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# Prospective Relationships Between Sleep Problems and Substance Use, Internalizing and Externalizing Problems

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**Abstract** While research has shown that sleep problems and substance use are reciprocally associated in adults, much less is known about this association in early adolescence. The main aim of the current longitudinal study was to explore bidirectional relationships between sleep problems, substance use, internalizing and externalizing problems in young adolescents. A prospective design was used incorporating two waves (approximately 1 year interval). A total of 555 young adolescents (290 females,  $M$  age = 13.96) participated in this study. All participants completed self-report measures in classrooms during regular school hours (questionnaires about sleep quality and sleep hygiene were used to measure sleep problems). The results indicated that sleep problems predicted changes in substance use, internalizing and externalizing problems over time, but problem behaviours did not predict changes in sleep problems, adjusted for gender, age and puberty. One exception was that alcohol use negatively predicted changes in sleep problems. This study suggests that sleep

problems are important precursors of substance use, internalizing and externalizing problems in adolescence.

**Keywords** Sleep problems · Substance use · Internalizing problems · Externalizing problems · Early adolescence

## Introduction

Sleep problems are highly prevalent in adolescents worldwide (Gradisar et al. 2011). Various forms of sleep problems have been concurrently linked to other problem behaviours in adolescence and adulthood, particularly substance use (Brower 2001; Johnson and Breslau 2001; Vignau et al. 1997), internalizing (Gregory et al. 2005) and externalizing problems (Mayes et al. 2009). The relationship between sleep problems and substance use in adults appears to have a reciprocal nature: the pharmacological effects of substances directly affect sleep during the subsequent night, and sleep problems predict substance use (problems) over time (Brower 2001). Studies in adolescents are less abundant, but have shown that sleep problems are related to substance use. There is evidence suggesting that sleep problems in childhood are a precursor to adolescent alcohol use (Wong et al. 2004, 2009, 2010). In addition, it has been shown that sleep problems predict internalizing and externalizing problems in adolescence (Gregory and O' Connor 2002; Gregory et al. 2005, 2009; Steele et al. 1995). Even though the evidence for a relationship between sleep problems and problem behaviours in adolescents is increasing, there is still a need for more studies examining this relationship prospectively.

Adolescents suffer from a wide range of sleep problems: 11–47 % of adolescents stated to have difficulties initiating and maintaining sleep (Liu and Zhou 2002; Russo et al.

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2007). In addition, 20–25 % of adolescents report excessive daytime sleepiness (Pagel et al. 2007; Roehrs et al. 2005). Sleep disorders, such as circadian rhythm disorders and insomnia, often have their onset during early adolescence (e.g., Johnson et al. 2006; Thorpy et al. 1988). Delayed sleep phase syndrome (DSPS) is a circadian rhythm disorder characterized by abnormal bed- and rise times; these are scheduled at a much later time compared to healthy individuals. The prevalence rate of this disorder lies between 7 and 16 % in adolescence (e.g., Pelayo et al. 1998). Insomnia is thought to occur in 4–10.7 % of the adolescent population, while 25 % of adolescents experience symptoms of insomnia, such as difficulties falling and staying asleep and nonrestorative sleep (Johnson et al. 2006; Ohayon et al. 2000). The main focus of the current study is on problems with the process of going to bed and falling asleep.

Scholars have suggested that the increase in sleep problems is related to changes in sleep patterns during the transition from childhood to adolescence. The most prominent changes that take place in the transition to adolescence are (a) a delayed phase preference, meaning that adolescents gradually prefer later bedtimes and rise times, (b) a decrease in the total time that is spent asleep at night and (c) a discrepancy in the timing and duration of sleep on weekdays and weekends. Factors that influence these changes in both timing and duration of sleep are suggested to be both intrinsic, related to puberty (Carskadon et al. 1993), and extrinsic, related to school, parents, technology and the use of substances before bedtime (e.g., Cain and Gradisar 2010). Although adolescents might experience a wide range of sleep problems, most commonly reported difficulties are related to problems going to bed and falling asleep. In the current study, a multi-item questionnaire was used to explore problems falling asleep in adolescents. Compared to single-item questionnaire that have been employed in previous research, this questionnaire may provide a more thorough view on those specific sleep problems.

