(2), 115–123. https://doi.org/10.1016/j.ijpsycho.2012.09.008

Greer, S. M., Goldstein, A. N., & Walker, M. P. (2013). The impact of sleep deprivation on food desire in the human brain. *Nature Communications*, *4*(1), ncomms3259. https://doi.org/10.1038/ncomms3259

Gruber, R., & Cassoff, J. (2014). The Interplay Between Sleep and Emotion Regulation: Conceptual Framework Empirical Evidence and Future Directions. *Current Psychiatry Reports*, *16*(11), 1–9. https://doi.org/10.1007/s11920-014-0500-x

Gujar, N., Yoo, S.-S., Hu, P., & Walker, M. P. (2011). Sleep Deprivation Amplifies Reactivity of Brain Reward Networks, Biasing the Appraisal of Positive Emotional Experiences. *Journal of Neuroscience*, *31*(12), 4466–4474. https://doi.org/10.1523/jneurosci.3220-10.2011

Gümüstekin, K., Seven, B., Karabulut, N., Aktas, Ö., Gürsan, N., Aslan, S., Keles, M., Varoglu, E., & Dane, S. (2004). Effects of sleep deprivation, nicotine, and selenium on wound healing in rats. *International Journal of Neuroscience*, *114*(11), 1433–1442. https://doi.org/10.1080/00207450490509168

Güth, W., Schmittberger, R., & Schwarze, B. (1982). An experimental analysis of ultimatum bargaining. *Journal of Economic Behavior & Organization*, *3*(4), 367–388. https://doi.org/10.1016/0167-2681(82)90011-7

Hanley, J. A. (2003). Statistical Analysis of Correlated Data Using Generalized Estimating Equations: An Orientation. *American Journal of Epidemiology*, *157*(4), 364–375. https://doi.org/10.1093/aje/kwf215

Harrison, Y., & Horne, J. (1998). Sleep loss impairs short and novel language tasks having a prefrontal focus. *Journal of Sleep Research*, *7*(2), 95–100. https://doi.org/10.1046/j.1365-2869.1998.00104.x

Harrison, Y., & Horne, J. A. (1997). Sleep Deprivation Affects Speech. *Sleep*, *20*(10), 871–877. https://doi.org/10.1093/sleep/20.10.871

Harrison, Y., & Horne, J. A. (2000). The impact of sleep deprivation on decision making: A review. *Journal of Experimental Psychology: Applied*, *6*(3), 236–249. https://doi.org/10.1037/1076-898x.6.3.236

Häusser, J. A., Leder, J., Ketturat, C., Dresler, M., & Faber, N. S. (2016). Sleep Deprivation and Advice Taking. *Scientific Reports*, *6*(1), 24386. https://doi.org/10.1038/srep24386

Hayes, A. F. (2012). *PROCESS: A versatile computational tool for observed variable mediation, moderation, and conditional process modeling*. [White Paper]. http://www.afhayes.com/index.html

Hewstone, M., Rubin, M., & Willis, H. (2002). Intergroup bias. *Annual Review of Psychology*, *53*, 575–604. https://doi.org/10.1146/annurev.psych.53.100901.135109.

Hilton, J. L., & von Hippel, W. (1996). STEREOTYPES. *Annual Review of Psychology*, *47*(1), 237–271. https://doi.org/10.1146/annurev.psych.47.1.237

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., Hazen, N., Herman, J., Katz, E. S., Kheirandish-Gozal, L., Neubauer, D. N., O’Donnell, A. E., Ohayon, M., Peever, J., Rawding, R., Sachdeva, R. C., Setters, B., Vitiello, M. V., Ware,

J. C., & Adams Hillard, P. J. (2015). National Sleep Foundation's sleep time duration recommendations: methodology and results summary. *Sleep Health*, *1*(1), 40–43. https://doi.org/10.1016/j.sleh.2014.12.010

Hoaglin, D. C., Iglewicz, B., & Tukey, J. W. (1986). Performance of Some Resistant Rules for Outlier Labeling. *Journal of the American Statistical Association*, *81*(396), 991–999. https://doi.org/10.1080/01621459.1986.10478363

Hoddes, E., Zarcone, V., Smythe, H., Phillips, R., & Dement, W. C. (1973). Quantification of Sleepiness: A New Approach. *Psychophysiology*, *10*(4), 431–436. https://doi.org/10.1111/j.1469-8986.1973.tb00801.x

Holding, B. C., Sundelin, T., Cairns, P., Perrett, D. I., & Axelsson, J. (2019). The effect of sleep deprivation on objective and subjective measures of facial appearance. *Journal of Sleep Research*, *28*(6), e12860. https://doi.org/10.1111/jsr.12860

Holding, B. C., Sundelin, T., Lekander, M., & Axelsson, J. (2019). Sleep deprivation and its effects on communication during individual and collaborative tasks. *Scientific Reports*, *9*(1), 3131. https://doi.org/10.1038/s41598-019-39271-6

Horne, J. A. (1988). Sleep Loss and "Divergent" Thinking Ability. *Sleep*, *11*(6), 528–536. https://doi.org/10.1093/sleep/11.6.528

Iber, C., Ancoli-Israel, S., Chesson, A. L., & Quan, S. F. (2007). *The AASM manual for the scoring of sleep and associated events: rules, terminology and technical specifications* (Vol. 1). Westchester: American academy of sleep medicine.

