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Article

Subclinically Depressed Individuals Showed Less Trust after a Night of Sleep Deprivation

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Abstract

Insufficient sleep's impact on cognitive and emotional function is well-documented, but its effects on social functioning remain understudied. This research investigates the influence of depressive symptoms on the relationship between sleep deprivation (SD) and social decision-making. Forty-two young adults were randomly assigned to either the SD or sleep control (SC) group. The SD group stayed awake in the laboratory, while the SC group had a normal night's sleep at home. During the subsequent morning, participants completed a Trust Game (TG) in which a higher monetary offer distributed by them indicated more trust toward their partners. They also completed an Ultimatum Game (UG) in which a higher acceptance rate indicated more rational decision-making. The results revealed that depressive symptoms significantly moderated the effect of SD on trust in the TG. However, there was no interaction between group and depressive symptoms found in predicting acceptance rates in the UG. This study demonstrates that individuals with higher levels of depressive symptoms display less trust after SD, highlighting the role of depressive symptoms in modulating the impact of SD on social decision-making. Future research should explore sleep-related interventions targeting the psychosocial dysfunctions of individuals with depression.

Keywords: depressive symptoms; sleep deprivation; social decision-making; trust; young adults

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Sleep Deprivation

The effects of sleep loss on core cognitive functions, such as verbal fluency, inhibition, and planning are well-studied (Harrison & Horne, 1998; Horne, 1988). In recent years, studies have embarked on investigating its effects on other important cognitive functions, including complex attention, working memory, and emotional functions (e.g., Lim & Dinges, 2010; Van Der Helm et al., 2010; Zhang et al., 2019). In comparison, less work has been done on sleep deprivation's (SD's) effects upon social functions, a critical domain contributing to health and quality of life (Rocco & Suhrcke, 2012). Simon and Walker (2018) found that participants kept a greater distance from a stranger in the laboratory setting after a night of SD and were rated lonelier than the controls by blinded raters. Recently, Zhang et al. (2020) found that participants who underwent a night of SD showed more intergroup bias compared to their sleep-satiated counterparts. In contrast, null effects were reported in studies that investigated a night of SD with interactive social tasks (Holding et al., 2019). Given the mixed findings of SD's effects on social functions, more efforts to elucidate their relationship and intervening factors such as mood are warranted. Indeed, previous studies have reported altered social behaviors in individuals with mood disorders such as depression (Destoop et al., 2012; Ong et al., 2017). Conceivably, these individuals would commonly have sleep disturbances (Baglioni et al., 2011), distinctive sleep features (Steiger et al., 2015), and unique responses to SD (e.g., enhanced mood; Schüle et al., 2001). It is therefore plausible that individuals with different levels of depressive symptoms may respond to SD in social decision-making situations differentially, especially considering the well-documented cognitive distortions (Beck, 2008) and information processing deficits in social situations among individuals with depression (Destoop et al., 2012). Given the important role of depressive symptoms in sleep and social functions, the current study aims at investigating the moderating effect of depressive symptoms on the relationship between SD and social decision-making.

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Social Decision-Making and Sleep

Among social functions, social decision-making is one form of goal-directed behavior that involves both cognitive and emotional component processes underlying human interactions in a social context (Engelmann & Fehr, 2017). Effective social decision-making requires the ability to think about future payoffs (planning), avoid irrelevant information (inhibition), regulate one's emotions, and so forth. To the extent that some of these core cognitive and emotional abilities have been found to be vulnerable to the effects of SD (Lim & Dinges, 2010; Van Der Helm et al., 2010; Zhang et al., 2019), it is conceivable that SD may result in alterations of social decision-making through the impairments of these abilities. In particular, trust and rational decision-making are two fundamental components of social decisions and essential ingredients of economic life, respectively. Trust Game (TG) is one standard way to experimentally assess trust (i.e., measured by the amount of monetary offers (i.e., "trust offer") in the TG; Berg et al., 1995), capturing the concept of trust as a behavior that makes an individual vulnerable to the action of another person (Engelmann & Fehr, 2017). While decision-making is often deemed as a rational cognitive process, emotion can affect it (Camerer, 2011). Ultimatum Game (UG) is a widely administered strategic economic game to capture one's rational decision-making under the influence of affective aversion to unfairness, measured by the acceptance rate of unfair monetary offers in UG (Güth et al., 1982). In the UG, one is expected to neglect the unfairness of the offers given to them and accept all offers to maximize their monetary payoffs, which would be considered as rational decision-making. To the best of our knowledge, Anderson and Dickinson (2010) is the only study that investigated the effect of total sleep deprivation (TSD) on trust and rational decision-making. Participants went through both a night of 36-h SD and normal sleep at home a week apart and completed the economic games following both conditions. Although participants showed a lower acceptance rate of unfair offers in the UG after TSD, there was no significant difference in the trust offers and ultimatum offers between the two conditions. These findings suggested that participants were less rational in their social decision-making after sleep loss. In a similar study, participants underwent a week of partial sleep restriction (5–6 h in bed) and a week of well-rested sleep (8–9 h in bed) with a week's interval and completed the economic games after each condition (Dickinson & McElroy, 2017). In contrast to TSD, partial SD resulted in fewer trust offers delivered in the TG but no significant difference in accepting unfair offers in the UG. The different findings between these two studies suggested that different sleep-loss protocols may have divergent effects on social decision-making outcomes. Moreover, discrepant results also indicate that SD's effect on social decision-making might be moderated by unknown factors, such as depressive symptoms.