The main aim of the current study is to investigate bidirectional links between sleep problems and other problem behaviours in early adolescence. Adolescence is a developmental period characterized by biological, cognitive, and social transitions. While the maturational changes of adolescence contribute to positive changes in several domains, this developmental period is also associated with an increase in emotional and behavioural difficulties, at least in susceptible youth. More generally, unhealthy trajectories that begin in this developmental period may increase the long-term course with respect to developing future psychopathology, such as depression, anxiety disorders and addiction (e.g., Grant and Dawson 1997). Insights into the mechanisms that are responsible for

negative spirals in development that could lead to problem behaviours are of great importance. It has been suggested that an early onset of substance use increases the odds of developing an addictive disorder (Agrawal et al. 2009; Hingson et al. 2006). In addition, having an anxiety or depressive disorder in adolescence increases the odds of having such a disorder in adulthood (Pine et al. 1998). Therefore, it is crucial to examine which factors are related to problem behaviours in early adolescence. Sleep could be one important factor that predicts problem behaviours in early adolescence.

Most research on the relationship between sleep and substance use in adolescents has been cross-sectional. Over all, the definition of sleep differs widely, although most studies have explored sleep *problems*. Holmen et al. (2000) have investigated the relationship between smoking and sleep problems. They found that daily smoking was related to sleep difficulties in adolescents. They assessed sleep difficulties in a single item questionnaire about problems going to sleep or waking to early. Tynjälä et al. (1997) examined the interrelationship between substance use, sleep habits and perceived tiredness and demonstrated that these factors are interrelated in adolescents. A previous study from our own lab, including data from the first wave of this study, showed that sleep problems, such as problems going to bed and falling asleep, were associated with alcohol use in adolescents (Pieters et al. 2010). Our study, as well as other studies, also examined sleep *preference*, using questionnaires to explore the extent of morningness/eveningness, also referred to as chronotype, and found that more evening-type tendencies were related to alcohol use, cigarette and marijuana smoking (Negri et al. 2011; Pieters et al. 2010).

However, prospective research is key when examining the temporal order of this relationship. To date, not many studies have examined the relationship between sleep and substance use over time. Wong et al. (2004, 2009, 2010) found that sleep problems in childhood predicted substance use in adolescence. Roberts et al. (2009) showed that insomnia in adolescence predicted substance use over time, although others have failed to find a relationship between insomnia and substance over time although effects were present concurrently (e.g., Roane and Taylor 2008). Pasch et al. (2012) have investigated whether sleep duration and patterns, which are detectable in all adolescents and not just a few with sleep problems, were related to substance use and indicated that baseline levels of sleep and substance use variables were consistently linked, but the pattern was less clear prospectively.

In addition, previous research has shown that sleep problems are associated with internalizing and externalizing problems (e.g., Gregory and O' Connor 2002; Gregory et al. 2005, 2009; Steele et al. 1995). For instance, Gregory

and O' Connor (2002) showed that sleep problems at age 4 predicted behavioural and emotional problems in mid-adolescence. Moreover, the association between sleep problems and depression/anxiety increased with age. Gregory et al. (2005) further showed that sleep problems in childhood predicted anxiety disorders, but not depressive disorders, in adulthood. In addition, it was shown by Gregory et al. (2009) that sleep problems at age 8 predicted depression at age 10. Evidence for the converse was not found. Related to externalizing problems, it has for instance been shown that sleep problems are highly prevalent in adolescents with Attention Deficit Hyperactivity Disorder (ADHD; Gau and Chiang 2009).

Puberty is an important factor related to sleep preference, sleep problems and other problem behaviours. That is, previous research indicated that sleep problems were more common in youth who were more developed compared to those who were not as developed yet (Pieters et al. 2010). In a similar vein, pubertal development has been associated with numerous other problem behaviours, in a way that more developed youth were more likely to have emotional or behavioural difficulties. For substance use, it was found that pubertal stage was associated with higher rates of substance use in adolescents independent of age and school grade level (Patton et al. 2004). Data from our lab also demonstrated that puberty, sleep and problem behaviours were interrelated, such that puberty directly affected problem behaviours, but also indirectly through sleep (Pieters et al. 2010). Moreover, it has been shown that puberty is related to increases in sensation seeking (review: Forbes and Dahl 2010). Likewise, pubertal status has been related to depressive symptoms, albeit dependent on the level of peer popularity (Teunissen et al. 2011). To conclude, puberty seems to be an important factor influencing both sleep and symptoms of psychopathology in adolescence.