Ioannidis, J. P. A. (2007). Why Most Published Research Findings Are False: Author's Reply to Goodman and Greenland. *PLoS Medicine*, *4*(6), e215. https://doi.org/10.1371/journal.pmed.0040215

Jackson, D. C., Malmstadt, J. R., Larson, C. L., & Davidson, R. J. (2000). Suppression and enhancement of emotional responses to unpleasant pictures. *Psychophysiology*, *37*(4), 515–522. https://doi.org/10.1111/1469-8986.3740515

Jackson, D. C., Mueller, C. J., Dolski, I., Dalton, K. M., Nitschke, J. B., Urry, H. L., Rosenkranz, M. A., Ryff, C. D., Singer, B. H., & Davidson, R. J. (2003). Now You Feel It, Now You Don't. *Psychological Science*, *14*(6), 612–617. https://doi.org/10.1046/j.0956-7976.2003.psci_1473.x

John, E., Ahn, H., Prichep, L., Trepetin, M., Brown, D., & Kaye, H. (1980). Developmental equations for the electroencephalogram. *Science*, *210*(4475), 1255–1258. https://doi.org/10.1126/science.7434026

Jones, D. T., Vemuri, P., Murphy, M. C., Gunter, J. L., Senjem, M. L., Machulda, M. M., Przybelski, S. A., Gregg, B. E., Kantarci, K., Knopman, D. S., Boeve, B. F., Petersen, R. C., & Jack, C. R. (2012). Non-Stationarity in the "Resting Brain's" Modular Architecture. *PLoS ONE*, *7*(6), e39731. https://doi.org/10.1371/journal.pone.0039731

Killgore, W. D. S. (2013). Self-Reported Sleep Correlates with Prefrontal-Amygdala Functional Connectivity and Emotional Functioning. *Sleep*, *36*(11), 1597–1608. https://doi.org/10.5665/sleep.3106

Killgore, W. D. S., Balkin, T. J., & Wesensten, N. J. (2006). Impaired decision making following 49 h of sleep deprivation. *Journal of Sleep Research*, *15*(1), 7–13. https://doi.org/10.1111/j.1365-2869.2006.00487.x

Killgore, W. D. S., Kahn-Greene, E. T., Lipizzi, E. L., Newman, R. A., Kamimori, G. H., & Balkin, T. J. (2008). Sleep deprivation reduces perceived emotional intelligence and constructive thinking skills. *Sleep Medicine*, *9*(5), 517–526. https://doi.org/10.1016/j.sleep.2007.07.003

Killgore, W. D. S., Killgore, D. B., Day, L. M., Li, C., Kamimori, G. H., & Balkin, T. J. (2007). The Effects of 53 Hours of Sleep Deprivation on Moral Judgment. *Sleep*, *30*(3), 345–352. https://doi.org/10.1093/sleep/30.3.345

Kim, S.-S., Chung, Y., Perry, M. J., Kawachi, I., & Subramanian, S. V. (2012). Association between Interpersonal Trust, Reciprocity, and Depression in South Korea: A Prospective Analysis. *PLoS ONE*, *7*(1), e30602. https://doi.org/10.1371/journal.pone.0030602

Knack, S., & Keefer, P. (1997). Does Social Capital Have an Economic Payoff? A Cross-Country Investigation. *The Quarterly Journal of Economics*, *112*(4), 1251–1288. https://doi.org/10.1162/003355300555475

Knyazev, G. G. (2012). Oscillatory systems and personality: The case of extraversion. *International Journal of Psychophysiology*, *85*(3), 307. https://doi.org/10.1016/j.ijpsycho.2012.06.050

Knyazev, G. G., & Slobodskaya, H. R. (2003). Personality trait of behavioral inhibition is associated with oscillatory systems reciprocal relationships. *International Journal of Psychophysiology*, *48*(3), 247–261. https://doi.org/10.1016/s0167-8760(03)00072-2

Koenigs, M., & Tranel, D. (2007). Irrational Economic Decision-Making after Ventromedial Prefrontal Damage: Evidence from the Ultimatum Game. *Journal of Neuroscience*, *27*(4), 951–956. https://doi.org/10.1523/jneurosci.4606-06.2007

Krueger, F., McCabe, K., Moll, J., Kriegeskorte, N., Zahn, R., Strenziok, M., Heinecke, A., & Grafman, J. (2007). Neural correlates of trust. *Proceedings of the National Academy of Sciences*, *104*(50), 20084–20089. https://doi.org/10.1073/pnas.0710103104

Kruglanski, A. W. (1990). Motivations for judging and knowing: Implications for causal attribution. In E. T. Higgins & R. M. Sorrentino (Eds.), *Handbook of motivation and cognition: Foundations of social behavior* (Vol. 2, pp. 333–368). The Guilford Press.

