Personal Sleep Debt And Daytime Sleepiness Mediate The Relationship Between Sleep And Mental Health Outcomes In Young Adults

By: **David L. Dickinson**, Alexander P. Wolkow, Shantha M.W. Rajaratnam, and Sean P.A. Drummond

Abstract

Background: Sleep duration and chronotype (i.e., morningness–eveningness) are associated with increased depression and anxiety risk, but differences in individual sleep need and lifestyle may mean these sleep parameters do not present the same risk across all individuals. This study explored the mediating role of sleep debt and daytime sleepiness in the relationship between sleep and mental health symptoms in young adults, a particularly vulnerable population. Methods: Young adult university students (n = 2,218) and young adults from the general population in the United States (n = 992) provided estimates of actual and optimal sleep duration, and completed validated measures of sleepiness, chronotype, and depression and anxiety risk. Mediation models examining sleepiness and sleep debt (i.e., difference between optimal and actual sleep) as parallel mediators were tested. Results: Sleepiness and sleep debt mediated the relationship between short sleep and depression and anxiety risk in the university sample, while sleepiness mediated these relationships in the general population sample. Sleepiness and sleep debt also mediated the impact of evening-type preferences on depression and anxiety risk in university students, but no mediation of this effect was found in young adults from the general population. Conclusions: This study reports potential mediating mechanisms related to the increased mental health risk conferred by short sleep and evening chronotype. These results have implications for how primary care physicians assess psychopathology risk, arguing for a focus on the assessment of daytime sleepiness and sleep debt in university populations, while for young adults in the general population, these factors may be less important.

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Personal sleep debt and daytime sleepiness mediate the relationship between sleep and mental health outcomes in young adults

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Results: Sleepiness and sleep debt mediated the relationship between short sleep and depression and anxiety risk in the university sample, while sleepiness mediated these relationships in the general population sample. Sleepiness and sleep debt also mediated the impact of evening-type preferences on depression and anxiety risk in university students, but no mediation of this effect was found in young adults from the general population.

Conclusions: This study reports potential mediating mechanisms related to the increased mental health risk conferred by short sleep and evening chronotype. These results have implications for how primary care physicians assess psychopathology risk, arguing for a focus on the assessment of daytime sleepiness and sleep debt in university populations, while for young adults in the general population, these factors may be less important.

KEYWORDS
anxiety, chronotype, depression, sleep debt, sleepiness, young adult

1 | INTRODUCTION

Sleep and circadian disturbances play a critical role in the development and maintenance of depressive (Harvey, 2011) and anxiety symptoms (Cox & Olatunji, 2016). Previous research in adults has consistently demonstrated a link between short sleep and increased risk of depression (Zhai, Zhang, & Zhang, 2015) and anxiety (Cox & Olatunji, 2016). Extended sleep has also been associated with depressive symptoms (Patel, Malhotra, Gottlieb, White, & Hu, 2006; Zhai et al., 2015) and the persistence of anxiety and depressive disorders (van Mill, Vogelzangs, van Someren, Hoogendijk, & Penninx, 2014). Sleep duration can be impacted by diurnal preference for sleep and activity (i.e., morningness–eveningness preference), which is known as one's chronotype. Evening chronotypes (i.e., evening-types) are reported to have reduced sleep on weekdays compared to weekends, show greater depressive (Hidalgo et al., 2009; Roepke & Duffy, 2010) and anxiety symptoms (Gaspar-Barba et al., 2009), and engage in greater negative health behaviors than morning-types (Patterson et al., 2018; Patterson, Malone, Lozano, Grandner, & Hanlon, 2016). Thus, sleep duration (van Mill et al., 2014; Zhai et al., 2015) and chronotype (Hidalgo et al., 2009; Roepke & Duffy, 2010) are both related to a risk of developing mental health symptoms. Nonetheless, individual differences in sleep need and the extent to which one's actual sleep–wake schedule matches one's chronotype mean that neither a given sleep duration

nor chronotype are experienced the same by every person. Thus, these sleep parameters may not confer the same risk across individuals.

