BRIEF REPORT

Poor Sleep Quality Is Significantly Associated With Effort but Not Temporal Discounting of Monetary Rewards

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Experimental sleep deprivation has been shown to differentially affect behavioral indices of effort and temporal discounting, 2 domains of reward processing often observed to be impaired in depression. Experimental sleep deprivation is phenomenologically different from sleep deprivation in everyday life (e.g., poor quality sleep or habitual short sleep duration). Thus, experimental findings may not explain how sleep disturbance impacts reward processing in everyday life. The present study examined associations of past-month self-reported typical sleep quality and duration among 325 young adults who completed behavioral tasks of effort and temporal discounting. Analyses accounted for the potential influence of self-reported mood symptoms and reward sensitivity. Results showed that poorer sleep quality, but not shorter sleep duration, was associated with less preference for high effort/high reward choices on the Effort Expenditure for Reward task (EEfRT) and was significant when accounting for depression and reward sensitivity, neither of which significantly predicted effort. Neither poorer sleep quality nor shorter sleep duration was significantly associated with a preference for smaller, more immediate reward on a delay discounting task. Findings suggest sleep quality, irrespective of total hours of sleep, may independently affect reward-relevant effort, which may have implications for the study and treatment of depression.

Keywords: sleep, effort, reward processing, depression

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Sleep disturbances and depression are increasing worldwide (Stickley et al., 2019). Disturbed sleep is frequently connected to poor depression treatment outcomes (Franzen & Buysse, 2008), and recent theoretical models have suggested that reward processing impairments may mediate this relationship (Boland et al., 2020;

Palagini et al., 2019). Depression is often associated with behavioral preference for smaller rewards that can be obtained more immediately (i.e., temporal discounting; Pulcu et al., 2014) and with less effort (i.e., effort discounting), the latter evidenced by both psychophysiological (e.g., cardiovascular response; Brinkmann et al.,

2009) and behavioral measures of effort expenditure (Treadway et al., 2012). The independent influence of sleep disturbance on these processes, however, is not well explicated.

Experimental sleep deprivation studies have yielded inconsistent results. One study utilizing 21 hr of sleep deprivation demonstrated evidence of temporal discounting (Reynolds & Schiffbauer, 2004), however two other studies utilizing 24-hr periods did not (Acheson et al., 2007; Libedinsky et al., 2013). Libedinsky et al. (2013) also examined effort discounting, finding that sleep deprivation was associated with less physical effort for larger reward compared to participants' rested state. Contrarily, Drummond et al. (2005) found that sleep deprived participants displayed *increased* effort in response to hard but not easy tasks, suggesting a compensatory mechanism, however tasks were not rewarded, and participants did not choose between easy and hard tasks.

Though experimentally rigorous, extended periods of experimental sleep deprivation are distinctly different from depression-related sleep disturbance (Tsuno et al., 2005). Curtis et al. (2018) found that individuals who reported sleeping less than 6 hr on average demonstrated greater temporal discounting behavior than those reporting 7 to 9 hr, however it is important to note that healthy sleep duration is not always synonymous with good sleep quality (Bin, 2016). Someone with uninterrupted sleep may report better daytime functioning than someone with identical duration interspersed with frequent and/or prolonged awakenings. Indeed, greater number and duration of midsleep awakenings was associated with choosing less difficult (yet more rewarding from a judgment/scoring perspective) skating moves among adolescent figure skaters, while sleep duration was not (Engle-Friedman et al., 2010). Similar to Drummond et al. (2005), Schmidt et al. (2010) demonstrated *increased* effort in the learning phase of an easy memory task with greater self-reported insomnia symptoms but did not assess choice of task difficulty. If sleep disturbance leads to global increases in effort as a compensatory mechanism, however, given the *choice* between easy and hard choices, poor sleep might make one more likely to select the easier option even if associated with smaller reward.

