OBJECTIVE COGNITIVE FUNCTIONING IN SELF-REPORTED HABITUAL SHORT SLEEPERS NOT REPORTING DAYTIME DYSFUNCTION: EXAMINATION OF IMPULSIVITY VIA DELAY DISCOUNTING

by

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A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Psychology

The University of Utah

May 2018

The University of Utah Graduate School

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ABSTRACT

In this study, our objectives were to 1) Examine performance on an objective measure of reward-related cognitive impulsivity (delay discounting) among self-reported habitual short sleepers not reporting daytime dysfunction in comparison to those reporting dysfunction and conventional sleepers; 2) Inform the debate regarding what type and duration of short sleep meaningfully influences cognitive impulsivity; 3) Compare the predictive utility of sleep duration and perceived daytime dysfunction to other factors previously shown to influence cognitive impulsivity via delay discounting performance (age, income, education, and fluid intelligence). We analyzed data from 1,190 adults from the Human Connectome Project database. Participants were grouped on whether they reported habitual short (≤ 6 hours) vs. conventional (7 to 9 hours) sleep duration and whether they perceived daytime dysfunction using the Pittsburgh Sleep Quality Index. Results indicated that short sleepers not reporting dysfunction evidenced increased delay discounting compared to conventional sleepers, but were not significantly different from short sleepers reporting dysfunction. Regardless of perceived dysfunction, all short sleepers exhibited increased delay discounting compared to all conventional sleepers. Of the variables examined, self-reported sleep duration was the strongest predictor of delay discounting behavior between groups and across all 1,190 participants. We conclude that individuals who report habitual short sleep are likely to exhibit increased reward-related cognitive impulsivity regardless of whether they perceive sleep-related daytime impairment. Therefore, there is reason to suspect that these individuals exhibit more daytime dysfunction, in the form of reward-related cognitive impulsivity, than they may assume. Current findings suggest that assessment of sleep duration over the prior month has meaningful predictive utility for human reward-related impulsivity.

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ACKNOWLEDGEMENTS

Data were provided [in part] by the Human Connectome Project, WU-Minn Consortium (Principal Investigators: David Van Essen and Kamil Ugurbil; 1U54MH091657) funded by the 16 NIH Institutes and Centers that support the NIH Blueprint for Neuroscience Research; and by the McDonnell Center for Systems Neuroscience at Washington University. Preparation of this manuscript was supported by the University of Utah Neuroscience Initiative and support from the National Institute of Mental Health (K08 MH092697).

INTRODUCTION

Habitual Short Sleepers Who Do and Do Not Report Daytime Dysfunction

Humans who claim to thrive on little sleep raise important biological and psychological questions. These individuals do not report the low behavioral drive, negative affect, and cognitive impairment typically associated with experimental sleep deprivation (Lim & Dinges, 2010; Waters & Bucks, 2011) and endorsed by habitual short sleepers who report daytime dysfunction (e.g., individuals with insomnia; Fernandez-Mendoza et al., 2015; van de Laar, Verbeek, Pevernagie, Aldenkamp, & Overeem, 2010) or insufficient sleep syndrome (American Academy of Sleep Medicine, 2014). Rather, habitual short sleepers who do not report daytime dysfunction have been described as active, vigorous, restless, and over-meticulous (Jones & Oswald, 1968), efficient, energetic, ambitious, decisive, extroverted, and nonworriers (Hartmann, Baekeland, & Zwilling, 1972), subclinically hypomanic (Monk, Buysse, Welsh, Kennedy, & Rose, 2001), and behaviorally driven (Curtis, Brewer, & Jones, 2011; He et al., 2009).

The claim of normative, or even superior, daytime functioning despite habitual short sleep duration (≤ 6 hours/night; Grandner, Patel, Gehrman, Perlis, & Pack, 2010) raises a fundamental question: Do these individuals function as well as they feel that they do? For the past 50 years, empirical examination of this question has been limited by relatively small sample sizes (N=2; He et al., 2009; N=2; Jones & Oswald, 1968; N=12;

Monk et al., 2001; *N*=37; Curtis et al., 2011; *N*=46; Hartmann et al., 1972) and by primarily relying on clinical judgments (Jones & Oswald, 1968) or self-report questionnaires and interviews (Curtis et al., 2011; Hartmann et al., 1972; He et al., 2009; Monk et al., 2001) to characterize outcomes of interest. Self-reports of functionality in habitual short sleepers may be problematic, as evidence suggests that we tend to underestimate our objective levels of daytime impairment as sleep deprivation (Van Dongen, Maislin, Mullington, & Dinges, 2003) or sleep restriction (Cohen et al., 2010) progress over time to a habitual/chronic state. Therefore, objective measures of daytime functioning in larger samples of habitual short sleepers with and without perceived daytime dysfunction are needed.

Prior research suggests that habitual short sleepers who do not report daytime dysfunction may have difficulty maintaining daytime alertness in the absence of environmental stimulation at levels comparable to habitual short sleepers who report daytime dysfunction (Curtis, Williams, Jones, & Anderson, 2016). This tentative conclusion was reached on the basis of resting functional brain connectivity patterns using the Human Connectome Project database. In the present study, we continue this line of investigation by examining an objective measure of reward-related cognitive impulsivity – monetary delay discounting performance – in habitual short and conventional sleepers with and without perceived daytime dysfunction using the Human Connectome Project database.

Delay Discounting

Delay discounting refers to the decrease in subjective value of a desirable outcome as the time to obtain the outcome increases (Vanderveldt, Oliveira, & Green, 2016). In humans, delay discounting taps the construct of cognitive impulsivity (Reynolds & Schiffbauer, 2004), with greater discounting of delayed rewards (i.e., preferring smaller, immediate rewards over larger, delayed rewards) indicating greater impulsivity. Although delay discounting appears ubiquitous across species and situations, suggesting evolutionary adaptability (Vanderveldt et al., 2016), excessive delay discounting appears to be a nonadaptive hallmark across a range of mental health disorders: hypomania (Mason, O'Sullivan, Blackburn, Bentall, & El-Deredy, 2012), bipolar disorder and schizophrenia (Ahn et al., 2011), major depressive disorder (Pulcu et al., 2014), addictive behaviors (MacKillop et al., 2011), and attention-deficit/hyperactivity disorder (Jackson & Mackillop, 2016), in particular, hyperactive-impulsive symptoms (Beauchaine, Ben-David, & Sela, 2017).

The Effects of Experimental Sleep Deprivation on Delay Discounting

Although experimental total sleep deprivation has been shown to have a negative effect on cognition across multiple domains (particularly simple attention and vigilance tasks; Lim & Dinges, 2010), tests of the effects on delay discounting performance have produced conflicting results. Twenty-one hours of total sleep deprivation was sufficient to enhance discounting of delayed monetary rewards in 12 healthy, young adult undergraduate students (Reynolds & Schiffbauer, 2004). In contrast, delay discounting was unaffected by 24 hours of total sleep deprivation in 20 healthy adults (Acheson, Richards, & de Wit, 2007) and 30 healthy young adults (Libedinsky et al., 2013). Attempts to model more real-world/ecologically valid instances of partial sleep deprivation (i.e., 4 consecutive nights of 6 hours/night; "short sleep") in 37 conventional-sleeping healthy adults found evidence for short-sleep-induced diminished behavioral inhibition via a Go/No-Go task, but no difference in impulsive decision-making via a computerized delay discounting task (Demos et al., 2016). These findings are similar to evidence of lowered behavioral inhibition on an emotional Go/No-Go task following 36 hours of total sleep deprivation in 32 conventional-sleeping healthy adults (Anderson & Platten, 2011). Given the relatively small sample sizes of these studies, examining the effects of a different form of short sleep (self-reported habitual short sleep duration) on delay discounting performance in a larger sample of adult participants may help inform the debate regarding what type and duration of short sleep is associated with cognitive impulsivity via delay discounting. However, examination of whether self-reported habitual short sleep duration is related to delay discounting behavior has not been reported to our knowledge.