Factors mediating the influence of sleep duration and/or chronotype on mental health have rarely been explored. Two potentially relevant factors are sleep debt and daytime sleepiness. Sleep debt results from insufficient sleep, and it builds with repeated nights of insufficient sleep. Sleep debt can be measured as the cumulative hours of sleep loss relative to one's daily sleep need (Van Dongen, Maislin, Mullington, & Dinges, 2003; Van Dongen, Rogers, & Dinges, 2003). Daytime sleepiness is a common consequence of poor sleep, regardless of the cause of sleep disruption. With individual differences in work, education, and social constraints impacting the ability to match lifestyle with endogenous sleep need and/or chronotype, sleep debt (Kitamura et al., 2016) and daytime sleepiness (Van Dongen, 2006) will develop at different rates and to different extents across individuals, even when those individuals are matched for sleep duration and/or chronotype. This is important, because greater sleep debt (Motomura et al., 2013) and daytime sleepiness (Hublin, Kaprio, Partinen, Heikkila, & Koskenvuo, 1996) in adults has been linked to worse mood symptoms.

The relationship between sleep and mental health may be particularly important for young adults. Changes in academic, social, and biological factors increase the risk for disrupted sleep and circadian rhythms. Consequently, a large proportion (70%) of university students sleep less than 8 hr (Lund, Reider, Whiting, & Prichard, 2010) and report increased evening preferences (Kabrita, Hajjar-Muca, & Duffy, 2014). Greater sleep debt has been shown to explain the relationship between eveningness and depressive symptoms in university students (Bakotic, Radosevic-Vidacek, & Koscec Bjelajac, 2016). Additionally, up to 50% of university students report daytime sleepiness (Lund et al., 2010; Oginska & Pokorski, 2006), which associates with increased risk of depression (Nyer et al., 2015; Regestein et al., 2010) and anxiety among students (Choueiry et al., 2016). Compared to other chronotypes, young adult evening-types at university also report greater daytime sleepiness (Fernández-Mendoza et al., 2010). But unlike sleep debt (Bakotic et al., 2016), sleepiness was not found to explain mental health symptoms among non-student young adult evening-types (Simor, Zavecz, Palosi, Torok, & Koteles, 2015). The mediating role of sleepiness in the relationship between sleep (e.g., eveningness, sleep duration) and mental health is therefore unclear and has not been specifically investigated among university students.

Despite a high prevalence of depression and anxiety among young adults (Center for Behavioral Health Statistics and Quality, 2016), and in particular students (Auerbach et al., 2016), no conclusive epidemiological studies investigating daytime sleepiness, and only limited research measuring sleep debt, have examined how these factors influence the relationship between sleep and depression or anxiety in these populations. To help fill this gap, this study explored the mediating role of sleep debt and daytime sleepiness in the relationship between sleep (sleep duration and chronotype) and depression and anxiety risk in two large samples of young adults: one of university students and one from the general population. We hypothesized greater sleep debt and daytime sleepiness would be mediators of depression and anxiety in university students, and that these findings would generalize to young adults in the general population, highlighting these factors as potential targets for the assessment and treatment of mental health problems in clinical settings.

2 | METHODS

2.1 | Participants

We recruited two distinct samples of participants to complete a short sleep and mental health survey: an Appalachian State University (ASU) sample located in the United States (North Carolina) and another more general sample using Amazon's Mechanical Turk (mTurk) workers, drawn from the entire United States. To recruit for the university sample, we sent an email invitation to randomly drawn subsamples of students each semester over the course of several semesters. A study advertisement was also posted on University websites. A total of 2,218 participants completed the online survey and were included in the ASU sample. The weighted average response rate (relative to each subsample) was 16.90%, which is slightly less than email survey response rates reported in student samples (Foust-Wright, Shobeiri, Curry, Quiroz, & Nihira, 2012; Paolo, Bonaminio, Gibson, Partridge, & Kallail, 2000). Advertisements were posted on the mTurk website (Buhrmester, Kwang, & Gosling, 2011; Paolacci, Chandler, & Ipeirotis, 2010) to recruit a total of 992 participants via self-selection. Samples of participants recruited via mTurk tend to be more demographically diverse than both American university samples and standard Internet samples. Initial assessments of mTurk data quality were promising (Buhrmester et al., 2011), with concerns over participant attentiveness not borne out in comparative studies (Paolacci et al., 2010), and growing research showing the validity of behavioral data from mTurk participants compared to traditional laboratory-generated experiment data (Arechar, Gächter, & Molleman, 2018). Table 1 shows descriptive statistics of each sample.