Depression and Social Decision-Making

Depression has been associated with a lack of reward sensitivity and decreased approach-related behaviors (Destoop et al., 2012; Pizzagalli et al., 2009), which may lead to a failure in maximizing potential monetary payoffs in the economic games. Indeed, the acceptance rates of unfair offers among depressed patients in playing the UG showed divergent patterns across studies. Harle and Sanfey (2007) found that healthy participants with an induced sad mood showed a lower acceptance rate for unfair offers in the UG. However, a later study showed that depressed patients accepted both fair and unfair offers as many times as healthy controls but they offered significantly more money than the controls when playing the role of the proposer (Destoop et al., 2012). Compared to the UG, less is known about trusting behaviors among individuals with depression in the TG. Ong et al. (2017) found that individuals with major depressive disorder showed more prosocial behaviors than healthy controls when playing a modified TG. Cáceda et al. (2014) found that depressed men showed more trust than healthy men, while there was no difference between depressed women and healthy women. To summarize, although social decision-making has been widely studied, how individuals with depressed mood behave in these tasks remains inconclusive and conflicting.

The Current Study

Empirical evidence suggested a bidirectional relationship between depression and disturbed sleep (Jansson-Fröjmark & Lindblom, 2008; Palagini et al., 2013). In a prospective population-based study spanning over 11 years, insomnia was found to predict the onset of depression across different age groups, while depression at baseline was linked to an increased risk of subsequent insomnia (Sivertsen et al., 2012). Both self-reported and objectively measured sleep disturbance were found to be elevated in depression. Interestingly, sleep deprivation can enhance the mood among depressed participants and affect the course of depression (see reviews in Boland et al., 2017). Depressed patients showed clinical improvement within hours (and relapse) in response to extended wakefulness (Hemmeter et al., 2010), although the antidepressant effect of SD is transient. Sleep-dependent mechanisms also appear to contribute to the affective-cognitive biases in clinical depression (Lau et al., 2020). Besides sleep disturbances, depressed patients often display social impairments (Baglioni et al., 2011; Robson et al., 2020). As such, the goal of the current research was to understand the association between sleep, depressive symptoms, and social decision-making. Given the close association between sleep and depression (Baglioni et al., 2011; Steiger & Pawlowski, 2019) and the well-known antidepressant effect of sleep deprivation (see reviews in Tsuno et al., 2005), it is conceivable that participants with more depressive symptoms may behave differently than their less depressed counterparts under different sleep conditions. Thus, we predicted that depressive symptoms would moderate the effect of one night of SD on social decision-making.

Method

Our study was 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 participants prior to the experiment.[1]

Participants

Based on a previous study using a similar between-subjects experimental design (Zhang et al., 2018), 51 healthy young adults aged 18–30 years (M_{age} = 21, SD = 2.62; 60.5% = female) were initially recruited through poster sign-up on campus. Screened participants were with no reported history of sleep disorders, head trauma, psychiatric conditions, use of medication or substances interfering with sleep or general cognitive/affective functioning, and overnight shift work in the past 2 weeks. Portable polysomnography (PSG) and the Berlin Questionnaire (Netzer et al., 1999) were used for additional screening of sleep abnormalities, and no sleep disorders were detected in our recruited participants, who were then randomly assigned to the SD or the sleep control (SC) groups. Four participants did not complete the experiment, four were excluded due to their short sleep duration the night before the experiment (< 6 h), and one was excluded due to an exceptional higher score in the depression subscales (> 3SD), resulting in a final sample of 42 participants (SD: N = 23; SC: N = 19).