It has been proposed that sleep problems and other problems behaviours may be related based on the observation that sleep deprivation affects brain areas that are associated with cognitive control and emotion regulation, processes that are also affected in emotional and behavioural problems. Studies have shown that sleep affects so-called executive functions (EFs), which are higher order cognitive processes that serve goal-directed behaviour, such as response inhibition, working memory (or updating) and task switching (Miyake et al. 2000; Hofmann et al. 2012). It has been shown that sleepiness is related to a poorer performance on EFs tasks (Anderson et al. 2009; Hahn et al. 2012). In addition, shorter sleep duration was also related to worse executive functioning in children (Astill et al. 2012). Neuroimaging studies have shown that sleep deprivation negatively affects areas related to executive functioning, such as the prefrontal cortex (Horne

1988). EFs have been related to other problem behaviours as well, including risk taking and substance (mis)use (Fillmore and Vogel-Sprott 2006). In addition, EFs have been implicated in several processes related to more internalizing and externalizing problems. That is, studies have shown that EFs are compromised in Attention Deficit Hyperactivity Disorder (Barkley 1997). Furthermore, EFs have been shown to be related to anxiety and depressive disorders (e.g., Stordal et al. 2004).

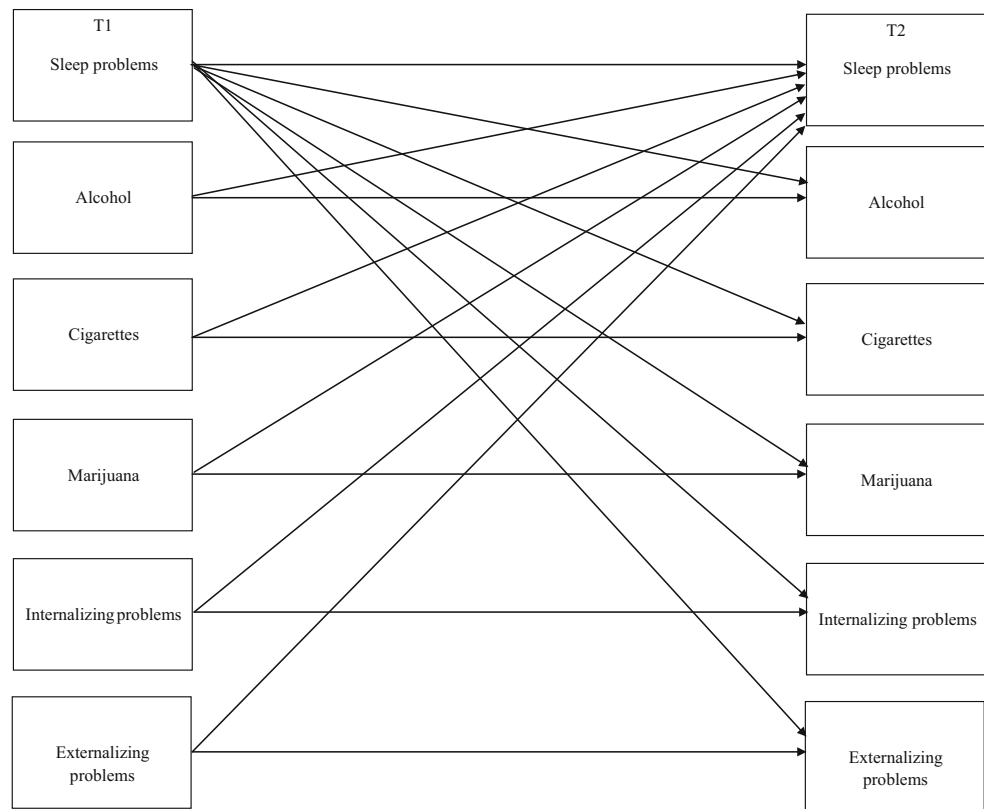
## The Current Study

It has been suggested that the relationship between sleep problems and other problem behaviours in *adulthood* is most likely reciprocal. That is, sleep problems predict problem behaviours, while problem behaviours increase sleep problems as well (e.g., Hasler et al. 2012). In the current study, this reciprocal relationship between sleep problems and other problem behaviours is tested in *young adolescents*. Our main hypothesis is that more sleep problems will predict more substance use, internalizing and externalizing problems, in line with previous research and in line with the abovementioned studies showing effects of sleep on emotion regulation and executive functions. Regarding the converse, substance use, internalizing and externalizing predicting sleep problems, we have less firm hypotheses. This is due to the fact that previous research did not consistently find an effect in that direction (e.g., Gregory et al. 2009). In order to test our longitudinal and cross-sectional hypotheses about the relationship between adolescent sleep and substance use, internalizing and externalizing problems, we have used a cross-lagged or bi-directional design incorporating two waves, including sleep, substance use, internalizing and externalizing problems measures at both waves (Fig. 1).