Unpacking these complex relationships is particularly important in the study of depression, a disorder marked by pervasive sleep impairments and reward dysfunction (Boland et al., 2020), which few studies have attempted. One longitudinal study found that blunted reward responsivity predicted greater depression symptoms at 12 months at average-to-high, but not low, levels of baseline self-reported sleep disturbance (Burani et al., 2021). A separate study found that that sleep disturbance was associated with depression only in the presence of lower activity in the ventral striatum, a reward-relevant brain region (Avinun et al., 2017). No study to date has examined these relationships with behavioral tasks of both effort and delay discounting in the context of depression symptoms, which could inform our understanding of how sleep disturbance may influence reward-related decision making in depression.

The current study explored these domains in connection to self-reports of typical sleep duration and quality, hypothesizing that shorter sleep duration and poorer sleep quality would be associated with both effort and temporal discounting. Next, we examined sleep disturbance and reward function in the context of self-reported reward sensitivity and depression symptoms, hypothesizing that poorer sleep would predict temporal and effort discounting when accounting for individual differences in trait reward responsivity and scores on a broad Anhedonia-Apprehension factor theorized to underlie depression.

Method

Participants

Participants were 325 young adults (M_{age} = 19.2, SD = .55) who completed baseline assessments as part of the Brain, Motivation and Personality Development (BrainMAPD) project, a longitudinal, multisite examination of psychological and neurological changes across late adolescence into early adulthood. Data were collected at the University of California Los Angeles (UCLA) and Northwestern University following IRB approved methods (Protocol STU00086626 "Symptom Dimensions of Threat and Reward Related Neurocircuitry"). Parent study methods are available in the online supplement materials.

Measures

Sleep Behaviors

Participants reported their typical sleep duration and quality over the preceding month: duration was reported in hours, and sleep quality was assessed by the sleep quality component of the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) which rates typical past-month sleep quality on a 4-point Likert scale (0 = very good, 1 = fairly good, 2 = fairly bad, and 3 = very bad sleep quality; reverse coded for current analyses). The sleep quality component demonstrated the highest correlation with the PSQI total score in the initial validation study (r = .76; Buysse et al., 1989) and has been used in numerous studies of sleep disturbance and depression (Chang et al., 2014; Raniti et al., 2017; Volkovich et al., 2016).

Effort Discounting

Participants completed the Effort Expenditure for Reward task (EEfRT; Treadway et al., 2009), which evaluates choice behavior in response to hard and easy physical tasks that range in value and likelihood of attainment. "Hard" trials required 100 computer button presses in 21 seconds with the nondominant pinky; "easy" trials required 30 button presses in 7 seconds with the dominant index finger. All easy trials were worth $1.00, while hard trials could range from $1.24 to $4.30. The variable reward probability (12%, 50% and 88% probability of payout upon successful completion) and value information was presented prior to decision-making. Participants were informed that they would receive a payout consisting of a random selection of 4 successfully completed trials.

Temporal Discounting

A delay discounting task (DDT) assessed willingness to delay receipt of hypothetical monetary reward. Participants chose between a smaller, immediate monetary reward or a future reward of $800, spread over six different delay conditions ranging from 2 weeks to 10 years, each with 6 individual trials. Participants made an initial selection, which was always the option of $400 now versus $800 at one of the future delay periods. If

the immediate reward was chosen, the subsequent trial reduced the amount of the immediate reward by half the distance between the current amount and $0 (Damme et al., 2019). The immediate option of the final trial of each delay condition represented the subjective value of $800 for that condition (i.e., consistent selection of the immediate reward in the 10-year condition would be the equivalent of the participant choosing to receive $6.25 immediately). Participants did not receive payment after DDT completion.

Trait Reward Responsivity

Reward sensitivity was measured with Carver and White (1994) BAS scale which reflects broad tendencies toward energetic goal pursuit, novelty/fun seeking, and reactivity upon reward receipt. The BAS total score was used, as a recent psychometric study of the BAS in the BrainMAPD sample (Kelley et al., 2019) demonstrated that a general factor accounts for approximately 68% of the variance in BAS total scores.