The Predictive Utility of Self-Reported Sleep Duration on Delay Discounting

Recently, the basic utility of asking about self-reported sleep duration without coincident objective data on sleep duration and quality has been questioned (Bianchi, Thomas, & Westover, 2017). To examine the predictive utility of self-reported sleep duration (and perceived daytime dysfunction) on delay discounting performance, we compared these measures to other factors previously shown to have a negative effect on delay discounting, including age (Steinberg et al., 2009), income (Ishii, 2015), education (Jaroni, Wright, Lerman, & Epstein, 2004), and objective measures of fluid intelligence (Osinski, Ostaszewski, & Karbowski, 2014; Shamosh et al., 2008) across all participants with complete delay discounting data in the Human Connectome Project database 1200 participant release.

Objective Validation of Daytime Dysfunction in Habitual Short Sleepers

Approximately 30% of employed U.S. adults in a large nationally representative sample reported sleeping 6 hours or less each day (Luckhaupt, Tak, & Calvert, 2010). A recent report using the Human Connectome Project database (Van Essen et al., 2013) supports this prevalence estimate (Curtis et al., 2016). Furthermore, these data also indicated that approximately 12% of participants reporting short sleep did not report daytime dysfunction, providing a tentative prevalence estimate (Curtis et al., 2016). Therefore, as approximately 10% of the adult U.S. population may claim to thrive on little sleep, objective validation of these claims appears warranted.

METHOD

We analyzed data from 1,190 participants with full delay discounting data from the Human Connectome Project (HCP) database (Van Essen et al., 2013) 1200 Participants Release. Participants were grouped based on whether they reported habitual short (≤ 6 hours) vs. conventional (7 to 9 hours) sleep duration over the past month, consistent with current National Sleep Foundation (NSF) sleep duration recommendations (Hirshkowitz et al., 2015). These data were derived from self-report answers to the Pittsburgh Sleep Quality Index (PSQI), a 24-item questionnaire comprising 7 component scores, including sleep duration (component 3) and daytime dysfunction (component 7) (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). Sleep duration was obtained from question #4 of the PSQI: "During the past month, how many hours of *actual sleep* did you get at night? (This may be different than the number of hours you spend in bed.)" (Buysse et al., 1989). Participants not reporting daytime dysfunction reported scores of zero on PSQI Component 7: Daytime Dysfunction. This corresponds to answering "Not during the past month" to PSQI question #8: "During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?" and answering "No problem at all" to PSQI question #9: "During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?" (Buysse et al., 1989). Participants reporting daytime dysfunction were conservatively characterized as having PSQI Component 7 scores greater than zero (Curtis et al., 2016).

This strategy resulted in the following groups: 1) all habitual short sleepers (All HSS; *n*=362); 2) all conventional sleepers (All CS; *n*=708); 3) habitual short sleepers not reporting daytime dysfunction (HSS-NRD; *n*=142); 4) habitual short sleepers reporting daytime dysfunction (HSS-RD; *n*=220); 5) conventional sleepers not reporting daytime dysfunction (CS-NRD; *n*=381); and 6) conventional sleepers reporting daytime dysfunction (CS-RD; *n*=327). This grouping strategy led to the exclusion of 118 participants reporting more than 6 and less than 7 hours of sleep at night over the prior month and to the exclusion of 12 participants reporting more than 9 hours of sleep at night over the prior month. To examine delay discounting in these individuals, multiple regression analysis with sleep duration as a continuous variable was performed across all 1,190 participants with full delay discounting data from the HCP database 1200 participants release.

Delay Discounting Task

The HCP assessed cognitive impulsivity (in the “self regulation/impulsivity” category of HCP measures) using a version of a monetary delay discounting task to identify indifference points at which an individual is equally likely to choose a smaller reward sooner (e.g., $100 today) versus a larger reward later (e.g., $200 in 1 month; Barch et al., 2013, p. 173). Reward amounts are adjusted on a trial-by-trial basis to efficiently determine indifference points (Barch et al., 2013; Estle, Green, Myerson, & Holt, 2006; Green, Myerson, Shah, Estle, & Holt, 2007). An area under the curve (AUC) summary measure is provided based on small monetary amount ($200) and high monetary amount ($40,000) conditions to yield a nontheoretical, valid, and reliable index of how quickly an individual discounts delayed rewards (Barch et al., 2013; Myerson, Green, & Warusawitharana, 2001). As described (Project, 2013), participants are presented with two choices on each trial: a smaller monetary amount today or a larger amount at a later time point. Participants choose amounts at each of six delays: 1 month, 6 months, 1 year, 3 years, 5 years, and 10 years based on two delayed amounts: $200 and $40,000. For each choice of delay and amount of delayed reward, participants make five choices. The indifference point for each condition is the value for a "sixth" choice, which is never presented to the participant but is based on an increment or decrement from the immediate value of their fifth choice. Participants make all five delay choices based on $200 before moving on to the next combination of delay choices based on $40,000. The order of delayed amounts based on $200 was fixed in order as follows: 1) today vs. 6 months; 2) today vs. 3 years; 3) today vs. 1 month; 4) today vs. 5 years; 5) today vs. 10 years; 6) today vs. 1 year. Once these choices based on $200 are made, participants are presented with the same order of delay decisions based on $40,000.

The first choice at each delay is between the delayed amount (i.e., $200 or $40,000) and an immediate amount equal to 50% of the delayed amount (i.e., $100 today vs. $200 in 1 month; $20,000 today vs. $40,000 in 1 month). If participants choose the immediate amount, the immediate amount is reduced by 50% on the next choice (e.g., $50 today vs. $200 in 1 month; $10,000 today vs. $40,000 in 1 month). If participants choose the delayed amount, the immediate amount is increased by 50% on the next choice (e.g., $150 today vs. $200 in 1 month; $30,000 today vs. $40,000 in 1 month). On the third trial, the immediate value will always increase or decrease by 50% of the prior change (i.e., by \$25 for the \$200 condition and \$5,000 for the \$40,000 condition), regardless of whether the participant chooses immediate or delayed amounts. Similarly, the fourth choice will always increase or decrease immediate values by \$12.50 (\$200 condition) or \$2,500 (\$40,000 condition) and the fifth choice will always increase or decrease immediate values by \$6.25 (\$200 condition) or \$1,250 (\$40,000 condition). The "sixth" choice value, which is never presented to participants but entered into the Human Connectome Project database, is always an increase or decrease of the immediate value by \$3.125 (\$200 condition) or \$625 (\$40,000 condition). This process was adopted to rapidly determine indifference points where immediate gains are close to subjective values for delayed gains for each participant.