## Materials and Methods

### Procedure

Data were derived from the first two waves of a longitudinal study assessing developmental risk and protective factors (e.g., sleep) related to adolescent substance use. A total of parents of 1,215 adolescents were contacted through schools in the province of Gelderland (the Netherlands) to give informed consent for their children to participate in the study. Of these, 725 parents provided informed consent. In the current study, data were used from 555 adolescents that completed wave 1 (approximately beginning 2008) and wave 2 (approximately end of 2008) measurements. These adolescents differed from the

**Fig. 1** Theoretical model

original 725 adolescents on the ASWS sleep measures (e.g., experienced more problems going to bed and falling asleep ( $p < .005$ ). They did not differ on the cognitive ASHS subscale ( $p > .05$ ). They drank less alcohol and used less cigarettes and marijuana than the original 725 adolescents ( $p < .005$ ). Measurements included self-reports. The testing session was completed individually under the supervision of a trained research assistant. A unique subject number was provided to each participant to ensure anonymity and confidentiality. For a detailed description of the procedure, see Pieters et al. (2010), who describe analyses about sleep and substance use on wave 1.

### Participants

The participants were 555 adolescents (290 girls) with a mean age of 13.96 ( $SD = .78$ ; range 11–16 years). The sample characteristics included: 86.2 % had two Caucasian parents, 9.7 % had a mix of Caucasian and non-Caucasian parents, and 4.2 % had two non-Caucasian parents. Regarding education, 29.1 % had attained a vocational level, 28.2 % an intermediate or basic level and 32.7 % a college-preparatory level. A total of 10.1 % of the participants was in the process of a decision, which is common in the Netherlands in the first year of secondary school.

### Measures

#### *Sleep Problems*

Two subscales from the Adolescent Sleep-Wake Scale (ASWS) and one subscale from the Adolescent Sleep Hygiene Scale (ASHS; LeBourgeois et al. 2005) were used in the current study. The subscales measured problems going to bed (e.g., try to put off going to bed), falling asleep (e.g., problems going to sleep) and cognitive problems (e.g., think of things to do) before bedtime. Rationale for this combination was derived from LeBourgeois et al. (2005), who demonstrated that among Italian and American adolescents, the cognitive and emotional domains of the ASHS were associated most strongly with quality of sleep. Responses were given on 6-point Likert scales ranging from (1) “Never” to (6) “Always”. Higher scores indicated more sleep problems (note that this deviates from LeBourgeois et al. (2005) who developed the questionnaires). Cronbach’s alpha’s were .74, .74 and .67 respectively. Z-scores were created for all three subscales and a mean of those reflects a composite score that was employed in the data analyses. LeBourgeois et al. (2005) showed that the ASWS and ASHS had an acceptable internal consistency. Storfer-Isser et al. (2013) showed that the

Adolescent Sleep Hygiene Scale had sufficient psychometric properties. In this sample, the Cronbach's alphas for "going to bed" and "falling asleep", subscales of the ASWS, suggest a good internal consistency, while the Cronbach's alpha for "cognitive problems", subscale of the ASHS, suggests an acceptable internal consistency.

Z-scores were calculated for each of the subscales, ASWS going to bed, falling asleep and ASHS cognitive. On the subscales, 4.5 % of the sample had a Z-score above 2 on the ASWS going to bed subscale, 3.6 % of the sample had a Z-score above 2 on the ASWS falling asleep subscale and 2.7 % of the sample had a Z-score above 2 on the ASHS cognitive subscale. The adolescents with Z-scores above 2 are the ones who had the most sleep problems in our sample. Nevertheless, we did not aim to set a diagnosis for the youth in our sample, so these results should be taken with caution.

#### *Alcohol Use*

Frequency of alcohol use was used as a measure of adolescents alcohol use (Engels and Knibbe 2000). The adolescents reported the frequency they drank alcohol in the past 4 weeks on a 6-point scale (1) "I did not drink alcohol in the past 4 weeks", (2) "I drank alcohol 1–3 times in the past 4 weeks", (3) "I drank alcohol 1–2 times per week in the past 4 weeks", (4) "I drank alcohol 3–4 times per week in the past 4 weeks", (5) "I drank alcohol 5–6 times per week in the past 4 weeks", (6) "I drank alcohol every day in the past 4 weeks".