Procedure

This study adopted a between-groups (SD versus SC) 9-day experimental design with 6-day pretest habitual sleep week and a 3-day

[1]All data and research materials are available at https://osf.io/cp9d5/?view_only=4533de35c3974ac1b089250f92272038v.

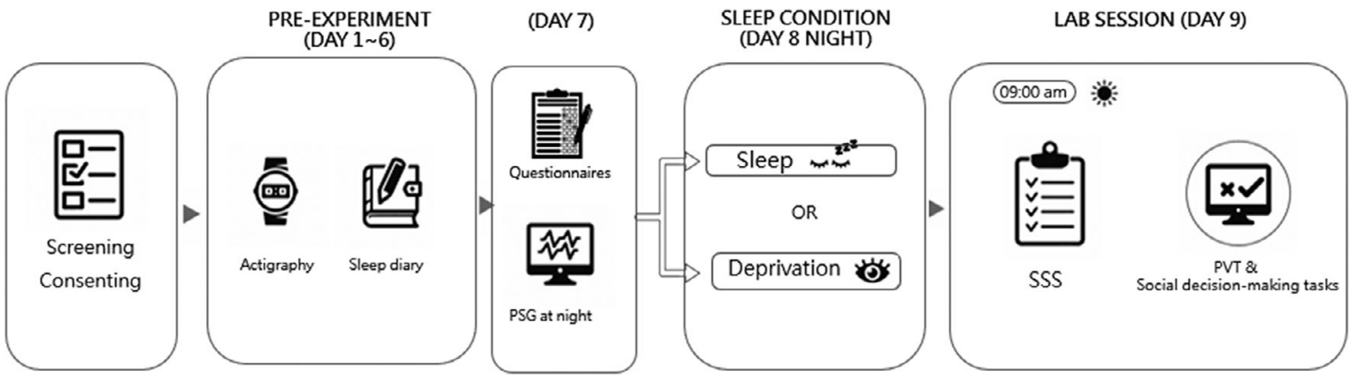

Figure 1. Procedures. PSG = polysomnography; SSS = Stanford Sleepiness Scale; PVT = Psychomotor Vigilance Test.

experimental protocol (Figure 1). After the screening and consent procedures, participants underwent the pretest sleep week and started to keep a sleep diary and wore an actigraph until the end of the experiment. On day 7, participants completed a battery of questionnaires, which took 30–45 min. Participants were asked to maintain their habitual sleep schedule at their residence on the night of day 7 and were monitored by the actigraph (with at least 7 h in bed and woke no later than 10 a.m.). Participants also wore a portable PSG on the night of day 7 for screening of sleep abnormalities. On the morning of day 8, participants were randomly assigned to either the SC or the SD group. They were instructed to go on with their lives as normal, except for avoiding intake of caffeine. On the night of day 8, the *SC* group had a normal night of sleep at their residence, while the SD group stayed awake in solitary activities such as reading but avoided emotional or physical arousal (e.g., playing computer games) in the laboratory. Snacks with calories lower than 100 kcal (e.g., small plain-flavored cake rolls) were provided at 1:00 a.m., 3:00 a.m. and 5:00 a.m. On day 9, participants had breakfast at 08:00–08:45 a.m., followed by a series of outcome measurements including sleepiness and vigilance measures, and social decision-making tasks. All measures were completed between 09:00 a.m. and 11:00 a.m. to control for potential circadian effects (e.g., Akerstedt & Wright, 2009). Participants wore the actigraph and abstained from caffeine, alcohol, and napping throughout the last 3 days of the experimental period and in the 24 h before the laboratory session. Finally, participants were debriefed and compensated with cash. Participants in the control group received 200 HKD (around 26 USD), while those in the SD group received 500 HKD (around 64 USD) for compensation. They also obtained a reward based on their performance on a trial randomly selected at the end of the games (amount ranging from 0 HKD to 150 HKD).

Measures

All scales in English were translated to Chinese with back translation.

Sleep Diary: Participants were instructed to record the time they went to bed, their sleep/wake time, and the time they got out of bed. The average sleep duration across the 6 days before the laboratory session was taken as the average nocturnal sleep duration.

Actigraphy: Recordings of continuous activity were collected by an AMI Motionlogger Micro Watch in the zero crossing mode (ZCM) (Ambulatory Monitoring, Inc.) throughout the experiment. The data were scored in ActionW 2.7 (Ambulatory Monitoring, Inc.) using a validated algorithm (Cole et al., 1992). The total sleep time (TST), sleep onset latency (SOL), and sleep efficiency (SE) were extracted after comparison to the sleep diary.