Mood Symptoms

To address depression symptoms we capitalized on the availability of participants' individual scores on factors of a Tri-level model of anxiety and depression (Kramer et al., 2019; Prenoveau et al., 2010) which identifies three factors that capture the structure of depression and anxiety at differing levels of breadth: a broad general distress factor, two intermediate factors capturing specific differences between fear- and misery-based disorders (e.g., a "Fears" factor and an "Anhedonia-Apprehension" factor), and narrower disorder-specific factors that may delineate among depression and anxiety diagnoses (see online supplemental materials for factor analytic methods of the parent study). Analyses utilized participants' scores on the Anhedonia-Apprehension factor, shown in the parent study sample to carry the highest (negative) loadings of self-report items related to positive affect (see Kramer et al., 2019 for details on factor items).

Data Analysis

Analyses were conducted using IBM SPSS Version 27. DDT data were fitted to a hyperbolic model that assumes the value of reward decreases at proportionally greater levels at short versus long delays (Odum, 2011). The model estimated individual k values, with larger k values corresponding to greater preference for smaller, more immediate reward. Data were normalized via natural log transformation. Per protocol, participants were excluded if they had R^2 values at the 25th percentile − 3× interquartile range, suggesting patterns of responding that were a poor fit to a hyperbolic curve (e.g., irregular responding demonstrating lack of task comprehension/attention, or for invariant selection of larger, delayed reward). Sleep duration and quality were modeled separately in linear regressions, first as singular effects, then adjusting for BAS and Anhedonia-Apprehension factor scores. All models adjusted for data collection site.

The EEfRT was analyzed with Generalized Estimating Equations that modeled the binary logistic outcome of high effort/high reward versus low effort/low reward choice with an exchangeable matrix. Models included reward magnitude (i.e., amount), probability (e.g., 12%, 50%, 88%), expected value (magnitude*probability) and trial number, representing the effects of fatigue across trials. All models

adjusted for gender due to published gender effects on this task (Treadway et al., 2009; 2012), and for site of data collection. Models were analyzed first with only sleep quality and sleep duration, then with the addition of Anhedonia-Apprehension and total BAS scores. Per parent study protocol, participants were excluded if they did not complete the requisite 50 trials across the 20-minute task, or if they had >3 SDs above the mean of incomplete trials.

Results

Descriptive and Clinical Characteristics

The full sample initially consisted of 334 participants who completed at least one behavioral task (326 completed the EEfRT, 325 completed the DDT). Participants were excluded for incomplete and/or invalid data on both tasks (n = 5) or missing sleep data (n = 4). The final sample consisted of 325 participants (n = 180 from Northwestern, and n = 145 from UCLA; see Table 1 for demographic and clinical characteristics). Excluded participants did not differ from the final sample on any clinical or demographic variable. Participants were excluded from certain task analyses due to invalid data (see legends for Tables 2 and 3).

The average sleep duration was approximately 7.1 hr. Approximately 32% reported less than 7 hr of sleep on average; 8.9% reported less than 6 hr. Average sleep quality was in the "good" range (M = 2.08, SD = .63). In the full sample, 5.4% met criteria for current unipolar depression.

Table 1
Demographic and Clinical Characteristics of Study Sample (N = 325)

	Mean (*SD*)	Range
Age	19.16 (0.55)	18–21
Sleep duration (hours)	7.08 (1.18)	3–12
Sleep quality (score)	2.08 (0.63)	0–3
Anhedonia factor score	−0.03 (0.92)	−2.79–2.25
BAS total	40.77 (5.61)	16–52
	N	%
Gender		
Male	111	34.2%
Female	214	65.8%
Sex		
Male	110	33.8%
Female	215	66.2%
Racial background		
White	172	52.9%
Asian	93	28.6%
Black	30	9.2%
Multiracial	22	6.8%
Native American	7	2.2%
Other	1	0.3%
DSM diagnoses		
Current anxiety disorder	54	18.3%
Current unipolar depression	16	5.4%
Current OCD	3	1.0%
Current alcohol use disorder	3	1.0%
Current substance use disorder	4	1.4%
Current ADHD	11	3.7%
Any history of psychopathology	146	49.5%

Note. BAS = Behavioral Activation Scale; OCD = Obsessive Compulsive Disorder; ADHD = Attention Deficit Hyperactivity Disorder. Diagnoses collected at baseline via the Structured Clinical Interview for the *DSM–5*.