#### *Smoking Cigarettes*

The adolescents were asked to report the stage of cigarette smoking on a 9-point scale, ranging from 1 (I have never smoked, not even one puff) to (9) I smoke at least once a day (Harakeh et al. 2006; De Leeuw et al. 2009).

#### *Smoking Marijuana*

The adolescents were asked to report the frequency of marijuana smoking on a 9-point scale ranging from 1 (I have never smoked, not even one puff) to (9) I smoke at least once a day (Harakeh et al. 2006).

#### *Internalizing and Externalizing Problems*

The Strengths and Difficulties Questionnaire was administered in the current study (Goodman 1997). We used the 'internalizing' and 'externalizing' problems subscales (Dickey and Blumberg 2004). The psychometric properties of this questionnaire are good (Muris et al. 2003).

Cronbach's alpha for 'internalizing' and 'externalizing' problems were .72 and .69, respectively.

#### *Puberty*

For the current study, a self-rating scale for pubertal development was used (Carskadon and Acebo 1993). For example, adolescents were asked to complete items about growth of body hair. A total of three items applied to both boys and girls. The boys also had to complete items about their level of voice deepening and facial hair growth. The girls had to provide information about breast growth and menses. The outcome was a score of pubertal development with a higher score reflecting more advanced development (see also [www.sleepforscience.org](http://www.sleepforscience.org)). Cronbach's alpha was .58.

#### *Data Analyses*

First, descriptive statistics and correlations are determined to explore means and standard deviations of variables of interest and to test associations between sleep problems and substance use, internalizing and externalizing problems. Second, a model was tested using structural equation modeling using the robust maximum likelihood estimator in MPlus version 5.1 (MLR, Muthen and Muthen 1998–2007). The model tested bidirectional associations between sleep problems, substance use, internalizing and externalizing problems while adjusting for confounders such as puberty, gender, age and education. The stability paths were estimated as well as concurrent correlations and these were included in the model. Baseline levels of sleep problems, substance use, internalizing and externalizing problems were controlled for. The fit of the models was assessed with global fit indexes: Comparative Fit Index and Root Mean Square Error of Approximation (Muthén and Muthén 1998–2007).

## **Results**

### *Descriptive Statistics and Correlations*

Descriptive statistics and Pearson's correlations at wave 1 are shown in Table 1, for the subscales of the sleep measure as well as the composite.

Puberty correlated positively with cognitive sleep problems, suggesting that adolescents more advanced in puberty had more cognitive sleep problems or the converse.

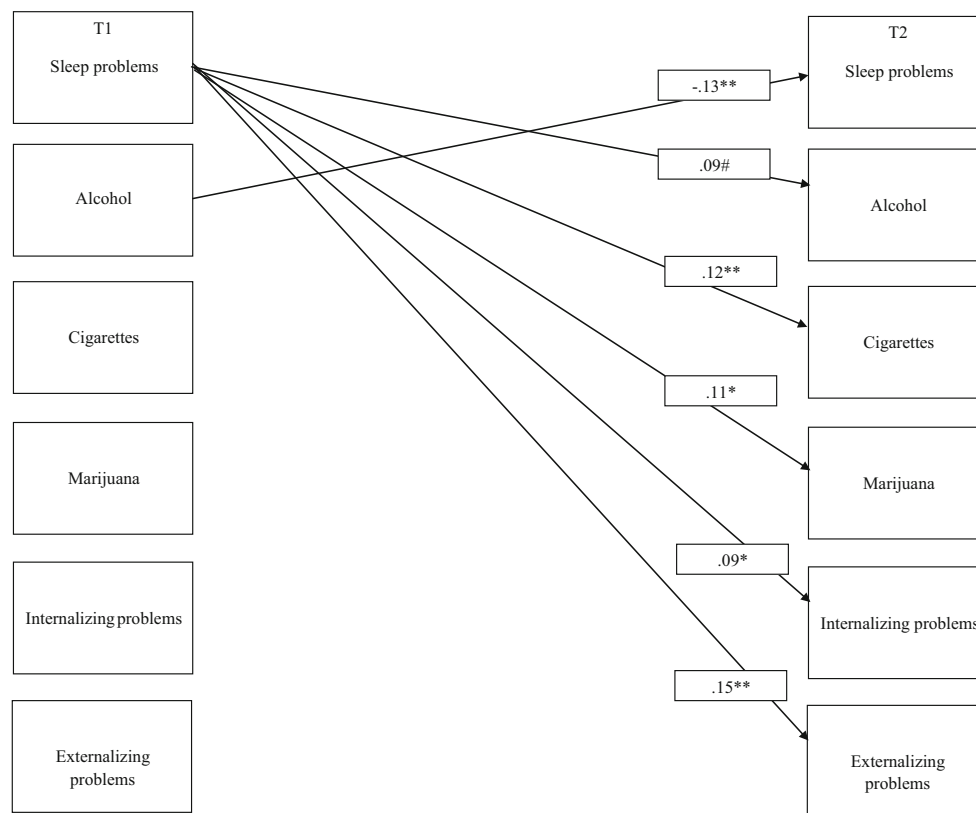
Substance use was positively associated with sleep problems, implying that adolescents who used more substances had more sleep problems or the converse. The individual substances were differently related to sleep problems. Alcohol use correlated with all three subscales of