La Porta, R., Lopez-de-Silanes, F., Shleifer, A., & Vishny, R. W. (1997). Trust in Large Organizations. *The American Economic Review*, *87*(2), 333–338. https://search.proquest.com/docview/233036449?accountid=11441

Lau, E. Y. Y., Wong, M. L., Ng, E. C. W., Hui, C.-H., Cheung, S. F., & Mok, D. S. Y. (2013). “Social Jetlag” in Morning-Type College Students Living On Campus: Implications for Physical and Psychological Well-being. *Chronobiology International*, *30*(7), 910–918. https://doi.org/10.3109/07420528.2013.789895

Lee, D. (2008). Game theory and neural basis of social decision making. *Nature Neuroscience*, *11*(4), 404–409. https://doi.org/10.1038/nn2065

Legislative Council Secretariat. (2018). *Overall study hours and student well-being in Hong Kong*. Legislative Council Secretariat. https://www.legco.gov.hk/research-publications/english/1718in05-overall-study-hours-and-student-well-being-in-hong-kong-20180130-e.pdf

Libedinsky, C., Massar, S. A. A., Ling, A., Chee, W., Huettel, S. A., & Chee, M. W. L. (2013). Sleep Deprivation Alters Effort Discounting but not Delay Discounting of Monetary Rewards. *Sleep*, *36*(6), 899–904. https://doi.org/10.5665/sleep.2720

Lim, J., & Dinges, D. F. (2010). A meta-analysis of the impact of short-term sleep deprivation on cognitive variables. *Psychological Bulletin*, *136*(3), 375–389. https://doi.org/10.1037/a0018883

Lindfors, P. M., Nurmi, K. E., Meretoja, O. A., Luukkonen, R. A., Viljanen, A.-M., Leino, T. J., & Härmä, M. I. (2006). On-call stress among Finnish anaesthetists*. *Anaesthesia*, *61*(9), 856–866. https://doi.org/10.1111/j.1365-2044.2006.04749.x

Lovibond, S. H., & Lovibond, P. F. (1995). *Manual for the depression anxiety stress scales* (2nd ed.). Psychology Foundation.

Lubar, J. F. (1991). Discourse on the development of EEG diagnostics and biofeedback for attention-deficit/hyperactivity disorders. *Biofeedback and Self-Regulation*, *16*(3), 201–225. https://doi.org/10.1007/bf01000016

Maric, A., Montvai, E., Werth, E., Storz, M., Leemann, J., Weissengruber, S., Ruff, C. C., Huber, R., Poryazova, R., & Baumann, C. R. (2017). Insufficient sleep: Enhanced risk-seeking relates to low local sleep intensity. *Annals of Neurology*, *82*(3), 409–418. https://doi.org/10.1002/ana.25023

Mendelson, W. B., James, S. P., Garnett, D., Sack, D. A., & Rosenthal, N. E. (1986). A psychophysiological study of insomnia. *Psychiatry Research*, *19*(4), 267–284. https://doi.org/10.1016/0165-1781(86)90120-4

Minkel, J., Moreta, M., Muto, J., Htaik, O., Jones, C., Basner, M., & Dinges, D. (2014). Sleep deprivation potentiates HPA axis stress reactivity in healthy adults. *Health Psychology*, *33*(11), 1430–1434. https://doi.org/10.1037/a0034219

Mitler, M. M., Carskadon, M. A., Czeisier, C. A., Dement, W. C., Dinges, D. F., & Graeber, R. C. (1988). Catastrophes, Sleep, and Public Policy: Consensus Report. *Sleep*, *11*(1), 100–109. https://doi.org/10.1093/sleep/11.1.100

Montoya, A. K. (2018). Moderation analysis in two-instance repeated measures designs: Probing methods and multiple moderator models. *Behavior Research Methods*, *51*(1), 61–82. https://doi.org/10.3758/s13428-018-1088-6

Mulert, C., Juckel, G., Brunnmeier, M., Karch, S., Leicht, G., Mergl, R., Möller, H.-J., Hegerl, U., & Pogarell, O. (2007). Prediction of treatment response in major depression: Integration of concepts. *Journal of Affective Disorders*, *98*(3), 215–225. https://doi.org/10.1016/j.jad.2006.07.021