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 other sleep disorders. An apnea-hypopnea index (AHI) score higher than 5 would be regarded as potential sleep apnea, which was not identified in our participants.

Depression Anxiety Stress Scales (DASS): The 21-item DASS was used to assess depression, anxiety, and stress over the past week, and each subscale includes seven items with a total score up to 21 (Lovibond & Lovibond, 1995). The items were scored on a four-point Likert scale ranging from 0 (never) to 3 (always). Since the current study only focused on depression scores, only the depression subscale was included in the analysis. The Cronbach's alpha for the depression subscale in the current study is .754, which indicates an acceptable internal reliability (Nunnally, 1978).

Stanford Sleepiness Scale (SSS): The SSS is a self-reported scale that assesses participants' perceived sleepiness (Hoddes et al., 1973). The total score ranges from 1 (very alert) to 7 (extremely sleepy).

Psychomotor Vigilance Test (PVT): On the 10-min computerized PVT, participants were required to press the "SPACE" bar as quickly as possible once a target appeared on the screen (Belenky et al., 2003). PVT is a widely used task to measure vigilant attention after sleep deprivation (Lee et al., 2010). There were 80 trails with the intertrial intervals ranging from 3,000 to 10,000 ms were included in the task. The average response time (RT) and the number of lapses (no response or response time > 500 ms) were recorded.

Pittsburgh Sleep Quality Index (PSQI): The Chinese PSQI was used to assess sleep quality over the past month retrospectively (Tsai et al., 2005), including seven components 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, with a cutoff score of 5/6 to identify good/poor sleepers (Buysse et al., 1989).

Composite Scale of Morningness (CSM): The CSM (Smith et al., 1989) is a 13-item scale assessing circadian preference in behavioral terms. A Chinese adapted version of the CSM (Lau et al., 2013; Wong et al., 2012) was employed with a higher score indicating a morning preference. A total score of 23 or below and a score of 40 or above indicate an evening type and a morning type, respectively, and a score in between indicates an intermediate type.

Social Decision-making Tasks: The social decision-making tasks included two games: The Trust Game (TG; Berg et al., 1995) and the Ultimatum Game (UG; Güth et al., 1982). Participants were informed in advance that they would take part in a draw after the full experiment

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to obtain an extra reward based on their performance in one of the trials in the games. There are two parts in the TG: the first part measures trust and the second part measures trustworthiness (see Supplementary Figure 1). In the first part, the participant who played the role of "trustor" decided how much of 100 HKD (around 13 USD) to deliver to the next participant (the "trustee"). The money was then tripled by the experimenters and the trustee decided how much of the money they would return to the trustor. Participants were informed that they would deliver the money to the next participant and that they would receive the final payoff after the experiment when all the payoffs were calculated for both the trustor and the trustee. The amount of money that the trustor delivered was regarded as a measure of trust. In the second part, participants were told that they were paired with a previous participant and would play the role of "trustee." Then, they were given half of the tripled amount of 100 HKD (150 HKD = 50% × 100 HKD × 3) and decided 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 preset at 150 HKD. Therefore, the ratio of trustworthiness was calculated and used in the analysis (i.e., ratio = the amount returned by the trustee/150).

In the UG, participants were introduced to 10 subjects (confederates) and told that they would be playing a game with each of them. The "proposer" decided how much of 10 HKD (around 1.3 USD) they would give to the "responder." The responder could accept or reject the offer. If the responder rejected the offer, both individuals received nothing (see Supplementary Figure 2). Participants were informed that they were randomly assigned to the role of proposer or responder; however, all participants were assigned the role of responder. All offers were predetermined such that all participants received the same set of offers. Half of these 10 offers were fair, that is, a proposal to divide the 10 HKD evenly (5 HKD: 5 HKD), while the remaining half were unfair (two 9 HKD: 1 HKD offers, two 8 HKD: 2 HKD offers, and one 7 HKD: 3 HKD offer). Participants were expected to receive a payoff no greater than 34 HKD (if they accepted all the offers). The acceptance rate was calculated and compared among the different offer conditions.

Analytic Strategies

Data were analyzed using SPSS statistics 27. To test the interaction effect of *SD* and depressive symptoms on trust and trustworthiness, we used a stepwise regression model where depressive symptom was entered as a continuous variable in the regression model. To interpret the interaction effect of *SD* and depressive symptoms on trust, the values of the moderator (i.e., depressive symptoms) were calculated using the mean plus/minus one standard deviation (Std Dev) from the mean. To test the between-subject differences in the probability of accepting Ultimatum offers (binary-dependent variable), we used the generalized estimating equations model (GEE). This analysis generates an estimate of odd ratio, 95% confidence interval, and the *p*-value.