**Table 1** Correlations between sleep problems and other study measures at time 1

	Problems going to bed	Problems falling asleep	Cognitive problems	Composite	Mean	SD	Reference range
Puberty	-.02	.08	.19***	.13	3.52	.78	1.96–5.08
Alcohol	.18***	.16***	.19***	.22	1.41	.76	0–2.93
Cigarettes	.07	.16***	.15***	.17	1.97	2.03	0–6.03
Marijuana	.13**	.16***	.11*	.16	1.34	1.23	0–3.8
Internalizing problems	.05	.19***	.27***	.22	1.39	.34	.58–2.26
Externalizing problems	.33***	.36***	.39***	.46	1.57	.31	.95–2.19
Mean	3.52	2.72	3.05				
SD	.98	.91	.91				
Reference range	1.56–5.48	0.9–4.54	1.23–4.87				

Pearson's correlations are shown between the different sleep problem indices and other study measures. In addition, correlations are shown between the overall sleep problems composite and other study measures. Means and standard deviations are provided for all study measures. The composite was based on Z-scores

\*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$

**Fig. 2** Model results

the sleep measure. Cigarette smoking was positively associated with problems falling asleep and cognitive sleep problems. Marijuana smoking was positively associated with sleep problems.

Internalizing problems were positively associated with problems falling asleep and cognitive sleep problems. Externalizing problems were positively associated with sleep problems.

## Associations Between Sleep Problems, Alcohol Use, Cigarette Smoking, Marijuana Smoking, Internalizing and Externalizing Problems Using Structural Equation Modeling

The fit of the Structural Equation Model (see Fig. 1 for a conceptual overview) was satisfactory [ $df = 20$ ,  $\chi^2 = 64.17$ ,  $p < .001$ , Comparative Fit Index ( $CFI$ ) = .96, Root Mean Square Error of Approximation ( $RMSEA$ ) = .06, Standardized Root Mean Square Residual ( $SRMR$ ) = .04]. The results are shown in Fig. 2. Significant paths in the model presented in Fig. 1 are shown. Not shown are the non-significant paths, concurrent correlations, the covariates puberty, age, gender and educational level, and stability paths. The stability paths were all significant with betas ranging from .28 (alcohol) to .6 (sleep problems).

Sleep problems at wave 1 positively predicted alcohol use, cigarette smoking, marijuana smoking, internalizing and externalizing problems at wave 2. Alcohol use at wave 1 negatively predicted sleep problems at wave 2, suggesting that drinking alcohol results in less sleep problems over time. The effects were significant adjusting for puberty, age, gender, education, concurrent correlations at wave 1 and wave 2, stability paths between waves and other bidirectional links.

## Discussion

Sleep problems in adolescents are highly prevalent (Grdisar et al. 2011). Research has shown that sleep problems are bi-directionally associated with affective problems and problem behaviours, such as substance use, anxiety and depression, in *adults* (e.g., Brower 2001). In *adolescents*, much less is known about the relationship between sleep problems and problem behaviours, although this developmental period is marked by vital changes in sleep and emotional and behavioural processes. Previous *cross-sectional* research has shown that sleep problems were related to substance use, internalizing and externalizing problems in adolescence (e.g., Holmen et al. 2000). However, to date, longitudinal research is less abundant. We sought to investigate the bidirectional links between sleep problems, substance use, internalizing and externalizing problems. We hypothesized that sleep problems would predict problem behaviours, based on previous research, and based on studies showing an effect of sleep deprivation on processes associated with problem behaviours, such as emotion regulation and executive functions. However, regarding the converse, previous research is equivocal: some fail to find a predictive effect of problem behaviours or find effects that are counterintuitive. Therefore, we had less clear

expectations of the converse, even though the relationship seems to be reciprocal in adults.