Mullette-Gillman, O. A., Kurnianingsih, Y. A., & Liu, J. C. J. (2015). Sleep deprivation alters choice strategy without altering uncertainty or loss aversion preferences. *Frontiers in Neuroscience*, *9*, 352. https://doi.org/10.3389/fnins.2015.00352

Naylor, M. W., King, C. A., Kathleen, A., Linsay, B. A., Evans, T., Armelagos, J., Shain, B. N., & Greden, J. F. (1993). Sleep Deprivation in Depressed Adolescents and Psychiatric Controls. *Journal of the American Academy of Child & Adolescent Psychiatry*, *32*(4), 753–759. https://doi.org/10.1097/00004583-199307000-00008

Netzer, N. C., Stoohs, R. A., Netzer, C. M., Clark, K., & Strohl, K. P. (1999). Using the Berlin Questionnaire To Identify Patients at Risk for the Sleep Apnea Syndrome. *Annals of Internal Medicine*, *131*(7), 485. https://doi.org/10.7326/0003-4819-131-7-199910050-00002

Nishitani, N. (2003). Dynamics of cognitive processing in the human hippocampus by neuromagnetic and neurochemical assessments. *NeuroImage*, *20*(1), 561–571. https://doi.org/10.1016/s1053-8119(03)00280-5

Numan, R. (2015). A Prefrontal-Hippocampal Comparator for Goal-Directed Behavior: The Intentional Self and Episodic Memory. *Frontiers in Behavioral Neuroscience*, *9*, 323. https://doi.org/10.3389/fnbeh.2015.00323

Ochsner, K. N., Bunge, S. A., Gross, J. J., & Gabrieli, J. D. E. (2002). Rethinking Feelings: An fMRI Study of the Cognitive Regulation of Emotion. *Journal of Cognitive Neuroscience*, *14*(8), 1215–1229. https://doi.org/10.1162/089892902760807212

Oosterbeek, H., Sloof, R., & van de Kuilen, G. (2004). Cultural Differences in Ultimatum Game Experiments: Evidence from a Meta-Analysis. *Experimental Economics*, *7*(2), 171–188. https://doi.org/10.1023/b:exec.0000026978.14316.74

Orzeł-Gryglewska, J. (2010). Consequences of sleep deprivation. *International Journal of Occupational Medicine and Environmental Health*, *23*(1), 95–114. https://doi.org/10.2478/v10001-010-0004-9

Osborne, M. J. (2004). *An Introduction to Game Theory*. Oxford University Press.

Papousek, I., Harald Freudenthaler, H., & Schulter, G. (2011). Typical performance measures of emotion regulation and emotion perception and frontal EEG asymmetry in an emotional contagion paradigm. *Personality and Individual Differences*, *51*(8), 1018–1022. https://doi.org/10.1016/j.paid.2011.08.013

Patrick, G. T. W., & Gilbert, J. A. (1896). Studies from the psychological laboratory of the University of Iowa: On the effects of loss of sleep. *Psychological Review*, *3*(5), 469–483. https://doi.org/10.1037/h0075739

Phillips, M. L., Young, A. W., Senior, C., Brammer, M., Andrew, C., Calder, A. J., Bullmore, E. T., Perrett, D. I., Rowland, D., Williams, S. C. R., Gray, J. A., & David, A. S. (1997). A specific neural substrate for perceiving facial expressions of disgust. *Nature*, *389*(6650), 495–498. https://doi.org/10.1038/39051

Pilcher, J. J., Callan, C., & Posey, J. L. (2015). Sleep deprivation affects reactivity to positive but not negative stimuli. *Journal of Psychosomatic Research*, *79*(6), 657–662. https://doi.org/10.1016/j.jpsychores.2015.05.003

Pillutla, M. M., & Murnighan, J. K. (1996). Unfairness, Anger, and Spite: Emotional Rejections of Ultimatum Offers. *Organizational Behavior and Human Decision Processes*, *68*(3), 208–224. https://doi.org/10.1006/obhd.1996.0100

Pinholster, G. (2014). *Sleep Deprivation Described as a Serious Public Health Problem*. American Association for the Advancement of Science. https://www.aaas.org/news/sleep-deprivation-described-serious-public-health-problem

Putman, P., van Peer, J., Maimari, I., & van der Werff, S. (2010). EEG theta/beta ratio in relation to fear-modulated response-inhibition, attentional control, and affective traits. *Biological Psychology*, *83*(2), 73–78. https://doi.org/10.1016/j.biopsycho.2009.10.008

Raichle, M. E., & Mintun, M. A. (2006). Brain work and brain imaging. *Annual Review of Neuroscience*, *29*(1), 449–476. https://doi.org/10.1146/annurev.neuro.29.051605.112819

Reznik, S. J., & Allen, J. J. B. (2017). Frontal asymmetry as a mediator and moderator of emotion: An updated review. *Psychophysiology*, *55*(1), e12965. https://doi.org/10.1111/psyp.12965

Robinson, R. G., & Downhill, J. E. (1995). Lateralization of psychopathology in response to focal brain injury. In R. J. Davidson & K. Hugdahl (Eds.), *Brain asymmetry* (pp. 693–711). MIT Press.