Results

Descriptive Statistics

The SD and SC groups did not differ significantly in age, sex ratios, and baseline sleep characteristics including habitual sleep duration, circadian preference, and sleep quality (Table 1). The depressive level (scores ranging from 0 to 11) between two groups at baseline was not significantly different (t (39) = 1.760, p = .086). The skewness, kurtosis, and Pearson's intercorrelation of the study variables are shown in Table 2. Full details of the participant characteristics in separate groups can be found in the Supplementary materials.

Table 1. Demographic characteristic of participants

	SD group (*n* = 22)	*SC* group (*n* = 19)	
	Mean/N (Std Dev)	Mean/N (Std Dev)	*p*-Value
Age	20.68(1.67)	21.37(3.483)	.440
Sex (% female)	56.5%	63.2%	.757ƚ
Averaged sleep duration(h)	7.58 (1.03)	7.66 (.87)	.753
Eveningness	1 (4.5%)	3 (15.8%)	
Intermediate	20 (90.9%)	13 (68.4%)	
Morningness	1 (4.5%)	3 (15.8%)	
PSQI global score	5.24 (1.95)	5.00 (2.65)	.746
Good sleeper	13 (61.9%)	12 (63.2%)	
Poor sleeper	8 (38.1%)	7 (36.8%)	

Note: Std Dev = standard deviation; CSM = Composite Scale of Morningness; Eveningness = CSM score ≤ 23; Intermediate = 23 < CSM score < 40; Morningness = CSM score ≥ 40; PSQI = Pittsburgh Sleep Quality Index; poor sleeper = PSQI score > 5; SD = sleep deprivation; SC = sleep control.
ƚ Chi-square analysis.
Demographic information of one participant in the SD group was missing.

Manipulation Check

On the morning of day 3, the SD group was significantly sleepier (t(31.59, corrected df) = 6.630, p < .001), slower in response time (t(40) = 4.822, p < .001), and displayed more attention lapses (t(26.59, corrected df) = 4.822, p < .001) than the SC group (Table 3).

Depressive Symptoms Moderated the SD Effects on Trust

In the TG, the average trust offer delivered by the first mover was 42.5 HKD of 100 HKD (42.5%). The average amount returned by the trustees was 63.55 HKD out of 150 HKD (42.37%). *T*-test analysis is shown that there was no significant difference between the SD and SC groups on either the trust offers or the amount returned by the trustee (*ps* > .05). The stepwise regression analysis (Table 4) showed a significant interaction effect between group and depression score in predicting trust (b = −.901, t = −3.682, p = .001). Participants of the SD group showed a stronger effect of depression score in lowering trust. Post hoc power analysis showed that when the effect size f^2 is 0.358 (based on an R^2 change = 0.263), number of tested predictors is 3, and number of predictors is 3, a sample size of 42 is able to achieve a statistical power level of 88% at a significant level of α = .05. In order to visualize the interaction effect, simple slope analysis was conducted. Among participants with more depressive symptoms (1 Std Dev above the mean), the SD group delivered less trusting offers than the SC group; the opposite effect was observed in participants with a low level of depression symptoms (1 Std Dev below the mean), with more trust in the SD group compared to the SC group (Figure 2).

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Table 2. Skewness, kurtosis, and Pearson's intercorrelation matrix

	Mean (Std Dev)	Skewness	Kurtosis	1.	2.	3.	4.	5.	6.
1. DASS_d	3.17(2.78)	.934	.531	1					
2. Trust	42.5(21.11)	.621	1.137	−.130	1				
3. Trustworthiness	0.42 (0.19)	.387	1.942	−.249	.519***	1			
4. Acceptance rate	0.78 (0.17)	−.888	−.851	.064	.234	−.017	1		
5. PSQI	5.13 (2.28)	1.208	1.810	.348*	−.025	−.112	−.160	1	
6. CSM	31.51 (5.58)	.386	−.125	−.233	.240	.367*	.170	−.329*	1

Note: DASS_d = depression subscale in DASS; Trust = amount of money delivered by trustors; Trustworthiness = ratio of the amount of money returned by trustees; Acceptance rate = ratio of accepting offers on the UG; CSM = Composite Scale of Morningness; PSQI = Pittsburgh Sleep Quality Index.
**p* < .05; ***p* < .01; ****p* < .001.