Table 2
Sleep Quality and Duration Predicting Likelihood of Choosing the High Effort/High Reward Choice

Sleep quality (n = 282)					Sleep duration (n = 282)				
Model 1	B	SE	p	OR	Model 1	B	SE	p	OR
Site (Northwestern)	−.146	.161	.37	0.86	Site (Northwestern)	−.229	.164	.16	0.80
Gender	.601	.169	<.001	1.82	Gender	.701	.167	<.001	2.02
Trials	−.017	.001	<.001	0.98	Trials	−.017	.001	<.001	0.98
Amount	.595	.059	<.001	1.81	Amount	.586	.059	<.001	1.80
Probability	.005	.003	.07	1.01	Probability	.005	.003	.11	1.01
Expected value	.012	.001	<.001	1.01	Expected value	.012	.001	<.001	1.01
Sleep quality	.305	.136	.03	1.36	Sleep duration	−.088	.067	.19	0.92
Sleep Quality (n = 273)*					Sleep Duration (n = 273)*				
Model 2	B	SE	P	OR	Model 2	B	SE	p	OR
Site (Northwestern)	−.184	.166	.27	0.83	Site (Northwestern)	−.261	.169	.12	0.77
Gender	.640	.172	<.001	1.90	Gender	.729	.171	<.001	2.07
Trials	−.016	.001	<.001	0.98	Trials	−.016	.001	<.001	0.98
Amount	.595	.061	<.001	1.82	Amount	.587	.061	<.001	1.80
Probability	.005	.003	.07	1.01	Probability	.005	.003	.09	1.01
Expected value	.012	.001	<.001	1.01	Expected value	.012	.001	<.001	1.01
Anhedonia	−.037	.109	.73	0.96	Anhedonia	−.093	.109	.39	0.91
BAS total	−.006	.016	.69	0.99	BAS total	−.010	.016	.52	0.99
Sleep quality	.319	.142	.02	1.38	Sleep duration	−.059	.070	.40	0.94

Note. BAS = Behavioral Activation Scale. Thirty-five participants were excluded due to failing to complete the requisite 50 trials; of these 35, 10 were also performance outliers, meaning they had greater than 3SD above the mean of incomplete trials. One participant reported sleep duration of 12 hours, which is a statistical outlier. Sensitivity analyses showed no change in pattern or significance of results when this participant was included. Reported results include this participant.
* BAS scores were unavailable for 9 participants in model 2.

Effort Discounting

Consistent with hypotheses, better sleep quality was associated with greater odds of making the high effort/high reward choice when modeled alone (B = .31, p = .03, OR = 1.36) and with Anhedonia-Apprehension and BAS covariates (B = .32, p = .02, OR = 1.38; see Table 2). Shorter sleep duration, however, did not significantly predict high effort/high reward choice, either alone (B = −.09, p = .19, OR = .92) or with Anhedonia-Apprehension and BAS covariates (B = −.06, p = .40, OR = .94). Neither

Anhedonia-Apprehension nor BAS scores significantly predicted choice behavior on the EEfRT.

Temporal Discounting

Neither sleep quality nor duration significantly predicted temporal discounting either alone, or with anhedonia and reward covariates (all p's > .05). Neither Anhedonia-Apprehension nor BAS scores significantly predicted choice behavior on the DDT. Full models are presented in Table 3.

Table 3
Associations of Sleep Quality and Duration With Preference for Smaller but More Immediate Rewards

Sleep quality (n = 292)						Sleep duration (n = 292)					
	B	SE	p	F	R²		B	SE	p	F	R²
Model 1				.418	.003	Model 1				.791	.005
Site	−.033	.159	.838			Site	−.010	.159	.951		
Sleep quality	−.114	.127	.370			Sleep duration	−.085	.068	.214		
Sleep quality (n = 282)*						Sleep duration (n = 282)*					
	B	SE	p	F	R²		B	SE	p	F	R²
Model 2				.574	.008	Model 2				.501	.007
Site	.037	.132	.819			Site	.061	.161	.707		
Anhedonia	.020	.095	.832			Anhedonia	.040	.094	.673		
BAS total	.003	.015	.851			BAS total	.002	.015	.878		
Sleep quality	−.187	.132	.158			Sleep duration	−.090	.069	.192		

Note. BAS = Behavioral Activation Scale. 19 participants were excluded for low R² values, and 7 for invariant responding. One participant reported sleep duration of 12 hours, which is a statistical outlier. Sensitivity analyses showed no change in pattern or significance of results when this participant was included. Reported results include this participant.
* BAS scores were unavailable for 10 participants in model 2.