Roets, A., & Van Hiel, A. (2011). Item selection and validation of a brief, 15-item version of the Need for Closure Scale. *Personality and Individual Differences*, *50*(1), 90–94. https://doi.org/10.1016/j.paid.2010.09.004

Ruehland, W. R., Rochford, P. D., O'Donoghue, F. J., Pierce, R. J., Singh, P., & Thornton, A. T. (2009). The New AASM Criteria for Scoring Hypopneas: Impact on the Apnea Hypopnea Index. *Sleep*, *32*(2), 150–157. https://doi.org/10.1093/sleep/32.2.150

Sanfey, A. G. (2003). The Neural Basis of Economic Decision-Making in the Ultimatum Game. *Science*, *300*(5626), 1755–1758. https://doi.org/10.1126/science.1082976

Schilgen, B., & Tölle, R. (1980). Partial Sleep Deprivation as Therapy for Depression. *Archives of General Psychiatry*, *37*(3), 267. https://doi.org/10.1001/archpsyc.1980.01780160037003

Schoeb, V. (2016). Healthcare Service in Hong Kong and its Challenges. *China Perspectives*, *2016*(4), 51–58. https://doi.org/10.4000/chinaperspectives.7118

Selvi, Y., Gulec, M., Agargun, M. Y., & Besiroglu, L. (2007). Mood changes after sleep deprivation in morningness?eveningness chronotypes in healthy individuals. *Journal of Sleep Research*, *16*(3), 241–244. https://doi.org/10.1111/j.1365-2869.2007.00596.x

Sheehan, C. M., Frochen, S. E., Walsemann, K. M., & Ailshire, J. A. (2019). Are U.S. adults reporting less sleep?: Findings from sleep duration trends in the National Health Interview Survey, 2004–2017. *Sleep*, *42*(2), zsy221. https://doi.org/10.1093/sleep/zsy221

Shelley, G. P., Page, M., Rives, P., Yeagley, E., & Kuhlman, D. M. (2009). Nonverbal communication and detection of individual differences in social value orientation. In R. M. Kramer, M. H. Bazerman, & A. E. Tenbrunsel (Eds.), *Social Decision Making: Social Dilemmas, Social Values and Ethical Judgments.* (pp. 147–170). Psychology Press (Member of Taylor Francis Group).

Smith, C. S., Reilly, C., & Midkiff, K. (1989). Evaluation of three circadian rhythm questionnaires with suggestions for an improved measure of morningness. *Journal of Applied Psychology*, *74*(5), 728–738. https://doi.org/10.1037/0021-9010.74.5.728

Sterpenich, V., Albouy, G., Boly, M., Vandewalle, G., Darsaud, A., Balteau, E., Dang-Vu, T., Desseilles, M., D’Argembeau, A., Gais, S., Rauchs, G., Schabus, M., Degueldre, C., Luxen, A., Collette, F., & Maquet, P. (2007). Sleep-Related Hippocampo-Cortical Interplay during Emotional Memory Recollection. *PLoS Biology*, *5*(11), e282. https://doi.org/10.1371/journal.pbio.0050282

Stevens, S., & Hening, W. A. (2007). Sleep and wakefulness. In C. G. Goetz (Ed.), *Textbook of Clinical Neurology* (pp. 21–33). Saunders Elsevier.

Strijkstra, A. M., Beersma, D. G. M., Drayer, B., Halbesma, N., & Daan, S. (2003). Subjective sleepiness correlates negatively with global alpha (8–12 Hz) and positively with central frontal theta (4–8 Hz) frequencies in the human resting awake electroencephalogram. *Neuroscience Letters*, *340*(1), 17–20. https://doi.org/10.1016/s0304-3940(03)00033-8

Sundelin, T., Bayard, F., Schwarz, J., Cybulski, L., Petrovic, P., & Axelsson, J. (2019). Framing effect, probability distortion, and gambling tendency without feedback are resistant to two nights of experimental sleep restriction. *Scientific Reports*, *9*(1), 8554. https://doi.org/10.1038/s41598-019-44237-9

Sundelin, T., & Holding, B. C. (2019). Sleep and Social Impressions. In Z. Križan (Ed.), *Sleep and Social Impressions* (pp. 119–133). Springer, Cham.