Delay Discounting Data Analyses

Theoretically neutral area under the curve (AUC) estimates of delay discounting behavior (Myerson et al., 2001) were examined to quantify global differences in delay discounting between groups (Figure 1a-b). AUC was selected to overcome limitations of positive skew in parameter estimates for discounting functions (Myerson et al., 2001), to remain consistent with the Human Connectome Project database selecting AUC as their discounting summary measure (Barch et al., 2013, p. 173), and to enable direct comparison with prior experimental total sleep deprivation delay discounting studies (Libedinsky et al., 2013). Two-tailed independent-samples *t*-tests with false discovery rate correction for multiple comparisons (i.e., 5 AUC comparisons per monetary condition (\$200 or \$40,000); $p<0.01$ significance threshold) and Cohen's *d* effect size estimates were run to examine these global differences. Lower AUC values indicate *greater* discounting of delayed rewards (i.e., *increased* cognitive impulsivity) (Libedinsky et al., 2013). Area under the curve (AUC) measures were calculated as described (Project, 2013).

Predictors of Delay Discounting Behavior

Two-tailed independent-samples *t*-tests with false discovery rate correction were run to examine between-group differences in factors previously implicated in delay discounting behavior: age (Steinberg et al., 2009), income (Ishii, 2015), education (Jaroni et al., 2004), and fluid intelligence (Osinski et al., 2014; Shamosh et al., 2008). Sex was included as a covariate, although prior research indicates that sex does not meaningfully impact delay discounting behavior (Cross, Copping, & Campbell, 2011) (Tables 1a-c; 5 variables examined between groups, $p<0.05/5 = p<0.01$ significance threshold).

Given the known curvillinar relationship between self-reported sleep duration and a host of adverse outcomes (Bianchi et al., 2017; Bliwise & Young, 2007; Grandner et al., 2010), including risky decision-making (Hisler & Krizan, 2017), multiple regression analyses were performed to examine the relative contribution of the following factors in predicting delay discounting behavior between groups (Tables 2a-c) and across the entire HCP 1200 database (Table 3): age, sex, income, education, fluid intelligence, sleep duration, and daytime dysfunction. These 7 predictors were entered into each model, with a Bonferroni-corrected significance threshold of $p<0.007$ (i.e., $p<0.05/7 = p<0.007$).

Age. Age in years was obtained from participants and included in the HCP 1200 Restricted Access database (Van Essen et al., 2013).

Sex. Sex (male or female) was obtained from participants and included in the HCP 1200 Open Access database.

Income. Total annual household income was obtained from participant responses to the Semi-Structured Assessment for the Genetics of Alcoholism (SSAGA; Bucholz et al., 1994) and included in the HCP 1200 Restricted Access database. Total household income was scored and entered as follows: < \$10,000 = 1; \$10,000-19,999 = 2; \$20,000-29,999 = 3; \$30,000-39,999 = 4; \$40,000-49,999 = 5; \$50,000-74,999 = 6; \$75,000-99,999 = 7; ≥ \$100,000 = 8.

Education. Total years of completed education was obtained from participant responses to the SSAGA (Bucholz et al., 1994) and included in the HCP 1200 Restricted Access database. Years of education was scored and entered as follows: < 11 years = 11; 12 years = 12; 13 years = 13; 14 years = 14; 15 years = 15; 16 years = 16; ≥ 17 years = 17.

Fluid intelligence. Nonverbal fluid intelligence was measured using Form A of an abbreviated version of Raven’s Progressive Matrices (Bilker et al., 2012). Participants were presented with 2X2, 3X3, or 1X5 arrangements of square patterns, with one square missing per pattern (Elam, 2014). Participants selected one of five choices that best completed the missing square on the pattern. Form A has 24 items and 3 bonus items in order of increasing difficulty. The task is discontinued after five consecutive incorrect responses. The total number of correct responses was entered into the HCP Open Access database.

Table 1a

Differences in Age, Sex, Income, Education, and Fluid Intelligence Between All HSS and All CS

	All HSS			All CS				
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*	*t*	*p*
Age	362	28.86	3.61	708	28.71	3.73	0.63	0.53
Female	180			394			-1.84	0.07
Male	182			314				
Income	360	**4.73****	2.09	705	**5.16****	2.19	-3.08	.002
Education	362	**14.43*****	1.87	707	**15.09*****	1.73	-5.78	<.001
Fluid Intelligence CR	362	**15.73*****	4.97	707	**17.09*****	4.78	-4.35	<.001

Note. HSS = habitual short sleepers. CS = conventional sleepers. *n* = subsample size. *M* = mean. *SD* = standard deviation. CR = correct responses. Bolded comparisons were significant after p<.01 false discovery rate correction. *$p < .05$, **$p < .01$, ***$p < .001$

Table 1b

Differences in Age, Sex, Income, Education, and Fluid Intelligence Between HSS-NRD and CS-NRD

	HSS-NRD			CS-NRD				
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*	*t*	*p*
Age	142	28.70	3.75	381	28.78	3.75	-0.20	0.84
Female	64*			220*			-2.60	0.01
Male	78*			161*				
Income	142	4.92	2.09	380	5.31	2.13	-1.86	0.06
Education	142	**14.32*****	1.95	380	**15.05*****	1.73	-4.17	<.001
Fluid Intelligence CR	142	**14.88*****	4.87	380	**16.75*****	4.89	-3.89	<.001

Note. HSS = habitual short sleepers. CS = conventional sleepers. NRD = not reporting daytime dysfunction. *n* = subsample size. *M* = mean. *SD* = standard deviation. CR = correct responses. Bolded comparisons were significant after p<.01 false discovery rate correction. *$p < .05$, **$p < .01$, ***$p < .001$

Table 1c

Differences in Age, Sex, Income, Education, and Fluid Intelligence Between HSS-RD and CS-RD

	HSS-RD			CS-RD				
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*	*t*	*p*
Age	220	28.97	3.53	327	28.64	3.71	1.04	0.30
Female	116			174			-0.11	0.91
Male	104			153				
Income	218	4.60	2.09	325	4.98	2.24	-1.98	0.05
Education	220	**14.50*****	1.82	327	**15.13*****	1.74	-4.14	<.001
Fluid Intelligence CR	220	**16.28****	4.97	327	**17.49****	4.62	-2.91	.004

Note. HSS = habitual short sleepers. CS = conventional sleepers. RD = reporting daytime dysfunction. *n* = subsample size. *M* = mean. *SD* = standard deviation. CR = correct responses. Bolded comparisons were significant after p<.01 false discovery rate correction. *$p < .05$, **$p < .01$, ***$p < .001$

Table 2a

Predictors of Delay Discounting Behavior Between All HSS and All CS

	All HSS and All CS							
	Area Under the Curve ($200)				Area Under the Curve ($40,000)			
Variable	*B*	*SE B*	β	% Var	*B*	*SE B*	β	% Var
Constant	.256***	.009			.500***	.008		
Income	.003	.027	.027	0.06	.007	.004	.049	0.18
Education	**.014*****	.004	.120	**1.08**	**.024*****	.005	.151	**1.74**
Fluid Intelligence CR	**.005*****	.001	.118	**1.14**	**.007*****	.002	.115	**1.21**
Age	-.001	.002	-.025	0.05	-.001	.002	-.011	0.01
Sex	.000	.013	.001	0.00	.004	.017	.007	0.00
Sleep Duration	**.027*****	.005	.152	**2.13**	**.045*****	.008	.179	**3.00**
Daytime Dysfunction	.010	.006	.050	0.24	.010	.008	.036	0.12
R^2				.077				0.105
F				12.51***				17.607***

Note. HSS = habitual short sleepers. CS = conventional sleepers. Sex: male = 0, female = 1. CR = correct responses. *B* = unstandardized. % Var = percent of unique variance (squared semi partial correlations). Predictors are centered about their means. Predictors satisfying Bonferroni-corrected p<.007 are bolded. *$p < .05$, **$p < .01$, ***$p < .001$