The results of the model showed that sleep problems at wave 1 predicted wave 2 substance use, internalizing and externalizing problems. The reverse pattern was not significant (substance use, internalizing and externalizing problems at wave 1 predicting sleep problems at wave 2), except for alcohol use, which negatively predicted sleep problems at wave 2. This is in line with previous longitudinal research, indicating that childhood sleep problems predicted onset of alcohol, cigarette and marijuana use, and internalizing and externalizing problems in adolescents (e.g., Wong et al. 2009). In addition, it has been shown that sleep problems at age 8 predicted depression at age 10, but not the converse (Gregory et al. 2009). Moreover, sleep problems at age 4 predicted depression, anxiety, attention problems and aggression in mid-adolescence, but not the converse (except for attention problems, Gregory and O'Connor 2002).

Alcohol use seems to be the only exception among other symptoms of risk for psychopathology: the more alcohol adolescents used, the less sleep problems adolescents had over time. One possibility is that this association is a first sign of an internalizing pathway to problematic alcohol use: there is some evidence that internalizing problems are not related to early onset of alcohol and drug use (for anxiety there is some evidence of a delay in onset), but that once drinking is begun, escalation takes place more rapidly (Saraceno et al. 2009). Alcohol use may thus be related to worry or stress at first, which may result in sleep problems over time, such that both repeated stress and alcohol use have negative effects on sleep.

Even though the results of our study suggest a predictive effect of sleep problems on substance use, it is less clear from our study what the underlying mechanism might be. Future research might investigate the exact way sleep problems affect substance use, internalizing and externalizing problems. As mentioned in the introduction, sleep problems or deprivation affects executive functions (EFs), such that processes involved in the attainment on long-term goals become compromised. Dual process models put forward that addiction is the product of an imbalance in the interplay between drug-specific impulsive processes and reflective processes (e.g., Wiers et al. 2007). With repeated drug use, drug-specific impulsive processes become stronger, while the ability to reflect on behaviour becomes weaker. As a result, drug-related paraphernalia activate automatic associations in memory, capture attentional processes compulsorily, and stimulate an automatic approach behaviour towards the drug. Because the ability to reflect on behaviour is compromised, these impulsive processes predominate reflective processes and new drug use is incited relatively involuntarily. We consider, based



on the above, that the effect of impulsive processes on substance use is larger when adolescents suffer from sleep problems, since these problems affect executive functions in adolescents. Studies have also shown that when executive functions are weak, impulsive processes predict behaviour. When executive functions were strong, reflective processes predict behaviour (e.g., Thush et al. 2008; Grenard et al. 2008).

With respect to impulsive processes, an exciting new area of research aims to investigate the relationship between sleep and reward-related brain networks in adolescence. A functional Magnetic Resonance Imaging (fMRI) study investigated the effect of sleep deprivation on reward-related brain function and found that adolescents with less adequate sleep displayed less activity in the caudate during reward anticipation and reward outcome (Holm et al. 2009). It is speculated that adolescents with less activity in reward related brain circuits have a tendency to compensate for this lack by engaging in reward-driven behaviour. One example would be related to substance use.

Several caveats must be stated. First, in this study, self-reports were used exclusively. Sleep diaries combined with actigraphy might provide a more reliable source of information compared to self-reports asking adolescents to recall information about their sleep/wake rhythm. Second, we did not investigate other important factors related to sleep problems as well as substance use (e.g., environmental factors). Nonetheless, this study is one of the first to explore the bi-directional relationship between sleep, substance use, internalizing and externalizing problems in adolescence.

## Conclusion

This study investigated bidirectional relationships between sleep problems, substance use, internalizing and externalizing problems. A longitudinal design was used, including two waves. It was demonstrated that sleep problems predicted substance use, internalizing and externalizing problems, but not the other way around, except for alcohol use. These findings show that sleep problems are vital in delineating factors related to adolescent substance use. It appears, from the studies described above, that sleep problems are related to several processes undergoing significant development in adolescence. We speculate that inadequate sleep, in combination with the effects of puberty, affects executive functions and reward processing such that adolescents are more inclined to engage in sensation seeking, have more emotional difficulties and associated problems. Future research should investigate links between sleep and these systems in adolescence. Since

adolescence is a period in which the brain reorganizes in terms of reward processing, it is very interesting to see how this relates to sleep. Understanding these processes could inform prevention and intervention programs for several psychopathological conditions.