Table 3. Effects of sleep deprivation on psychomotor vigilance and sleepiness

	SD group (n = 23)	SC group (n = 19)		
	Mean (Std Dev)	Mean (Std Dev)	t	p-Value
PVT_RT (ms)	399.22(46.73)	332.36(37.25)	5.048	<.001
PVT_lapses	15.26(10.99)	3.63(3.27)	4.822	<.001
SSS	4.43(1.34)	2.37(0.60)	6.630	<.001

Note: PVT = Psychomotor Vigilance Test; RT = response time; PVT_lapse = response time > 500 ms; SSS = Stanford Sleepiness Scale; SD = sleep deprivation; SC = leep control.

Table 4. Effects of sleep deprivation and depressive symptoms on trust and trustworthiness

	Trust		Trustworthiness	
Predictors (β)	Model 1	Model 2	Model 1	Model 2
SD	−.047	−.098	.464*	.427
DASS-d	−.117	.636*	−.399*	−.219
SD X depression		−.901**		−.199
R square change of the model	.019	.263**	.255*	.010

Note: β = standardized coefficient; Trust = amount of money delivered by trustors; Trustworthiness = ratio of the amount of money returned by trustees; DASS_d = depression subscale in the DASS.
**p* < .05; ***p* < .01.

In contrast, group and depression score together could predict 25.5% of the total variance of trustworthiness, with $F(2,28) = 4.784$, $p = .016$. However, there was no interaction effect between group and depression score on trustworthiness.

In the UG, unfair offers of 9 HKD: 1 HKD ($b = -2.334$, $p < .001$, $OR = .097$, 95% CI = .044, .215) or 8 HKD: 2 HKD ($b = -2.259$, $p < .01$, $OR = .104$, 95% CI = .028, .394) were less likely to be accepted than the fair offer of 5 HKD: 5 HKD (see Supplementary Figure 3 for the distribution of offers). However, there was no significant main effect of group ($b = .2553$, $p = .838$, $OR = 1.179$, 95% CI = .243, 5.713) or interaction effect between group and offer condition (9 HKD: 1 HKD: $b = -.685$, $p = .447$, $OR = .504$, 95% CI = .086, 2.947; 8 HKD: 2 HKD: $b = .474$, $p = .641$, $OR = 1.606$, 95% CI = .219, 11.791; 7 HKD: 3 HKD: $b = .732$, $p = .593$, $OR = 2.082$, 95% CI = .143, 30.217). The results remained the same ($b = .231$, $p = .775$, $OR = 2.080$, 95% CI = .142, 30.392) after including depression score as a predictor in the model.

Discussion

This study provides the first evidence that depressive symptoms moderate the effect of 24-h SD on trust, suggesting mood states influence the response to SD. Interestingly, opposite patterns of depression-moderated effects were identified for SD versus SC conditions: individuals with a higher level of depressive symptoms showed more trust after normal sleep but less trust after SD, compared to those with lower level of depressive symptoms. A recent review of psychiatric disorders and economic games suggested that abnormalities in social interaction are common in psychiatric disorders (Robson et al., 2020). Making social decisions (as implicated in economic games) is complex as it requires not only a substantial cognitive capacity to make effective decisions but also perspective taking such as inferring others' emotions and understanding the motivations and consequences of one's actions. Our finding of participants with more depressive symptoms demonstrating more trusting behaviors after normal sleep is consistent with findings from previous studies (Cáceda et al., 2014; Ong et al., 2017). One explanation is that depressed participants may lack the cognitive capacity of predicting and considering others' decisions, hence leading to misjudgment of the bargaining situation that results in higher amounts of money offered. Another explanation is that depressed individuals behave in a prosocial way to help reduce their stress in socially stressful situations, which may reflect their higher need to accommodate others, driven by an inflated fear of being negatively evaluated (Cáceda et al., 2014). In this light, our findings corroborate with the information processing model explaining the altered social behaviors of depressed individuals in dealing with the cognitive load in social interactions.