Table 2b

Predictors of Delay Discounting Behavior Between HSS-NRD and CS-NRD

	HSS-NRD and CS-NRD							
	Area Under the Curve ($200)				Area Under the Curve ($40,000)			
Variable	*B*	*SE B*	β	% Var	*B*	*SE B*	β	% Var
Constant	.250***	.008			.492***	.018		
Income	-.001	.004	-.016	0.02	.001	.006	.009	0.01
Education	__.016**__	.005	.147	**1.66**	__.027***__	.007	.169	**2.19**
Fluid Intelligence CR	__.006**__	.002	.142	**1.63**	__.008**__	.003	.136	**1.49**
Age	.003	.002	.056	0.27	.003	.003	.039	0.13
Sex	-.007	.018	-.018	0.03	.013	.026	.022	0.04
Sleep Duration	__.025**__	.008	.137	**1.80**	__.039**__	.011	.145	**1.99**
Daytime Dysfunction	-	-	-	-	-	-	-	-
R^2				.088				0.103
F				8.249***				9.819***

Note. HSS = habitual short sleepers. CS = conventional sleepers. NRD = not reporting daytime dysfunction. Sex: male = 0, female = 1. CR = correct responses. *B* = unstandardized. % Var = percent of unique variance (squared semi partial correlations). Predictors are centered about their means. Predictors satisfying Bonferroni-corrected $p<.007$ are bolded. *$p < .05$, **$p < .01$, ***$p < .001$

Table 2c

Predictors of Delay Discounting Behavior Between HSS-RD and CS-RD

	HSS-RD and CS-RD							
	Area Under the Curve ($200)				Area Under the Curve ($40,000)			
Variable	*B*	*SE B*	β	% Var	*B*	*SE B*	β	% Var
Constant	.256***	.012			.496***	.021		
Income	.006	.005	.067	0.35	.012	.006	.090	0.62
Education	.011*	.006	.096	0.69	__.021**__	.008	.131	**1.30**
Fluid Intelligence CR	.004	.002	.089	0.66	.006*	.003	.097	0.77
Age	-.006*	.003	-.100	0.86	-.005	.003	-.061	0.32
Sex	.005	.018	.013	0.02	-.005	.024	-.008	0.01
Sleep Duration	__.029***__	.008	.165	**2.53**	__.050***__	.010	.209	**4.04**
Daytime Dysfunction	.011	.010	.049	0.22	.018	.013	.057	0.31
R^2				.077				.114
F				6.401***				9.871***

Note. HSS = habitual short sleepers. CS = conventional sleepers. RD = reporting daytime dysfunction. Sex: male = 0, female = 1. CR = correct responses. *B* = unstandardized. % Var = percent of unique variance (squared semi partial correlations). Predictors are centered about their means. Predictors satisfying Bonferroni-corrected $p<.007$ are bolded. *$p < .05$, **$p < .01$, ***$p < .001$

Table 3

Predictors of Delay Discounting Behavior Across the HCP 1200 Database

	Area Under the Curve ($200)				Area Under the Curve ($40,000)			
Variable	*B*	*SE B*	β	% Var	*B*	*SE B*	β	% Var
Constant	.263***	.009			.507***	.012		
Income	.003	.003	.036	0.10	.010*	.004	.073	0.41
Education	**.013*****	.004	.119	**1.08**	**.022*****	.005	.142	**1.54**
Fluid Intelligence CR	**.005*****	.001	.108	**0.98**	**.006*****	.002	.109	**0.98**
Age	-.001	.002	-.011	0.01	-.002	.002	-.025	0.05
Sex	-.009	.012	-.023	0.05	-.004	.016	-.008	0.00
Sleep Duration	**.027*****	.005	.151	**2.16**	**.040*****	.007	.161	**2.43**
Daytime Dysfunction	.009	.006	.043	0.18	.012	.008	.042	0.17
R^2				.073				.095
F				13.33***				17.77***

Note. N = 1,190. Sex: male = 0, female = 1. CR = correct responses. B = unstandardized. % Var = percent of unique variance (squared semi partial correlations). Predictors are centered about their means. Predictors satisfying Bonferroni-corrected p<.007 are bolded. *p < .05, **p < .01, ***p < .001.

RESULTS

Global area under the curve (AUC) measures of delay discounting behavior at \$200 and \$40,000 conditions are shown in Figure 1a-b. Following false discovery rate correction for multiple comparisons (i.e., five comparisons per monetary condition; $p<0.05/5 = p<0.01$ threshold), all habitual short sleepers exhibited significantly greater discounting of delayed monetary rewards (i.e., *decreased* AUC values; *increased* cognitive impulsivity) compared to all conventional sleepers at \$200 and \$40,000 conditions. Habitual short sleepers, regardless of perceived dysfunction, evidenced greater delay discounting compared to conventional sleepers.

To examine non-sleep-related factors previously shown to be associated with delay discounting performance that may contribute to current findings, we examined differences in participant age, sex, income, education, and fluid itelligence between groups (Tables 1a-c). These findings indicate that habitual short sleepers report fewer years of education (Cohen's d range=0.35-0.40) and may exhibit decreased fluid intelligence (Cohen's d range=0.28-0.38) compared to conventional sleepers, regardless of their perception of sleep-related daytime dysfunction.

To compare the predictive utility of self-reported habitual sleep duration and perceived daytime dysfunction to these non-sleep-related factors in predicting global delay discounting performance between groups, we ran a series of multiple regressions (Tables 2a-c). Seven predictors were entered into each model, resulting in a Bonferroni-corrected significance threshold of $p<0.007$. Using these criteria, income, age, sex, and perceived daytime dysfunction did not meaningfully predict delay discounting performance between groups. Years of education, fluid intelligence, and self-reported sleep duration were consistently the strongest predictors of delay discounting behavior between groups. Increased years of education, higher fluid intelligence, and longer self-reported sleep duration predicted greater area under the curve values (i.e., *less* global cognitive impulsivity/delay discounting). Notably, with one exception, self-reported sleep duration accounted for the largest amount of unique variance in delay discounting performance between all habitual short sleepers and all conventional sleepers, between short sleepers and conventional sleepers not reporting dysfunction, and between short sleepers and conventional sleepers reporting dysfunction.

Finally, to examine whether these variables similarly predicted delay discounting behavior across the entire Human Connectome Project database, we applied the above regression model to all 1,190 participants who completed the delay discounting task (Table 3). This entire sample includes 120 additional participants with self-reported sleep durations falling outside of our short (≤ 6 hours; n=362) and conventional (7-9 hours; n=708) sleep duration cutoffs in prior analyses. Similar to findings between groups, years of education, fluid intelligence, and self-reported habitual sleep duration remained the strongest predictors of delay discounting behavior. Notably, self-reported habitual sleep duration was the strongest predictor of delay discounting behavior within $200 and $40,000 conditions across all 1,190 participants.