2.2 | Procedures

For the ASU sample, an online survey link was included in the recruitment email sent to potential participants and in the online advertisements (between 2013 and 2014). The final ASU sample was ~90% university student respondents (n = 1,988/2,218). The mTurk sample was collected in 2015 and, similar to the ASU sample, it required participants to be at least 18 years of age. ASU respondents were incentivized with a $95 gift code prize drawing, while mTurk participants each received 15 cents to complete the survey and were eligible for a $50 bonus payment drawing.

2.3 | Measures

The first page of the survey was an informed consent page requiring consent to continue. The survey included demographic questions, self-reported sleep habits and preferences, and validated instruments on sleep, circadian preferences, and mental health risk (see Supporting Information 1 for survey). To evaluate sleep duration (SleepDur), participants were asked: "Over the last 7 nights, what is the average amount of sleep you obtained each night?" Participants

TABLE 1 Descriptive statistics for ASU sample and mTurk sample

Variable	ASU Sample ($n = 2,218$)	mTurk Sample ($n = 992$)	*t*-test (unequal variance) T-stat
Age, mean (SD), years	22.25 (4.99)	32.87 (11.42)	28.11†
Female, *n* (%)	1,463 (66.0)	525 (52.9)	−6.94†
SleepDur, mean (SD), hours/night	6.67 (1.21)	6.75 (1.34)	1.55
Morning-type, *n* (%)	197 (8.9)	138 (13.9)	4.01†
Evening-type, *n* (%)	972 (43.8)	398 (40.1)	−1.97*
Self-reported sleep disorder, *n* (%)	66 (3.0)	49 (4.9)	2.53*
Minority status			
Racial minority, *n* (%)	142 (6.4)	212 (21.4)	−10.68†
Ethnic minority, *n* (%)	97 (4.4)	60 (6.1)	−1.92
Sleepiness, mean (SD), ESS score	8.05 (3.63)	7.93 (3.83)	−0.83
Personal sleep debt, mean (SD), hours/night	1.36 (1.31)	1.05 (1.33)	−6.33†
Psychopathology risk measures			
PHQ-2 (depression), mean (SD), score	1.32 (1.46)	1.68 (1.76)	5.67†
Positive for depression (PHQ-2 score ≥ 3), *n* (%)	418 (18.9)	267 (26.9)	
GAD-7 (anxiety), mean (SD), score	6.47 (4.55)	6.45 (5.23)	−0.10
Moderate to severe anxiety (GAD-7 score ≥ 10), *n* (%)	517 (23.3)	253 (25.5)	

ASU, Appalachian State University; mTurk, mechanical Turk sample; SleepDur, nightly sleep the previous week; racial minority, number listed reflect those identifying as Black American, Asian, American Indian/Alaska Native, Pacific Islander, mixed race or other; ethnic minority, number listed reflect those identifying as Hispanic or Latino; ESS, Epworth sleepiness scale; PHQ, patient health questionnaire; GAD, generalized anxiety disorder.
*$P < 0.05$, †$P < 0.01$, for the two-tailed test.

were also asked: "What do you feel is the optimal amount of sleep for you personally to get each night?" The difference between one's perceived optimal nightly sleep and SleepDur was used as a measure of the individual's personal sleep debt (Personal SD). Chronotype was derived from the reduced Horne and Östberg scale using standard cut-off scores (Adan & Almirall, 1991). Daytime sleepiness was measured using Epworth Sleepiness Scale (ESS) scores (Johns, 1991). An indicator variable (Sleep Disorder) was constructed from the question: "Do you have a diagnosed sleep disorder?" To assess psychopathology risk, we administered the two-item Patient Health Questionnaire (PHQ-2) (Kroenke, Spitzer, & Williams, 2003) for depression risk and the seven-item generalized anxiety disorder (GAD-7) (Spitzer, Kroenke, Williams, & Lowe, 2006) instrument to measure anxiety risk. These two assessment tools are commonly used by primary care physicians to screen for psychopathology risk (Duffy et al., 2008; Kroenke, Spitzer, Williams, & Lowe, 2010; Nease et al., 2008). Finally, an attention check question was included in the survey to alleviate concerns over attentiveness (Paolacci et al., 2010), and we restrict our analysis to participants who passed this question. All procedures were in accordance with the Helsinki declaration and approved by the ASU human research ethics committee.