Participants with more depressive symptoms made more trust offers from their less depressed counterparts in the normal sleep condition. However, a night of SD seemed to change the tendency to trust among participants, in such a way that sleep-deprived participants with a lower level of depressive symptoms seemed to mimic the tendency of more depressed participants in normal sleep condition in their trusting behaviors. This interesting pattern might be understood from the perspective of the sleep-associated cognitive capacity that was hampered by a night of sleep loss, increasing the fear of negative evaluation by others in the less depressed participants, who in turn demonstrated more prosocial behaviors, as detected in the participants with more depressive symptoms in normal sleep conditions (Robson et al., 2020). On the other hand, given the SD-induced transient antidepressant effects on patients with depression (Naylor et al., 1993; Schilgen & Tolle, 1980), it is possible that more depressed participants have a temporary recovery

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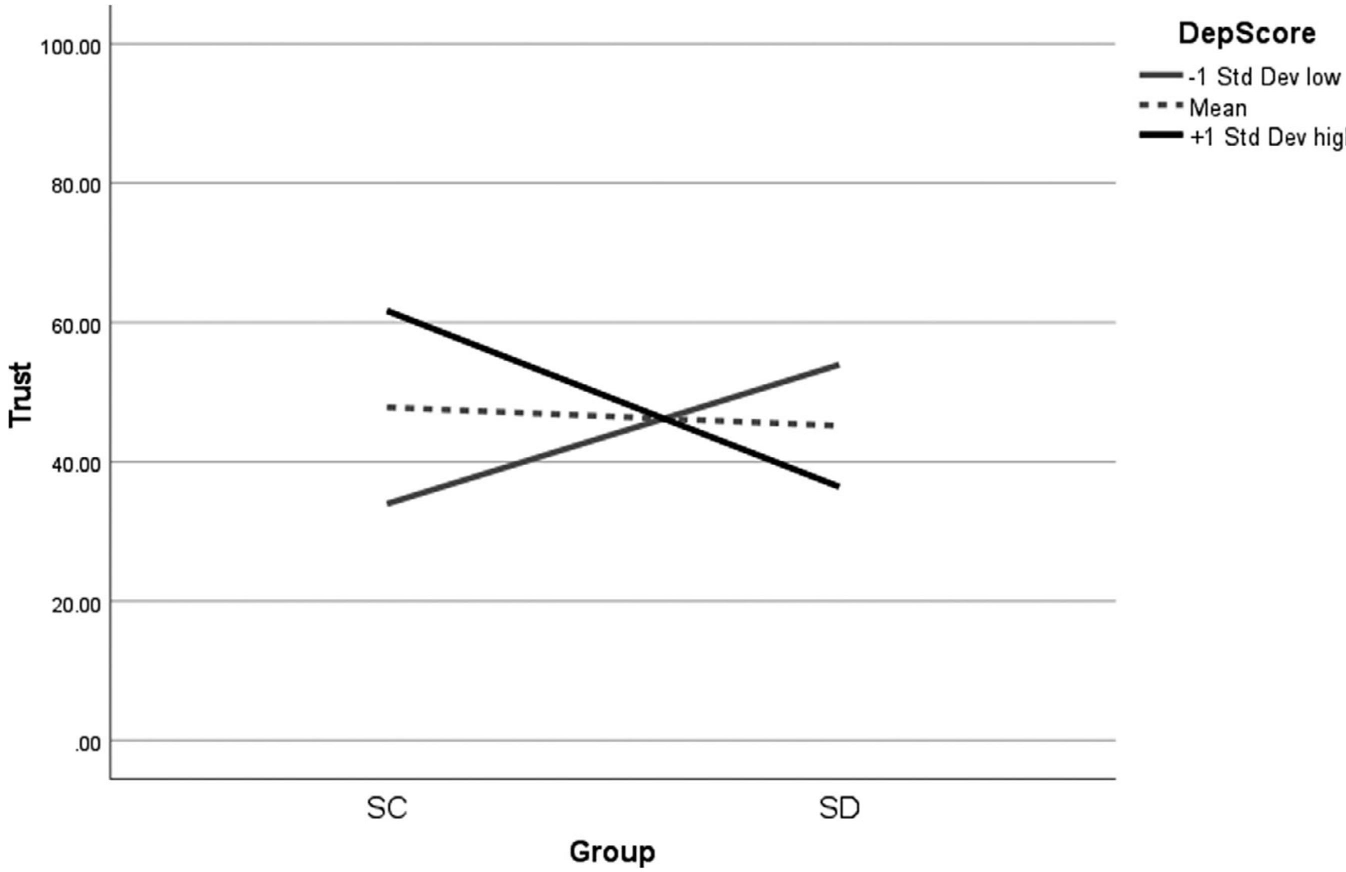

Figure 2. Depression level moderates sleep deprivation effects on trust. SD = sleep deprivation; SC = sleep control; DesScore = depression score; Std Dev = standard deviation.

from the "limited ability" in social interaction and behave as non-depressed participants after a night of SD. That is, the "baseline"-elevated trust level that is related to the depressive symptoms is now "normalized" by the antidepressant effect of SD, hence resulting in lowered trust after SD. With sufficient cognitive capacity to predict their counterparts' actions after SD, participants with more depressive symptoms may deliver fewer trust offers to "secure" their final payoffs. However, the antidepressant effect of SD on depressed mood is suggested to disappear after recovery sleep (Schilgen & Tolle, 1980). In the current study, we did not measure the mood level or cognitive capacity level after sleep condition, thus further studies are needed to examine the lasting effect of SD on trust among depressed participants by adding mood- and cognitive-capacity-level measurements to understand the underlying mechanism of the effect of SD on trust.