Sutter, C., Zöllig, J., Allemand, M., & Martin, M. (2012). Sleep quality and cognitive function in healthy old age: The moderating role of subclinical depression. *Neuropsychology, 26*(6), 768–775. https://doi.org/10.1037/a0030033

Tanis, M., & Postmes, T. (2005). A social identity approach to trust: interpersonal perception, group membership and trusting behaviour. *European Journal of Social Psychology*, *35*(3), 413–424. https://doi.org/10.1002/ejsp.256

Tankova, I., Adan, A., & Buela-Casal, G. (1994). Circadian typology and individual differences. A review. *Personality and Individual Differences*, *16*(5), 671–684. https://doi.org/10.1016/0191-8869(94)90209-7

Taylor, D. J., & McFatter, R. M. (2003). Cognitive performance after sleep deprivation: does personality make a difference? *Personality and Individual Differences*, *34*(7), 1179–1193. https://doi.org/10.1016/s0191-8869(02)00108-3

Tempesta, D., Socci, V., Dello Ioio, G., De Gennaro, L., & Ferrara, M. (2017). The effect of sleep deprivation on retrieval of emotional memory: a behavioural study using film stimuli. *Experimental Brain Research*, *235*(10), 3059–3067. https://doi.org/10.1007/s00221-017-5043-z

Tisserand, J.-C., Gallo, J. L., & Cochard, F. (2017). *Social preferences across different populations: Meta-analyses of the ultimatum and dictator games*. AFSC meeting.

Tsai, P.-S., Wang, S.-Y., Wang, M.-Y., Su, C.-T., Yang, T.-T., Huang, C.-J., & Fang, S.-C. (2005). Psychometric Evaluation of the Chinese Version of the Pittsburgh Sleep Quality Index (CPSQI) in Primary Insomnia and Control Subjects. *Quality of Life Research*, *14*(8), 1943–1952. https://doi.org/10.1007/s11136-005-4346-x

van der Helm, E., Gujar, N., & Walker, M. P. (2010). Sleep Deprivation Impairs the Accurate Recognition of Human Emotions. *Sleep*, *33*(3), 335–342. https://doi.org/10.1093/sleep/33.3.335

van 't Wout, M., Kahn, R. S., Sanfey, A. G., & Aleman, A. (2006). Affective state and decision-making in the Ultimatum Game. *Experimental Brain Research*, *169*(4), 564–568. https://doi.org/10.1007/s00221-006-0346-5

von Neumann, J., & Morgenstern, O. (1944). *Theory of Games and Economic Behavior*. Princeton Univ. Press.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*(6), 1063–1070. https://doi.org/10.1037/0022-3514.54.6.1063

Webster, D. M., Richter, L., & Kruglanski, A. W. (1996). On Leaping to Conclusions When Feeling Tired: Mental Fatigue Effects on Impressional Primacy. *Journal of Experimental Social Psychology*, *32*(2), 181–195. https://doi.org/10.1006/jesp.1996.0009

Wong, C.-S., & Law, K. S. (2004). Development and Validation of a Forced Choice Emotional Intelligence Measure for Chinese Respondents in Hong Kong. *Asia Pacific Journal of Management*, *21*(4), 535–559. https://doi.org/10.1023/b:apjm.0000048717.31261.d0

Wong, M. L., Lau, E. Y. Y., & Wan, J. (2012). *The relationship between sleep quality and daytime sleepiness with chronotype latent constructs: an exploratory and confirmatory factor analysis in Chinese college students.* 191.

Wong, M. L., Lau, E. Y. Y., Wan, J. H. Y., Cheung, S. F., Hui, C. H., & Mok, D. S. Y. (2013). The interplay between sleep and mood in predicting academic functioning, physical health and psychological health: A longitudinal study. *Journal of Psychosomatic Research*, *74*(4), 271–277. https://doi.org/10.1016/j.jpsychores.2012.08.014

World Medical Association. (2001). World Medical Association Declaration of Helsinki. *Swiss Medical Forum – Schweizerisches Medizin-Forum*, 373–374. https://doi.org/10.4414/smf.2001.04031

Xu, H., Shen, H., Wang, L., Zhong, Q., Lei, Y., Yang, L., Zeng, L., Zhou, Z., Hu, D., & Yang, Z. (2018). Impact of 36 h of total sleep deprivation on resting-state dynamic functional connectivity. *Brain Research*, *1688*, 22–32. https://doi.org/10.1016/j.brainres.2017.11.011

Yoo, S.-S., Gujar, N., Hu, P., Jolesz, F. A., & Walker, M. P. (2007). The human emotional brain without sleep — a prefrontal amygdala disconnect. *Current Biology*, *17*(20), R877–R878. https://doi.org/10.1016/j.cub.2007.08.007

Zhang, J., Lau, E. Y. Y., & Hsiao, J. H. (2018a). Sleep deprivation compromises resting-state emotional regulatory processes: An EEG study. *Journal of Sleep Research*, *28*(3), e12671. https://doi.org/10.1111/jsr.12671

Zhang, J., Lau, E. Y. Y., & Hsiao, J. H. (2018b). Using emotion regulation strategies after sleep deprivation: ERP and behavioral findings. *Cognitive, Affective, & Behavioral Neuroscience*, *19*(2), 283–295. https://doi.org/10.3758/s13415-018-00667-y