2.4 | Statistical analysis

First, a direct effects model was estimated to test the association between sleep duration and chronotype on depression and anxiety. In subsequent models, the indirect effects of sleep duration and chronotype on depression and anxiety via sleep mediators were examined. All analyses were conducted first on the ASU sample to examine effects in a specific university/college sample, followed by mTurk sample analysis to assess generalizability to a more wide-ranging young adult population. In each analysis, we controlled for age, sex, self-reported sleep disorder, and minority status, which combined racial and ethnic minority.

The first analyses used least squares regressions to examine the direct effects on psychopathology risk of: (1) SleepDur (i.e., the linear term of sleep duration, centered); (2) the squared (i.e., quadratic term) value of SleepDur (SleepDurSq) because both short (Cox & Olatunji, 2016; Zhai et al., 2015) and long sleep (Patel et al., 2006; van Mill et al., 2014; Zhai et al., 2015) are related to psychopathology risk, and (3) indicator variables for morning-type and evening-type preferences (intermediate type = reference group). We then performed separate mediation analysis on PHQ-2 and GAD-7 scores, using only those sleep variables with significant direct effects from the first analysis. Because both Personal SD and daytime sleepiness (ESS scores) were hypothesized as mediators, our analysis examined these variables as potential parallel mediators.

The PROCESS macro for SPSS (IBM Corp, Version 24.0, Armonk, NY) (Hayes, 2013) was used to complete the mediation analyses. When sleep duration (i.e., SleepDur and SleepDurSq) and evening-type were not examined as independent variables, they were included as possible covariates in the mediation model. To test significance, bootstrapped confidence intervals (CI) were generated from repeated resampling (10,000 samples) of the observed data (Preacher & Hayes, 2008), and mediation was considered statistically significant when the 95% CI did not span zero. The bootstrapped CI method controls for the positive

skew associated with indirect effects (Preacher & Hayes, 2008) and is therefore more statistically powerful (Fritz & Mackinnon, 2007) when compared to other methods. The difference between indirect effects was also tested using the PROCESS macro. Pairwise contrasts were then applied to determine the size of the indirect effects through each mediator.

3 | RESULTS

Our ASU sample was consistent in age to the ASU population (average age 22 years) and to college students in the U.S. (U.S. Department of Education, 2016), whereas female students were slightly overrepresented in our ASU sample (66.0 vs. 54.9% university population and 54.8% nationwide) (U.S. Department of Education, 2016). Racial/ethnic minorities in our university sample (6.4% racial minority, 4.4% Hispanic) were similar to the wider ASU population (7.2% racial minority; 4.1% Hispanic), but underrepresented compared to national data (24.1% racial minority, 15.8% Hispanic) (U.S. Department of Education, 2016). In our mTurk sample, average age (33 years), racial minority (21.4%), and Hispanic minority (6.1%) were similar to a larger sample of U.S. mTurk subjects (31.6–36.0 years; racial minority 21.3%; Hispanic 5.6%) (Levay, Freese, & Druckman, 2016; Paolacci et al., 2010), and the proportion of females (52.9%) in our mTurk sample is also within the range of larger mTurk samples (46.1–64.9% female) (Levay et al., 2016; Paolacci et al., 2010). The proportion of Hispanic subjects (6.1%) in our sample was similar to a larger U.S. mTurk sample (5.6%) (Levay et al., 2016), though underrepresented compared to nationwide data (17.6%) (U.S. Census Bureau, 2015).