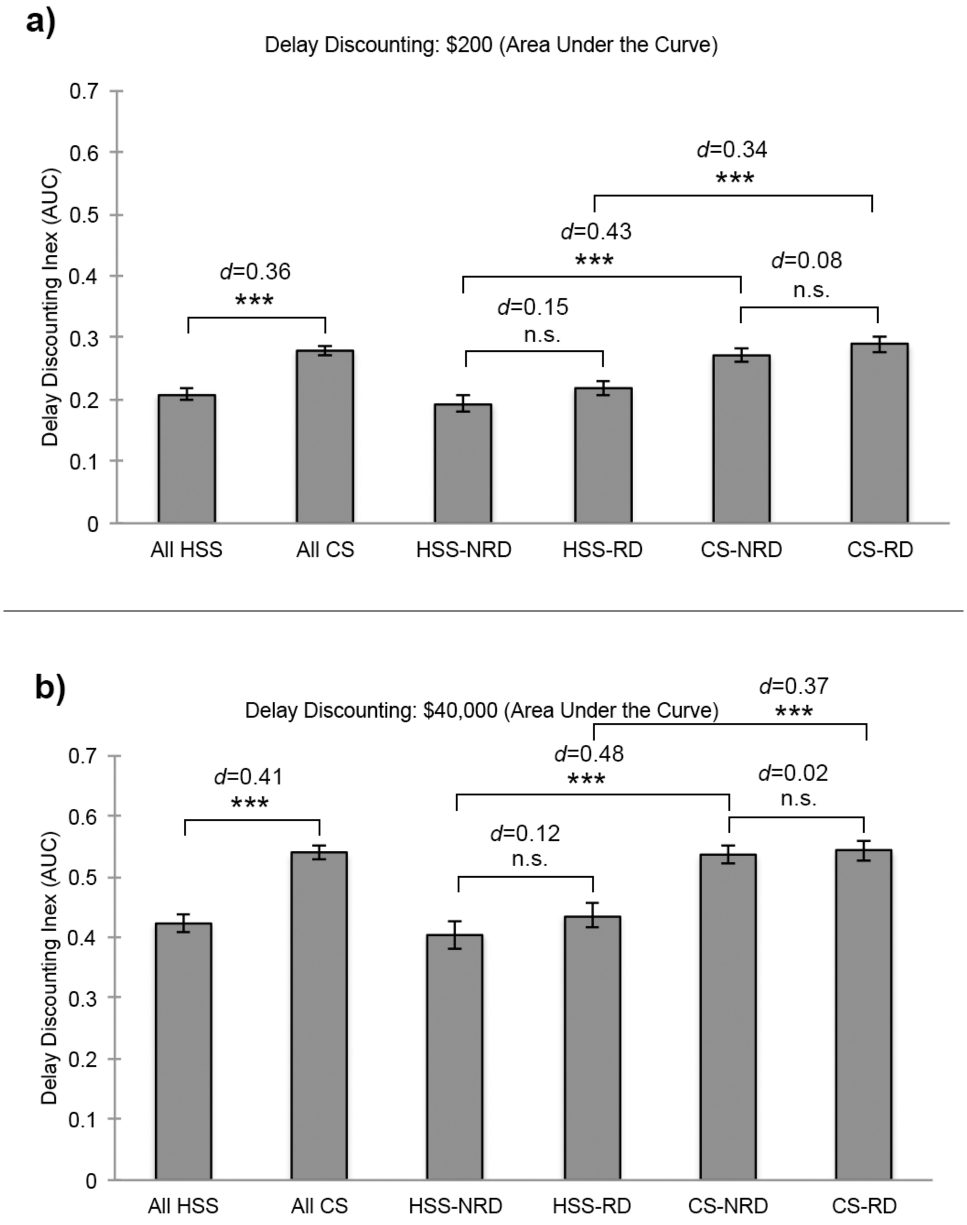

Figure 1. Global measures of delay discounting. *a.* Delay Discounting $200 Area Under the Curve. *b*. Delay Discounting $40,000 Area Under the Curve.

Note. Global differences in monetary delay discounting between self-reported short sleepers, conventional sleepers, and their subtypes. All HSS = all habitual short sleepers; All CS = all conventional sleepers; HSS-NRD = habitual short sleepers not reporting daytime dysfunction; HSS-RD = habitual short sleepers reporting daytime dysfunction; CS-NRD = conventional sleepers not reporting daytime dysfunction; CS-RD = conventional sleepers reporting daytime dysfunction; Error bars = standard error of the mean; n.s. = not significant. ** = p<.01; *** = p<.001. *d*=Cohen's *d*.

DISCUSSION

In this study, we examined an objective measure of reward-related cognitive impulsivity among self-reported habitual short sleepers. The findings suggest that self-reported short sleepers, regardless of their perceived level of dysfunction, exhibit significant and meaningfully greater reward-related impulsivity compared to self-reported conventional sleepers (Figure 1a-b; Tables 2a-c). In other words, there is reason to suspect that habitual short sleepers who do not report daytime dysfunction may exhibit more functional difficulties than they assume. The current study also found that reported short sleep duration was a more meaningful predictor of delay discounting behavior compared to age (Steinberg et al., 2009), income (Ishii, 2015), education (Jaroni et al., 2004), and fluid intelligence (Osinski et al., 2014; Shamosh et al., 2008).

To our knowledge, the present findings provide the first reported answer to the question of whether self-reported habitual short sleep duration is meaningfully associated with delay discounting performance. Our findings indicate that the answer to this question is yes--habitual short sleep duration is associated with greater reward-related cognitive impulsivity (Figure 1a-b). These findings are consistent with a related and conceptually overlapping literature on the effects of sleep loss on risk-taking behavior (Hisler & Krizan, 2017; Womack, Hook, Reyna, & Ramos, 2013) and may help to clarify prior conflicting results regarding what type and duration of short sleep meaningfully influences cognitive impulsivity via delay discounting performance. Twenty-one hours of total sleep deprivation was shown to significantly increase delayed discounting in one study (Reynolds & Schiffbauer, 2004), whereas 24 hours of total sleep deprivation failed to replicate these results in two subsequent investigations (Acheson et al., 2007; Libedinsky et al., 2013). Partial sleep deprivation to 6 hours/night over 4 consecutive nights did not meaningfully impact delay discounting behavior (Demos et al., 2016). Three differences between these prior studies and the present findings appear particularly useful for discussion: 1) monetary amounts and time delays used in delay discounting tasks; 2) sample sizes; and 3) the nature of short sleep duration. These differences are summarized in Table 4.

As depicted in Table 4, the range of monetary amounts ($0.30 to $40,000), time delays (60 seconds to 120 months), and sample sizes (12 to 1,070) vary dramatically between studies. Although Reynolds and colleagues reported increased delay discounting following 21 hours of sleep deprivation based on a standard amount of $0.30 and rapid decision delays of 0-60 seconds in 12 within-subjects participants (Reynolds & Schiffbauer, 2004), Acheson and colleagues failed to replicate these findings using the same discounting task, 24 hours of total sleep deprivation, and an increased sample size of 20 within-subjects participants (Acheson et al., 2007). Accordingly, it would appear that only the present findings using standard monetary amounts based on considerably larger rewards ($200 and $40,000) over much longer time intervals (1-120 months) may be sufficient to reveal the effects of short sleep duration on cognitive impulsivity. Future research examining whether acute total sleep deprivation and partial sleep restriction replicate the present findings based on these monetary amounts and time delays are needed.