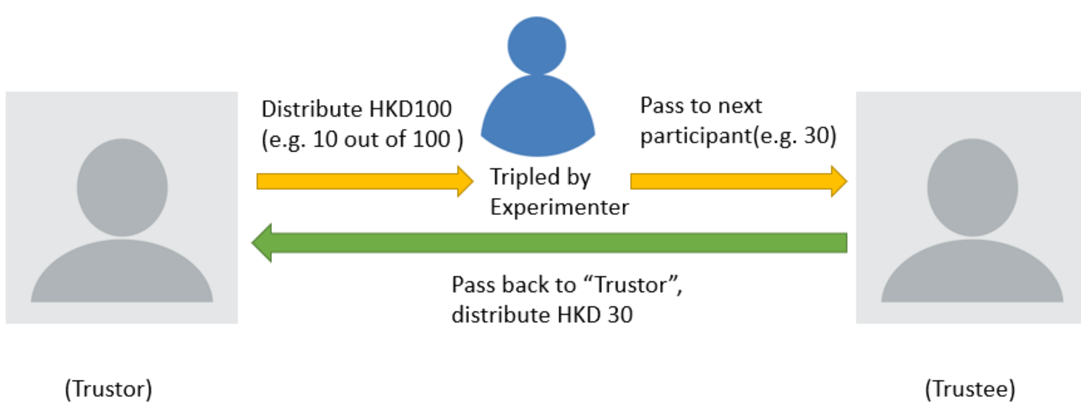
Appendix I

Study 1

Instruction script for social decision-making tasks:

In this following task, you will be playing two simple games with other participants. They could be participants who have already completed the experiment or participants who will join the experiment. Since we will need to calculate your payoff in this task after receiving responses from participants who will join the experiment later, we will notice you and ask you to come to our lab to collect the payoff later.

In the first game, you have been matched with other participants and your role as a first mover is to decide how much of HKD100 you want to pass or keep. Whatever you decide to pass will be tripled by the experimenter and pass to your partner. Your partner will then decide how much they want to pass back to you. Please see the following figure and see if you can understand it. Now please decide how much you want to pass to the next participant. You can pass from 0 to 100. Please bear in mind that the money is real and will be given to you after calculation as an extra payoff.



Now you will play the role as the second mover. Participant No.XX has been matched with you and he/she has already made a distribution out of HKD100. Now you will need to decide how much you want to pass back to participant No.XX.

Note: In Study 1, when participants played the role as trustees, they would receive HKD150 (a tripled amount of HKD50) from the trustors.

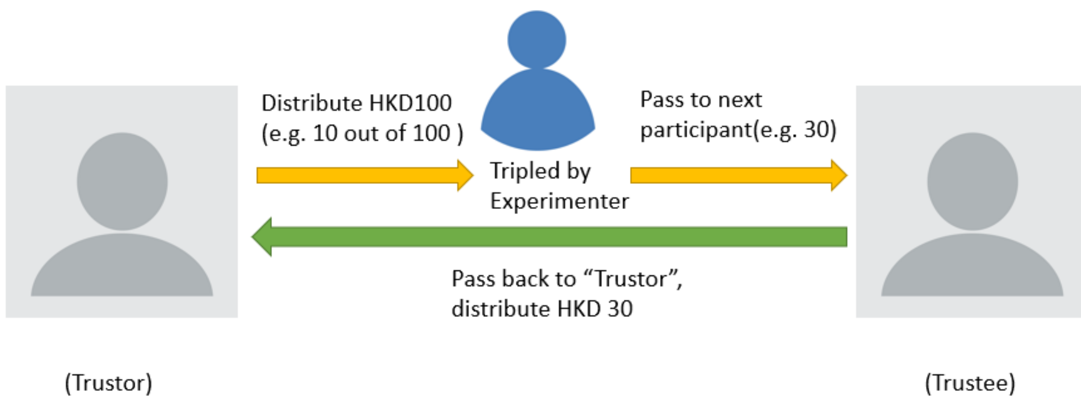
In the second game, you have been assigned the role of responder and you have been randomly matched with ten previous participants. They have played the role as proposers and decided how much of HKD 10 to pass to you. Now you will make a decision to accept or reject the offer made by these 10 participants. If you accept the offer, you and the proposer will both get the amount of money that the proposer distributed. If you reject the offer, neither you or the proposer will get any amount of money. Please bear in mind that the money is real and will be given to you after calculation as an extra payoff.

Study 2:

Instruction script for social decision-making tasks:

In this following task, you will complete three simple games. You will be assigned to different roles and play the games with other participants in this experiment. They could be participants who have already completed the experiment or participants who will join the experiment. Since we will need to calculate your payoff in this task after receiving responses from participants who will join the experiment later, we will notice you and ask you to come to our lab to collect the payoff later.