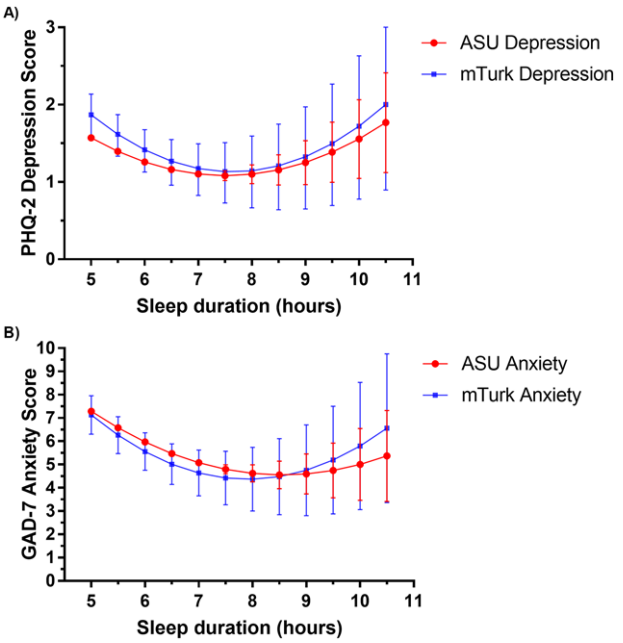

FIGURE 1 Forecast psychopathology score for depression (A) and anxiety (B) in ASU sample (red) and mTurk sample (blue). Note: Nightly sleep levels from 5 hr to 10.5 hr/night represent the range of sleep levels in our samples. We generate forecasts using Tables 2 and 3 estimated coefficients and constant terms. All significant dummy variables are set to zero (e.g., forecast of anxiety risk for ASU sample is based on a baseline male participant who is not an evening-type). For the mTurk forecasts, results are based on the mean age individual in the sample (32.87 years of age). Results are similar if using a dichotomous variable equal to one if an individual would have surpassed a typically primary care screening cut-off point as the dependent variable. In such modeling, results are similar if using ordinary least squares estimation (i.e., a linear probability model) or nonlinear probit estimation techniques.

4 | UNIVERSITY SAMPLE

4.1 | Depression

Among the ASU sample, 18.9% screened positive for a high risk of depression (Table 1), defined as a score of ≥3 on the PHQ-2 (Kroenke et al., 2003). Direct effects on psychopathology risk scores are shown in Table 2. Higher PHQ-2 scores (i.e., greater risk of depression diagnosis) were predicted by evening-type and both the linear and quadratic sleep duration terms. Figure 1 shows that the lowest predicted PHQ-2 scores from the estimated quadratic sleep duration effect is at 7.5 hr of nightly sleep.

Mediation results for the ASU sample are presented in Figure 2. Full details of the indirect effects and predictors of the mediator variables for the ASU sample are shown in Supporting Information 2, Tables S1 and S3, respectively. Indirect effects for depression risk show that daytime sleepiness and Personal SD mediated both short sleep duration and evening-type effects on PHQ-2 scores (Figure 2; Supporting Information Table S1). Pairwise comparisons revealed no significant differences in the size of the indirect effects (Supporting Information Table S1), indicating daytime sleepiness and Personal SD made similar contributions in mediating the effect of short sleep duration and evening chronotype on depression.

4.2 | Anxiety

In the ASU sample, 23.3% had a score of ≥10 on the GAD-7, indicating high risk of moderate to severe anxiety (Spitzer et al., 2006) (Table 1). Direct effects for anxiety risk in the ASU sample revealed that higher GAD-7 scores (i.e., greater risk of generalized anxiety disorder) were predicted by evening-type and both linear and quadratic sleep duration terms (Table 2). Figure 1 shows that the lowest anxiety risk in the ASU sample is predicted at 8.5 hr of nightly sleep (Figure 1). Regarding sleep duration, shorter sleep duration predicts higher anxiety scores more than does longer sleep duration.

Greater Personal SD mediated the quadratic effect of sleep duration on GAD-7 scores (Figure 2, Supporting Information Table S1). In addition, both Personal SD and daytime sleepiness mediated the linear effect of sleep duration on GAD-7 scores, with pairwise contrasts showing the effects through Personal SD were significantly stronger than those through daytime sleepiness (Figure 2; Supporting Information Table S1). Personal SD and daytime sleepiness were also found to mediate the effect of evening-type on anxiety and, in this case, the size of the two mediation effects was similar (Figure 2; Supporting Information Table S1).

TABLE 2 Direct effect regressions for ASU sample ($n = 2,188$)

	PHQ-2 Depression Scores				GAD-7 Anxiety Scores			
Variable	Coefficient (SE)	*P* Value	St. Beta	Partial n^2	Coefficient (SE)	*P* Value	St. Beta	Partial h^2
Constant	1.137 (0.154)	<.001	–	–	5.325 (0.468)	<.001	–	–
SleepDur	−0.130 (0.025)	<.001	−0.107	0.0117	−0.815 (0.077)	<.001	−0.217	0.0484
SleepDurSq	0.077 (0.016)	<.001	0.102	0.0106	0.216 (0.048)	<.001	0.092	0.0091
Evening-type	0.321 (0.065)	<.001	0.109	0.0109	0.678 (0.197)	.001	0.074	0.0053
Morning-type	−0.056 (0.113)	.62	−0.011	0.0001	−0.462 (0.341)	.176	−0.029	0.0008
Sleep disorder	0.428 (0.180)	.018	0.050	0.0025	1.539 (0.547)	.005	0.058	0.0036
Age	−0.006 (0.006)	.35	−0.020	0.0004	−0.013 (0.019)	.49	−0.014	0.0002
Female	0.074 (0.065)	.25	0.024	0.0006	1.242 (0.196)	<.001	0.129	0.0179
R-squared	0.0448				0.0894			