The effects of SD on social decision-making remain conflicting and underexplored in the literature. In Anderson and Dickinson' (2010), 36-h sleep deprivation did not affect trusting offers in the TG but only the acceptance rate in the UG. Opposite results were reported by the same group employing a partial SD protocol (Dickinson & McElroy, 2017). Although previous studies suggested that the limited cognitive capacity in participants with psychiatric disorders may influence their performance in UG (Robson et al., 2020), we did not find a significant difference in performance between the SD and SC groups. We speculate that the null finding in our UG task might be due to the small amount of money (10 HKD) distributed and that the incentive to earn a larger final payoff might not have been enough to create between-group differences in the acceptance rates. Taken together, nonsignificant impact of SD on social decision-making might have been due to differences in methodological factors, namely the longer SD duration (36 h versus 24 h) and the circadian phase of the testing time (in the afternoon versus morning). Given that there were no other studies examining the effect of SD on social decision-making except the two studies that have been reviewed (Anderson & Dickinson, 2010; Dickinson & McElroy, 2017), the research concerning sleep loss and social functions is still at its infancy and warrants more future investigations.

Limitation

Our study has several limitations. First, our participants played the economic games with computers. Nevertheless, post-experiment questions validated that all participants did believe they were playing with actual participants and with real money. Second, only healthy young adults were recruited, which limits generalization to other age-groups. Future studies could extend our study to other populations with a different sleep pattern (e.g., elderly). Third, participants' depressive symptom level was assessed by self-rating without formal diagnostic assessment. Previous studies have reported conflicting results in social decision-making tasks among community samples (e.g., with induced sad mood, Harlé & Sanfey, 2007; with a single dose of citalopram (selective serotonin reuptake inhibitor (SSRI)), Crockett et al., 2010; and high in depressive symptoms, Harlé et al., 2010) and patients with depression (Destoop et al., 2012). With our groundwork, further studies may explore whether depression would moderate the effects of SD on social decision-making by comparing patient samples and healthy volunteers with different demographic characteristics. Fourth, we did not counterbalance the order of two social decision-making tasks. Nevertheless, the tasks were simple and once-shot only, rendering the ordering effect less likely. Last but not least, the sample size of the current study was rather small. Yet, a stringent inclusion/exclusion criteria and random assignment were implemented, providing a clean sample with sufficient duration of sleep, without any sleep disorders and diagnosed psychiatric conditions. The sample size was also comparable to previous studies with similar experimental design (e.g., $N = 32$, in Anderson & Dickinson, 2010; $N = 52$ in Zhang et al., 2018).

Conclusion and Implication

Our findings carry several implications. Clinically, the critical role of sleep in depression is once again highlighted as we demonstrated how SD would modulate interpersonal functions differentially in depressed versus nondepressed individuals. To prevent disturbance of social functions of depressed individuals owing to sleep loss, regular sleep schedule and other sleep health enhancement strategies should be introduced as a core treatment component of depression. Organizationally, our findings may inform recruitment or deployment strategies of occupations involving periodic sleep loss such as medical and law enforcement personnel. While the extent and precise nature of the sleep-mediated changes in social functions in depressed individuals are yet to be ascertained, here we demonstrated that social decision-making in depressed individuals may be disproportionately affected by a night of sleep loss. While a night of sleep loss may be an extreme case of sleep irregularity, a more common form of that is the circadian misalignment, so-called social jetlag (i.e., under-sleeping on weekdays and over-sleeping on weekends), which was commonly seen among students and young people (Lau et al., 2013). Future studies could consider examining the impact of social jetlag on social decision-making among depressed individuals, given that its close association with academic and cognitive performance (Díaz-Morales & Escribano, 2015). As SD's impact on social decision-making seems more subtle and nuanced than its cognitive effects, more psychoeducation is warranted in heightening awareness of how social interactions could be interfered by sleep loss, especially in depressed individuals.

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