In the part one of the first game, you have been matched with another participant and your role as a first mover is to decide how much of HKD100 you want to pass or keep. Whatever you decide to pass will be tripled by the experimenter and pass to your partner. Your partner will then decide how much they want to pass back to you. Please see the following figure and see if you can understand it. Now please decide how much you want to pass to the next participant. You can pass from 0 to 100. Please bear in mind that the money is real and will be given to you after calculation as a possible extra payoff.



In the second part of the first game, you will play the role as a second mover and you have been matched with participant XX. Participant XX has already decided how much of HKD100 he/she will pass to you and the amount passed to you has been tripled. However, we will not tell you exactly how much participant XX has passed to you so you will decide how much you would return for any probability of the distribution. Now you will decide how much you want to pass back to participant XX. Please bear in mind that the money is real and will be given to you after calculation as a possible extra payoff.

In the first part of the second game, you have been matched with another participant and your role as a first mover is to decide how much of HKD100 you want to pass or keep. Different to the last game, your partner now has the option to accept or reject your offer. If he/she rejects your offer, both of you will get zero amount of money. Please answer honestly and bear in mind that the money is real and will be given to you after calculation as a possible extra payoff.

In the second part of the second game, you have been assigned the role of responder and you have been randomly matched with another participant XX. He/she has played the role as proposers and decided how much of HKD 100 to pass to you. However, we will not tell you exactly how much participant XX has passed to you so you will decide how much you would return for any probability of the distribution. Offers included: HKD0, HKD5, HKD10, HKD15, HKD20, HKD25, HKD30, HKD35, HKD40, HKD45, HKD50, HKD55, HKD60, HKD65, HKD70, HKD75, HKD80, HKD85, HKD90, HKD95, HKD100. Now you will make a decision to accept or reject the offer made by participant XX. If you accept the offer, you and the proposer will both get the amount of money that the proposer distributed. If you reject the offer, neither you or the proposer will get any amount of money. Please bear in mind that the money is real and will be given to you after calculation as a possible extra payoff.

In the third game, you now have been randomly assigned to the role of proposer and you have been randomly matched with another participant XX and you will decide how much of HKD100 you will pass or keep. In this game, the participant XX does not have the right to reject your offer, therefore, what you propose to keep will be your final payoff for this game. Please bear in mind that the money is real and will be given to you after calculation as a possible extra payoff.

Appendix II

Supplementary Table 1 Correlation between baseline variables and outcome variables in SD group

	1	2	3	4	5	6	7	8	9	10
1.Trust	-									
2.Trustworthi-ness	.670**	-								
3.Acceptance rate(unfair)	.216	.035	-							
4.PSQI	.029	.236	.049	-						
5.CSM	.461*	.356	.188	-.369	-					
6..DepScore	-.490*	-.475*	.019	.364	-.685**	-				
7..AnxScore	-.148	-.004	-.154	.467*	-.077	.483*	-			
8..StrScore	-.108	.083	-.010	.566**	-.478*	.663**	.525*	-		
9.TotalNFC	.064	.058	-.169	-.169	-.098	-.131	-.337	.588	-	
10. EI	-.218	-.356	.160	.160	-.110	-.199	-.483*	-.246	.034	-

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Supplementary Table 2 Correlation between baseline variables and outcome variables in SC group

	1	2	3	4	5	6	7	8	9	10
1.Trust	-									
2.Trustworthi-ness	.154	-								
3.Acceptance rate(unfair)	.235	-.240	-							
4.PSQI	-.074	-.520	-.271	-						
5.CSM	.009	.434	.224	-.424	-					
6..DepScore	.478*	-.176	-.108	.541*	-.035	-				
7..AnxScore	.197	-.188	.147	.565*	-.101	.742**	-			
8..StrScore	.046	-.074	-.085	.452*	-.045	.636**	.857**	-		
9.TotalNFC	.037	.057	.271	-.017	.032	.083	.349	.222	-	
10. EI	-.494*	.848	-.323	-.188	-.026	-.630**	-.399	-.285	.131	-

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Appendix III

Supplementary Table 3 Demographic characteristic of participants in 10-trial UG

	SD group(n=17)	SC group(n=14)	
	Mean (SD)	Mean (SD)	p-value
Age	20.29(1.57)	20.57(2.14)	.681
Sex (% female)	56.52%	65.00%	.756
DASS_Depression scale	4.35(3.62)	1.86(1.92)	.021
DASS_Anxiety scale	3.65(2.62)	1.86(1.88)	.041
DASS_Stress scale	6.94(3.19)	3.64(2.93)	.006
NFC (total score)	64.94(7.20)	57.21(7.66)	.007
EI	13.53(3.94)	13.71(4.08)	.899
Baseline Affect			
Positive	2.49(.40)	2.48(.54)	.970
Negative	1.71(.54)	1.52(.29)	.217