PHQ, patient health questionnaire; GAD, generalized anxiety disorder; SleepDur, nightly sleep the previous week.

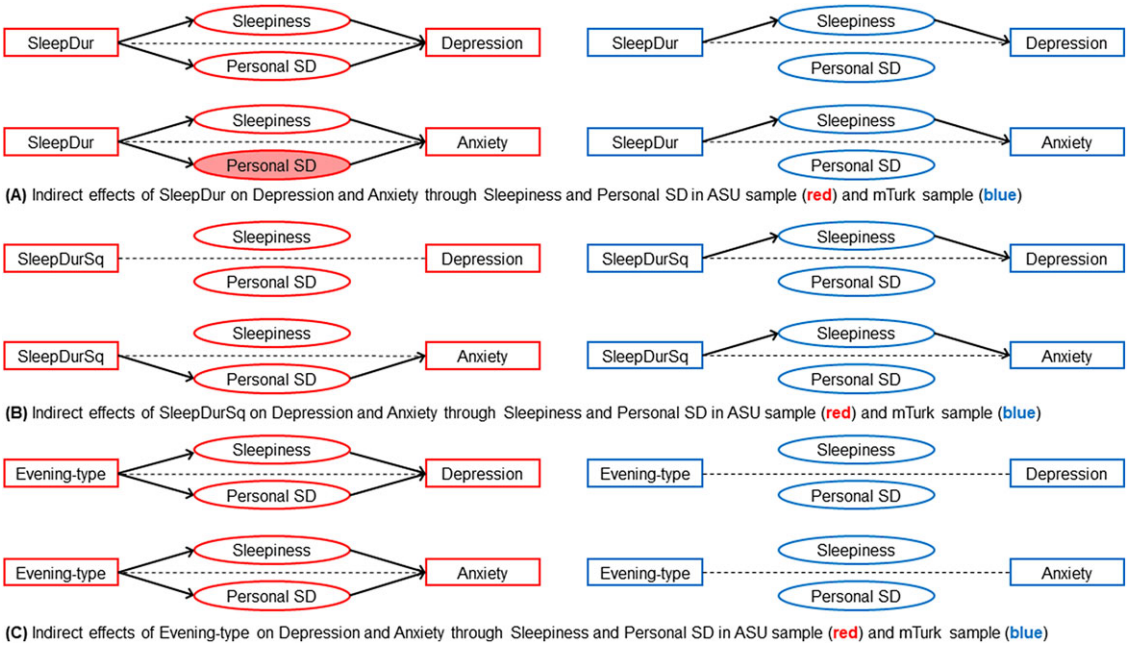

FIGURE 2 Simplified models showing indirect effects of SleepDur (A), SleepDurSq, (B) and evening-type (C) on depression and anxiety through the mediators of sleepiness and Personal SD for the ASU sample (red) and mTurk sample (blue). Solid lines indicate statistically significant indirect effect paths and dotted lines indicate statistically significant direct effect paths. Shaded ovals indicate significant differences in the size of indirect effects through mediators. For further indirect effect details, see Supporting Information 2, Table S1 and Table S2. Each model controlled for age, female, sleep disorder, and minority status, as well predictor variables (i.e., SleepDur, SleepDurSq, and evening-type) when not used in the models.