A fundamental difference among the studies depicted in Table 4 is the nature of short sleep duration. It seems reasonable to expect different outcomes based on different short sleep scenarios, such as staying up all night (e.g., 21-24 hours of total sleep deprivation; Acheson et al., 2007; Libedinsky et al., 2013; Reynolds & Schiffbauer, 2004), obtaining less sleep than normal during a particularly stressful week (e.g., partial sleep restriction to 6 hours/night over 4 consecutive nights; Demos et al., 2016), or habitually sleeping 6 hours/night or less, on average, during the past month (present study). These different scenarios and possible outcomes highlight a known obstacle inherent in this type of research on the effects of short sleep duration (Grandner et al., 2010). Whereas the self-report nature of sleep duration and daytime dysfunction represent fundamental limitations in the present study, the *perception* of being a short sleeper and the *perception* of thriving or experiencing daytime dysfunction as a result of one's short sleep schedule are of primary interest in our ongoing line of research.

In addition to recommendations for bridging the gap between experimental and survey studies of short sleep duration (Grandner et al., 2010), the basic utility of asking about self-reported sleep duration without coincident objective data on sleep duration and quality has been questioned (Bianchi et al., 2017). The present findings that self-reported sleep duration was consistently the strongest predictor of delay discounting behavior compared to other predictive factors (age (Steinberg et al., 2009), income (Ishii, 2015), education (Jaroni et al., 2004), and similar objective measures of fluid intelligence as the present study (Osinski et al., 2014; Shamosh et al., 2008)), suggests that even without objective verification, subjective reports have meaningful predictive utility, at least in the domain of reward-related impulsivity. Future research comparing the predictive utility of reported and objective habitual sleep duration to similar cognitive outcomes would help to clarify and extend the present findings.

Limitations, Future Directions, and Conclusions

The current study demonstrated that self-reported short sleep duration, regardless of perceived daytime dysfunction, was associated with greater cognitive impulsivity. The use of a large, nationally representative sample and an objective cognitive assessment are notable strengths. Findings are qualified by several limitations, however. Categorization of habitual short sleepers was limited as daytime dysfunction was derived from two items on the PSQI that ask about subjective trouble staying awake and keeping up enthusiasm to gets things done during the past month. Direct questioning of subjective functioning in the same domain as objective testing (e.g., reward-related cognitive impulsivity in the present study) would represent a more rigorous test of subjective/objective discrepancies in future research. The study was also limited by the cross-sectional nature of data available in the Human Connectome Project database. Accordingly, we cannot explore questions of causation or mechanisms underlying observed differences in delay discounting performance between habitual short and conventional sleepers.

With these limitations in mind, viewing the present findings using the lens of the past 50 years of research on habitual short sleepers raises hypotheses to explore in future investigations. Are there individuals who objectively thrive on short sleep that are not represented in the current study? For example, there may be genetic short sleepers (He et al., 2009) who are quite rare, estimated by experts in sleep genetics to range from 1% even among short sleepers (Harmon, 2009) to 1% of the general population (Ramsey, 2015). To what extent do habitual short sleepers reporting or not reporting daytime dysfunction exhibit objective symptoms of (hypo)mania and/or attention-deficit/hyperactivity disorder (ADHD)? Subclinical hypomanic symptoms (Monk et al., 2001), increased energy and ambition (Hartmann et al., 1972), increased activity and restlessness (Jones & Oswald, 1968), and increased behavioral drive (Curtis et al., 2011; He et al., 2009) have been suggested to characterize habitual short sleepers who do not report daytime dysfunction and are consistent with symptoms of (hypo)mania and ADHD (in particular, hyperactive-impulsive symptoms). Accordingly, it may be notable that symptoms of hypomania (Mason et al., 2012), bipolar disorder (Ahn et al., 2011), and ADHD (Jackson & Mackillop, 2016) (in particular, hyperactive-impulsive symptoms; Beauchaine et al., 2017) have all been associated with increased delay discounting performance similar to habitual short sleepers in the present study. Our prior findings that habitual short sleepers may require environmental stimulation to maintain wakefulness (Curtis et al., 2016) is consistent with a vigilance regulation model of mania and ADHD, whereby an increased drive for seeking environmental stimulation may be a behavioral strategy to override underlying daytime sleepiness (Hegerl & Hensch, 2014). Therefore, future efforts to explore objectively symptoms of (hypo)mania and ADHD between habitual short sleepers reporting or not reporting daytime dysfunction (e.g., Conners' Continuous Performance Test [CPT] for symptoms of ADHD; Epstein et al., 2003; actigraphic assessment of motor activity for (hypo)mania; Krane-Gartiser, Henriksen, Morken, Vaaler, & Fasmer, 2014; Rock, Goodwin, Harmer, & Wulff, 2014) appear warranted.

Claims by some habitual short sleepers of adequate or even superior daytime functioning raises a fundamental question: Do these individuals function as well as they feel that they do? Our prior findings suggest that regardless of whether individuals who report habitual short sleep perceive sleep-related daytime dysfunction, they may be at increased risk of drowsiness in situations characterized by low environmental stimulation (Curtis et al., 2016). The present findings suggest that habitual short sleepers are also likely to exhibit increased reward-related cognitive impulsivity, regardless of whether they perceive sleep-related daytime impairment. As 30% of working U.S. adults report habitual short sleep duration (Curtis et al., 2016; Luckhaupt et al., 2010), and approximately 10% of U.S. adults report sleeping 6 hours or less each night without perceived daytime dysfunction (Curtis et al., 2016), continued objective validation of these claims appears warranted.

Table 4

Differential Effects of Short Sleep Duration on Delay Discounting Performance.

	Reynolds et al., 2004(Reynolds & Schiffbauer, 2004)	Acheson et al., 2007(Acheson et al., 2007)	Libedinsky et al., 2013(Libedinsky et al., 2013)	Demos et al., 2016(Demos et al., 2016)	Present Study
Increased delay discounting performance?	Yes	No	No	No	Yes
Nature of Short Sleep	Total sleep deprivation: 21 hours	Total sleep deprivation: 24 hours	Total sleep deprivation: 24 hours	Partial sleep deprivation: 6 hours/night for 4 nights	Self-reported habitual sleep durations ≤ 6 hours/night for prior month
Standard Monetary Amounts	$0.30	$0.30(Reynolds & Schiffbauer, 2004) $10(Richards, Zhang, Mitchell, & de Wit, 1999)	$20	$11 to $85(Kirby, Petry, & Bickel, 1999)	$200 or $40,000
Time Delays	0, 15, 30, or 60 seconds	0, 15, 30, or 60 seconds(Reynolds & Schiffbauer, 2004) 0, 2, 30, 180, or 365 days(Richards et al., 1999)	2, 3, 4, 5, or 6 months	7 to 186 days(Kirby et al., 1999)	1, 6, 12, 36, 60, or 120 months
Sample Size	*N*=12	*N*=20	*N*=30	*N*=37	*N*=1,070
Study Design	Within subjects	Within subjects	Within subjects	Within subjects	Between subjects

REFERENCES

Acheson, A., Richards, J. B., & de Wit, H. (2007). Effects of sleep deprivation on impulsive behaviors in men and women. *Physiology & Behavior*, *91*(5), 579–587. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0031938407001138

Ahn, W.-Y., Rass, O., Fridberg, D. J., Bishara, A. J., Forsyth, J. K., Breier, A., … O'Donnell, B. F. (2011). Temporal discounting of rewards in patients with bipolar disorder and schizophrenia. *Journal of Abnormal Psychology*, *120*(4), 911–921. Retrieved from http://doi.apa.org/getdoi.cfm?doi=10.1037/a0023333

American Academy of Sleep Medicine. (2014). *International classification of sleep disorders: Diagnostic and coding manual* (3rd ed). Darien, IL: American Academy of Sleep Medicine. Retrieved from https://doi.org/10.1111/febs.12678