Discussion

Consistent with hypotheses, we found that poorer sleep quality was associated with lower odds of selecting the hard choice on the EEfRT. On the other hand, shorter sleep duration was not significantly associated with effort discounting in this sample, nor were poorer sleep quality or shorter duration significantly associated with temporal discounting. These inconsistent findings are not without precedent, however the inclusion of Anhedonia-Apprehension scores nevertheless helps identify appropriate next steps for unpacking these complex relationships in depression.

Findings suggest poor subjective sleep quality may influence effort-based decision making. Biological mechanisms underscoring this relationship are speculative, but may involve downregulation of the orexin system, which is implicated in insomnia, depression, and reward-seeking behavior, (Palagini et al., 2019), or mesolimbic dopaminergic pathways salient to depression and reward (Monti & Monti, 2007). It is also possible that poor sleep contributes to fatigue thus influencing effort allocation, a hypothesis supported by decades of research into the main tenants and fatigue-related extensions of motivational intensity theory (MIT; Richter et al., 2016). In scenarios where success is possible, tests of MIT demonstrate that effort rises with task difficulty, whereas perceptions that success is unattainable yield effort disengagement (Richter et al., 2008). When fatigued, individuals do not disengage unilaterally, but rather allocate more effort toward easier tasks and less effort toward harder tasks (Wright, 2014). Moreover, fatigue can alter visual perception of task difficulty (Proffitt, 2006), thus potentially influencing assessment of the effort required for successful completion. Whether sleep disturbance impacts effort through alterations of neural reward networks, fatigue mechanisms, or both warrants future study.

Poorer sleep quality was associated with lower likelihood of hard task choices even when accounting for scores on a factor comprised of strong negative loadings for items related to positive affect. Sleep disturbance may thus be independently associated with effort expenditure, underscoring the need for continued examination of sleep/reward relationships in the context of depression symptoms. Given that both sleep disturbance and anhedonia/low motivation are diagnostic criteria of depression, however, we cannot rule out that a third variable increases the severity of problems with both sleep and effort mobilization. Longitudinal reevaluation of these effects in clinical samples is necessary.

Shorter sleep duration was not significantly associated with lower effort, and neither sleep duration nor quality was significantly associated with temporal discounting. The modal sleep duration was approximately 7 hr and only 8.5% reported durations <6 hr, potentially impacting our ability to detect duration-associated effects. Replication in samples with significant sleep disturbance is needed. Additionally, the EEfRT offered monetary payout while the DDT did not, potentially driving the null temporal discounting findings. This is speculative, however, as several studies point to comparable temporal discounting behavior across real and hypothetical rewards (Johnson & Bickel, 2002; Lagorio & Madden, 2005; Madden et al., 2003, 2004).

The present study was the first to our knowledge to examine associations of typical self-reported sleep with behavioral assessments of effort and temporal discounting. Conducted on a large multisite sample, the current analysis adds to a growing literature examining these relationships in the context of depression symptoms. These strengths notwithstanding, there are notable limitations. Sleep was self-reported and in the healthy range (Hirshkowitz et al., 2015) limiting assessment of objective sleep fragmentation and the consequences of severe sleep disturbances on reward functioning. Analyses were cross-sectional, limiting our ability to draw conclusions about causal relationships. Finally, results may not generalize beyond young adulthood.

Research investigating the underlying causes of poor depression outcomes in the presence of disturbed sleep is vital to enhancing intervention. The present study contributes to the burgeoning literature examining the relationship of reward processing impairment to these outcomes. Future studies exploring the role of sleep disturbance or reward function in depression are encouraged to incorporate concurrent analyses of both processes to enhance our understanding of their complex interplay.

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