TABLE 3 Direct effect regressions for mTurk sample ($n = 922$)

	PHQ-2 Depression Scores				GAD-7 Anxiety Scores			
Variable	Coefficient (SE)	*P* Value	St. Beta	Partial n^2	Coefficient (SE)	*P* Value	St. Beta	Partial h^2
Constant	1.642 (0.182)	<.001	–	–	6.514 (0.538)	<.001	–	–
SleepDur	−0.189 (0.040)	<.001	−0.145	0.0224	−0.759 (0.118)	<.001	−0.195	0.0406
SleepDurSq	0.106 (0.017)	<.001	0.188	0.0365	0.327 (0.051)	<.001	0.195	0.0399
Evening-type	0.516 (0.117)	<.001	0.144	0.0195	0.819 (0.344)	.017	0.077	0.0057
Morning-type	−0.119 (0.164)	.47	−0.023	0.0005	−0.104 (0.485)	.83	−0.007	0.0000
Sleep disorder	0.628 (0.245)	.011	0.0773	0.0066	2.26 (0.723)	.002	0.094	0.0099
Age	−0.013 (0.005)	.006	−0.087	0.0077	−0.052 (0.014)	<.001	−0.113	0.0133
Female	0.125 (0.108)	.24	0.036	0.0014	1.184 (0.317)	<.001	0.113	0.0140
R-squared	0.1112				0.1197			

PHQ, patient health questionnaire; GAD, generalized anxiety disorder; SleepDur, nightly sleep the previous week.

5 | GENERAL POPULATION SAMPLE

5.1 | Depression

Over a quarter of mTurk participants (26.9%) screened positive for a high risk of depression (Table 1). Consistent with the ASU sample, direct effects in the mTurk sample indicated that depression risk was predicted by evening-type and both linear and quadratic sleep duration terms (Table 3). Similar to the ASU sample, predicted depression risk in the mTurk sample was lowest at 7.5 hr of nightly sleep (Figure 1).

Mediation model results for the mTurk sample are presented in Figure 2. In Supporting Information 2, full details of the indirect effects for the mTurk sample are shown in Supporting Information Table S2 and the predictors of the mediator variables are shown in Supporting Information Table S4. Daytime sleepiness mediated the linear and quadratic effects of sleep duration on PHQ-2 scores, with no other mediation effects found (Figure 2; Supporting Information Table S2).

5.2 | Anxiety

Twenty-five percent of the mTurk sample screened positive for anxiety (Table 1). The direct effects for anxiety in the mTurk sample were similar to the ASU sample, with higher GAD-7 scores predicted by evening-type and both linear and quadratic sleep duration terms (Table 3). The lowest anxiety risk in the mTurk sample is predicted at 8 hr of nightly sleep (Figure 1).

In the mTurk sample, daytime sleepiness was found to mediate both linear and quadratic sleep duration effects on GAD-7 scores, while Personal SD had no significant direct mediation effects on GAD-7 scores, and thus could not be estimated to mediate any of the other effects (Figure 2; Supporting Information Table S2).

6 | DISCUSSION

Short sleep duration and evening-type preference were directly associated with an increased psychopathology risk in young adults at university and in the more general population. A robust nonlinear effect of sleep duration further highlights the negative impact of both short and long sleep on depression and anxiety (Figure 1), which is consistent with prior studies examining young adults (Regestein et al., 2010) and adults more broadly (Cox & Olatunji, 2016; Patel et al., 2006; van Mill et al., 2014; Zhai et al., 2015). Specifically, we estimated that 7.5–8.5 hr of nightly sleep predicts the lowest risk of depression and anxiety in young adults (Figure 1), which is slightly more than a recent consensus statement suggested for overall health (Watson et al., 2015). In an important step forward for this area of research, we provide evidence that sleep-related daytime consequences of sleep duration and evening-type preferences mediate the link between sleep disturbances and psychopathology risk. However, these mediation pathways differ for young adults at university compared to the general population, which expands this research area to identify mediating mechanisms that differ by social context.

Daytime sleepiness and sleep debt in students and sleepiness among young adults in the more general population mediated the impact of short sleep on depression and anxiety. In the more general mTurk sample, daytime sleepiness also mediated the quadratic effect of sleep duration on both depression and anxiety. Because short sleep duration is more likely to produce daytime sleepiness and sleep debt (Wey, Garefelt, Fischer, Moreno, & Lowden, 2016), one might expect these daytime symptoms to more robustly mediate short sleep compared to long sleep duration. Consistent with this view, we estimated less mediation for the quadratic effect of sleep duration on depression and anxiety risk in the university sample, suggesting the mediation effect in students is stronger for short sleep duration compared to long sleep. Sleep debt and daytime sleepiness can decrease certain behaviors (e.g., physical activity, leisure activities) (McAllister et al., 2009; McClain, Lewin, Laposky, Kahle, & Berrigan, 2014) and alter neurochemical (e.g., serotonin and norepinephrine) (Chellappa, Schroder, & Cajochen, 2009; Walker & van der Helm, 2009) and neuroanatomical processes (e.g., amygdala activity) (Motomura et al., 2013, 2014) that accentuate negative emotions and increase psychopathology risk. Further research is needed to better understand the physiological and behavioral mechanisms underlying the interactions between sleep and mental health in different populations of young adults and other high-risk groups (e.g., emergency personnel).