Anderson, C., & Platten, C. R. (2011). Sleep deprivation lowers inhibition and enhances impulsivity to negative stimuli. *Behavioural Brain Research*, *217*(2), 463–466. Retrieved from https://doi.org/10.1016/j.bbr.2010.09.020

Barch, D. M., Burgess, G. C., Harms, M. P., Petersen, S. E., Schlaggar, B. L., Corbetta, M., … Consortium, W.-M. H. C. P. (2013). Function in the human connectome: task-fMRI and individual differences in behavior. *NeuroImage*, *80*, 169–189. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S1053811913005272

Beauchaine, T. P., Ben-David, I., & Sela, A. (2017). Attention-deficit/hyperactivity disorder, delay discounting, and risky financial behaviors: A preliminary analysis of self-report data. *PLoS ONE*, *12*(5), 1–11. Retrieved from https://doi.org/10.1371/journal.pone.0176933

Bianchi, M. T., Thomas, R. J., & Westover, M. B. (2017). An open request to epidemiologists: Please stop querying self-reported sleep duration. *Sleep Medicine*, *35*, 92–93. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S1389945717300576

Bilker, W. B., Hansen, J. A., Brensinger, C. M., Richard, J., Gur, R. E., & Gur, R. C. (2012). Development of abbreviated nine-item forms of the Raven's standard progressive matrices test. *Assessment*, *19*(3), 354–369. Retrieved from http://asm.sagepub.com/cgi/doi/10.1177/1073191112446655

Bliwise, D. L., & Young, T. B. (2007). The parable of parabola: What the U-shaped curve can and cannot tell us about sleep. *Sleep*, *30*(12), 1614–1615. Retrieved from https://doi.org/10.1093/sleep/30.12.1614

Bucholz, K. K., Cadoret, R., Cloninger, C. R., Dinwiddie, S. H., Hesselbrock, V. M., Nurnberger, J. I., … Schuckit, M. A. (1994). A new, semi-structured psychiatric interview for use in genetic linkage studies: A report on the reliability of the SSAGA. *Journal of Studies on Alcohol*, *55*(2), 149–158. Retrieved from http://www.jsad.com/doi/10.15288/jsa.1994.55.149

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. Retrieved from http://eutils.ncbi.nlm.nih.gov/entrez/eutils/elink.fcgi?dbfrom=pubmed&id=2748771&retmode=ref&cmd=prlinks

Cohen, D. A., Wang, W., Wyatt, J. K., Kronauer, R. E., Dijk, D.-J., Czeisler, C. A., & Klerman, E. B. (2010). Uncovering residual effects of chronic sleep loss on human performance. *Science Translational Medicine*, *2*(14), 14ra3-14ra3. Retrieved from http://stm.sciencemag.org/cgi/doi/10.1126/scitranslmed.3000458

Cross, C. P., Copping, L. T., & Campbell, A. (2011). Sex differences in impulsivity: A meta-analysis. *Psychological Bulletin*, *137*(1), 97–130. Retrieved from http://doi.apa.org/getdoi.cfm?doi=10.1037/a0021591

Curtis, B. J., Brewer, J. A., & Jones, C. R. (2011). Short sleeper syndrome (SSS): A possible sleep-duration, circadian, metabolic, affective, pain-tolerance, normal variant in humans. *Sleep*, *34*, A259–A260. Retrieved from papers3://publication/uuid/B91ABB5D-5FDC-4009-97E4-8258E1D47996

Curtis, B. J., Williams, P. G., Jones, C. R., & Anderson, J. S. (2016). Sleep duration and resting fMRI functional connectivity: Examination of short sleepers with and without perceived daytime dysfunction. *Brain and Behavior*, *6*(12), 1–13. Retrieved from https://doi.org/10.1002/brb3.576

Demos, K. E., Hart, C. N., Sweet, L. H., Mailloux, K. A., Trautvetter, J., Williams, S. E., … McCaffery, J. M. (2016). Partial sleep deprivation impacts impulsive action but not impulsive decision-making. *Physiology and Behavior*, *164*, 214–219. Retrieved from https://doi.org/10.1016/j.physbeh.2016.06.003

Elam, J. (2014, November 13). HCP Data Dictionary Public - 500 Subject Release. Retrieved from https://wiki.humanconnectome.org/display/PublicData/HCP+Data+Dictionary+Public-+500+Subject+Release. Retrieved from papers3://publication/uuid/9245AEB4-846C-4280-B495-B6D5243AF4CF

Epstein, J. N., Erkanli, A., Conners, C. K., Klaric, J., Costello, J. E., & Angold, A. (2003). Relations between Continuous Performance Test performance measures and ADHD behaviors. *Journal of Abnormal Child Psychology*, *31*(5), 543–554. Retrieved from http://eutils.ncbi.nlm.nih.gov/entrez/eutils/elink.fcgi?dbfrom=pubmed&id=14561061&retmode=ref&cmd=prlinks

Estle, S. J., Green, L., Myerson, J., & Holt, D. D. (2006). Differential effects of amount on temporal and probability discounting of gains and losses. *Memory & Cognition*, *34*(4), 914–928. Retrieved from http://eutils.ncbi.nlm.nih.gov/entrez/eutils/elink.fcgi?dbfrom=pubmed&id=17063921&retmode=ref&cmd=prlinks

Fernandez-Mendoza, J., Shea, S., Vgontzas, A. N., Calhoun, S. L., Liao, D., & Bixler, E. O. (2015). Insomnia and incident depression: role of objective sleep duration and natural history. *Journal of Sleep Research*, *24*(4), 390–398. Retrieved from http://doi.wiley.com/10.1111/jsr.12285

Grandner, M. A., Patel, N. P., Gehrman, P. R., Perlis, M. L., & Pack, A. I. (2010). Problems associated with short sleep: Bridging the gap between laboratory and epidemiological studies. *Sleep Medicine Reviews*, *14*(4), 239–247. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S1087079209000914

Green, L., Myerson, J., Shah, A. K., Estle, S. J., & Holt, D. D. (2007). Do adjusting-amount and adjusting-delay procedures produce equivalent estimates of subjective value in pigeons? *Journal of the Experimental Analysis of Behavior*, *87*(3), 337–347. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1868587

Harmon, K. (2009, August 13). Rare Genetic Mutation Lets Some People Function with Less Sleep. Retrieved January 10, 2017, from https://www.scientificamerican.com/article/genetic-mutation-sleep-less/

Hartmann, E., Baekeland, F., & Zwilling, G. R. (1972). Psychological differences between long and short sleepers. *Archives of General Psychiatry*, *26*(5), 463–468. Retrieved from http://eutils.ncbi.nlm.nih.gov/entrez/eutils/elink.fcgi?dbfrom=pubmed&id=5019885&retmode=ref&cmd=prlinks

He, Y., Jones, C. R., Fujiki, N., Xu, Y., Guo, B., Holder, J. L., … Fu, Y.-H. (2009). The transcriptional repressor DEC2 regulates sleep length in mammals. *Science (New York, N.Y.)*, *325*(5942), 866–870. Retrieved from http://www.sciencemag.org/cgi/doi/10.1126/science.1174443

Hegerl, U., & Hensch, T. (2014). The vigilance regulation model of affective disorders and ADHD. *Neuroscience and Biobehavioral Reviews*, *44*, 45–57. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0149763412001753

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., … Ware, J. C. (2015). National Sleep Foundation's updated sleep duration recommendations: Final report. *Sleep Health*, *1*(4), 233–243. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S2352721815001606

Hisler, G., & Krizan, Z. (2017). Sleepiness and behavioral risk-taking: Do sleepy people take more or less risk? *Behavioral Sleep Medicine*, *1*(1), 1–14. Retrieved from https://doi.org/10.1080/15402002.2017.1357122

Ishii, K. (2015). Subjective socioeconomic status and cigarette smoking interact to delay discounting. *SpringerPlus*, *4*(1), 560. Retrieved from http://www.springerplus.com/content/4/1/560

Jackson, J. N. S., & Mackillop, J. (2016). Attention-deficit/hyperactivity disorder and monetary delay discounting: A meta-analysis of case-control studies. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *1*(4), 316–325. Retrieved from https://doi.org/10.1016/j.bpsc.2016.01.007

Jaroni, J. L., Wright, S. M., Lerman, C., & Epstein, L. H. (2004). Relationship between education and delay discounting in smokers. *Addictive Behaviors*, *29*(6), 1171–1175. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0306460304000917

Jones, H. S., & Oswald, I. (1968). Two cases of healthy insomnia. *Electroencephalography and Clinical Neurophysiology*, *24*(4), 378–380. Retrieved from http://eutils.ncbi.nlm.nih.gov/entrez/eutils/elink.fcgi?dbfrom=pubmed&id=4174010&retmode=ref&cmd=prlinks

Krane-Gartiser, K., Henriksen, T. E. G., Morken, G., Vaaler, A., & Fasmer, O. B. (2014). Actigraphic assessment of motor activity in acutely admitted inpatients with bipolar disorder. *PLoS ONE*, *9*(2), 1-9. Retrieved from https://doi.org/10.1371/journal.pone.0089574

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. Retrieved from http://www.journalsleep.org/ViewAbstract.aspx?pid=28973

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. Retrieved from http://doi.apa.org/getdoi.cfm?doi=10.1037/a0018883

Luckhaupt, S. E., Tak, S., & Calvert, G. M. (2010). The prevalence of short sleep duration by industry and occupation in the National Health Interview Survey. *Sleep*, *33*(2), 149–159. Retrieved from http://eutils.ncbi.nlm.nih.gov/entrez/eutils/elink.fcgi?dbfrom=pubmed&id=20175398&retmode=ref&cmd=prlinks

MacKillop, J., Amlung, M. T., Few, L. R., Ray, L. A., Sweet, L. H., & Munafò, M. R. (2011). Delayed reward discounting and addictive behavior: A meta-analysis. *Psychopharmacology*, *216*(3), 305–321. Retrieved from https://doi.org/10.1007/s00213-011-2229-0

Mason, L., O'Sullivan, N., Blackburn, M., Bentall, R., & El-Deredy, W. (2012). I want it now! Neural correlates of hypersensitivity to immediate reward in hypomania. *Biological Psychiatry*, *71*(6), 530–537. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0006322311009668

Monk, T. H., Buysse, D. J., Welsh, D. K., Kennedy, K. S., & Rose, L. R. (2001). A sleep diary and questionnaire study of naturally short sleepers. *Journal of Sleep Research*, *10*(3), 173–179. Retrieved from http://eutils.ncbi.nlm.nih.gov/entrez/eutils/elink.fcgi?dbfrom=pubmed&id=11696070&retmode=ref&cmd=prlinks

Myerson, J., Green, L., & Warusawitharana, M. (2001). Area under the curve as a measure of discounting. *Journal of the Experimental Analysis of Behavior*, *76*(2), 235–243. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1284836/

Osinski, J. T., Ostaszewski, P., & Karbowski, A. (2014). Social discounting rate is negatively correlated with fluid intelligence. *Personality and Individual Differences*, *59*, 44–49. Retrieved from papers3://publication/uuid/8A823057-2E00-49E6-92A7-657347867423

Project, T. H. C. (2013, March 5). The Human Connectome Project: WU-Minn HCP Quarter 1 (Q1) Data Release: Reference Manual. Retrieved from http://www.humanconnectome.org/storage/app/media/documentation/q1/Q1_Release_Reference_Manual.pdf

Pulcu, E., Trotter, P. D., Thomas, E. J., McFarquhar, M., Juhasz, G., Sahakian, B. J., … Elliott, R. (2014). Temporal discounting in major depressive disorder. *Psychological Medicine*, *44*(9), 1825–1834. Retrieved from http://www.journals.cambridge.org/abstract_S0033291713002584

Ramsey, L. (2015). A tiny percentage of the population needs only 4 hours of sleep per night. Retrieved from http://www.businessinsider.com/people-who-sleep-short-hours-2015-11

Reynolds, B., & Schiffbauer, R. (2004). Measuring state changes in human delay discounting: An experiential discounting task. *Behavioural Processes*, *67*(3), 343–356. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0376635704001408

Rock, P., Goodwin, G., Harmer, C., & Wulff, K. (2014). Daily rest-activity patterns in the bipolar phenotype: A controlled actigraphy study. *Chronobiology International*, *31*(2), 290–296. Retrieved from https://doi.org/10.3109/07420528.2013.843542

Shamosh, N. A., Deyoung, C. G., Green, A. E., Reis, D. L., Johnson, M. R., Conway, A. R. A., … Gray, J. R. (2008). Individual differences in delay discounting: Relation to intelligence, working memory, and anterior prefrontal cortex. *Psychological Science*, *19*(9), 904–911. Retrieved from http://journals.sagepub.com/doi/10.1111/j.1467-9280.2008.02175.x

Steinberg, L., Graham, S., O'Brien, L., Woolard, J., Cauffman, E., & Banich, M. (2009). Age differences in future orientation and delay discounting. *Child Development*, *80*(1), 28–44. Retrieved from http://doi.wiley.com/10.1111/j.1467-8624.2008.01244.x

van de Laar, M., Verbeek, I., Pevernagie, D., Aldenkamp, A., & Overeem, S. (2010). The role of personality traits in insomnia. *Sleep Medicine Reviews*, *14*(1), 61–68. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S1087079209000732

Van Dongen, H. P. A., Maislin, G., Mullington, J. M., & Dinges, D. F. (2003). The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*, *26*(2), 117–126. Retrieved from http://eutils.ncbi.nlm.nih.gov/entrez/eutils/elink.fcgi?dbfrom=pubmed&id=12683469&retmode=ref&cmd=prlinks

Van Essen, D. C., Smith, S. M., Barch, D. M., Behrens, T. E. J., Yacoub, E., Ugurbil, K., & Consortium, W.-M. H. C. P. (2013). The WU-Minn Human Connectome Project: An overview. *NeuroImage*, *80*, 62–79. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S1053811913005351

Vanderveldt, A., Oliveira, L., & Green, L. (2016). Delay discounting: Pigeon, rat, human-does it matter? *Journal of Experimental Psychology. Animal Learning and Cognition*, *42*(2), 141–162. Retrieved from http://doi.apa.org/getdoi.cfm?doi=10.1037/xan0000097

Waters, F., & Bucks, R. S. (2011). Neuropsychological effects of sleep loss: Implication for neuropsychologists. *Journal of the International Neuropsychological Society : JINS*, *17*(4), 571–586. Retrieved from http://www.journals.cambridge.org/abstract_S1355617711000610

Womack, S. D., Hook, J. N., Reyna, S. H., & Ramos, M. (2013). Sleep loss and risk-taking behavior: A review of the literature. *Behavioral Sleep Medicine*. *11*(5), 343–359. Retrieved from https://doi.org/10.1080/15402002.2012.703628