Effects of evening-type preference on depression and anxiety were mediated by daytime sleepiness and personal sleep debt in university students, but not in the more general young adult sample. This lack of mediation effect in the mTurk sample persists even if restricting analysis to the subsample of mTurk respondents of similar age to the ASU sample (data not presented, see Supporting Information 2, Table S5 and Table S6). Social activity can also influence chronotype (Leonhard & Randler, 2009), and growing research suggests that the contribution of social relative to biological (circadian and sleep) factors on eveningness may vary in different social contexts (Natale, Adan, & Fabbri, 2009; Randler, Faßl, & Kalb, 2017). For instance, university students have an active social life that is organized more toward the evening than non-university adults of similar age (Bachman et al., 2002). Therefore, evening-type preferences in students may be influenced relatively more by social pressures, whereas biological factors may be relatively more important drivers of chronotype in non-university contexts. The direct effect of evening chronotype on depression and anxiety estimated in the more general sample supports this biological link between chronotype and mental health in individuals with potentially less social pressures, while daytime sleepiness and sleep debt mediated this relationship in the (likely) more socially driven student sample.

A limitation of the current study was the reliance on self-report measures. However, such measures allow practical large-scale screening in primary care clinics. The optimal sleep measure may be open to bias, because individuals with greater sleep debt may either underestimate optimal sleep (they feel fine on less sleep) or overestimate optimal sleep (due to perceived sleep loss and/or awareness of normal sleep standards) (Altman et al., 2012). Our data (see Supporting Information 3) suggest any bias in self-reported optimal sleep is likely

not that simple, though. Furthermore, the cross-sectional design limits its interpretation of causality from the mediation models. Future longitudinal research, potentially with objective sleep data, is needed to examine causality within the mediation findings.

7 | CONCLUSION

A large proportion of young adults at university and in the general population had a high risk of depression and anxiety in our study. Daytime sleepiness and sleep debt significantly mediated the impact of sleep duration and chronotype on depression and anxiety risk, but contrary to our hypothesis, the mediation pathways differed slightly between young adults at university compared to young adults in the general population. These mediators highlight that sleep disturbances (i.e., short and long sleep and chronotype) do not affect mental health risk the same in all young adults. Given growing evidence that sleep complaints are distinct from, and may predict mental health outcomes (Cox & Olatunji, 2016; Harvey, 2011), this important finding suggests that the assessment of mental health risk, and interventions aimed to reduce that risk, should focus on measures of the daytime consequences of poor sleep, in addition to sleep itself. This may be especially important in assessing those who are particularly sensitive to psychopathology risks, such as young adults in university populations. These findings may lead to additional tools for primary care physicians to identify mental health risk in patients, which should ultimately result in a more efficient use of resources by promoting early interventions.

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CONFLICT OF INTEREST

D.L.D. and A.P.W. report no conflicts of interest. S.P.A.D. reports that he is the current President of the Sleep Research Society. S.M.W.R. reports that he has served as a consultant through his institution to Philips Respironics, EdanSafe, National Transport Commission, Vanda Pharmaceuticals, Rail, Bus and Train Union, Tontine Group, Australian Workers' Union, Transport Accident Commission, Meda Consumer Healthcare, New South Wales Department of Education and Communities, and has through his institution received grants from Philips Respironics and Vanda Pharmaceuticals and reimbursements for conference travel expenses from Vanda Pharmaceuticals. He currently serves as a consult to, and is a Program Leader for, the Cooperative Research Centre for Alertness, Safety and Productivity. His institution has received equipment donations or other support from Compumedics, Philips Lighting, Optalert and Tyco Healthcare. He is a former President of the Australasian Sleep Association and is a Director of the Sleep Health Foundation. He has also served as an expert witness and/or consultant to shift work organizations.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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