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**Authors' Contributions** SP was involved in the design of the study, the coordination of the study, conducted the measurements, ran the statistical analyses, interpreted data and wrote the draft of the manuscript; WB was involved in the design of the study, the coordination of the study, ran the statistical analyses, interpreted data and wrote the draft of the manuscript; HV was involved in the design of the study, the coordination of the study, interpreted data and wrote the draft of the manuscript; RD was involved in the design of the study, interpreted data and wrote the draft of the manuscript; RW was involved in the design of the study, the coordination of the study, interpreted data and wrote the draft of the manuscript; RE was involved in the design of the study, the coordination of the study, interpreted data and wrote the draft of the manuscript. All authors read and approved the final manuscript.

**Conflict of interest** None of the authors declares a conflict of interest.

## References

- Agrawal, A., Sartor, C. E., Lynskey, M. T., Grant, J. D., Pergadia, M. L., Gruzca, R., et al. (2009). Evidence for an interaction between age at first drink and genetic influences on DSM-IV alcohol dependence symptoms. *Alcoholism, Clinical and Experimental Research*, *33*(12), 2047–2056.
- Anderson, B., Storfer-Isser, A., Taylor, H. G., Rosen, C. L., & Redline, S. (2009). Associations of executive function with sleepiness and sleep duration in adolescents. *Pediatrics*, *123*(4), e701–e707.
- Astill, R. G., Van der Heijden, K. B., Van IJzendoorn, M. H., & Van Someren, E. J. (2012). Sleep, cognition, and behavioral problems in school-age children: A century of research meta-analyzed. *Psychological Bulletin*, *138*(6), 1109–1138.
- Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, *121*(1), 65.
- Brower, K. J. (2001). Alcohol's effects on sleep in alcoholics. *Alcohol Research & Health*, *25*(2), 110–125.
- Cain, N., & Gradisar, M. (2010). Electronic media use and sleep in school-aged children and adolescents: A review. *Sleep Medicine*, *11*(8), 735–742.
- Carskadon, M. A., & Acebo, C. (1993). A self-administered rating scale for pubertal development. *Journal of Adolescent Health*, *14*(3), 190–195.
- Carskadon, M. A., Vieira, C., & Acebo, C. (1993). Association between puberty and delayed phase preference. *Sleep*, *16*(3), 258–262.
- De Leeuw, R. N., Engels, R. C., Vermulst, A. A., & Scholte, R. H. (2009). Relative risks of exposure to different smoking models on the development of nicotine dependence during adolescence: A five-wave longitudinal study. *Journal of Adolescent Health*, *45*(2), 171–178.

- Dickey, W. C., & Blumberg, S. J. (2004). Revisiting the factor structure of the strengths and difficulties questionnaire: United States, 2001. *Journal of the American Academy of Child and Adolescent Psychiatry*, 43(9), 1159–1167.
- Engels, R. C., & Knibbe, R. A. (2000). Alcohol use and intimate relationships in adolescence: When love comes to town. *Addictive Behaviors*, 25(3), 435–439.
- Fillmore, M. T., & Vogel-Sprott, M. (2006). Acute effects of alcohol and other drugs on automatic and intentional control. *Handbook of Implicit Cognition and Addiction*, pp 293–306.
- Forbes, E. E., & Dahl, R. E. (2010). Pubertal development and behavior: Hormonal activation of social and motivational tendencies. *Brain and Cognition*, 72(1), 66–72.
- Gau, S. S. F., & Chiang, H. L. (2009). Sleep problems and disorders among adolescents with persistent and subthreshold attention-deficit/hyperactivity disorders. *Sleep*, 32(5), 671.
- Goodman, R. (1997). The strengths and difficulties questionnaire: A research note. *Journal of Child Psychology and Psychiatry*, 38(5), 581–586.
- Gradisar, M., Gardner, G., & Dohnt, H. (2011). Recent worldwide sleep patterns and problems during adolescence: A review and meta-analysis of age, region, and sleep. *Sleep Medicine*, 12(2), 110–118.
- Grant, B. F., & Dawson, D. A. (1997). Age at onset of alcohol use and its association with DSM-IV alcohol abuse and dependence: Results from the National Longitudinal Alcohol Epidemiologic Survey. *Journal of Substance Abuse*, 9, 103–110.
- Gregory, A. M., Caspi, A., Eley, T. C., Moffitt, T. E., O'Connor, T. G., & Poulton, R. (2005). Prospective longitudinal associations between persistent sleep problems in childhood and anxiety and depression disorders in adulthood. *Journal of Abnormal Child Psychology*, 33(2), 157–163.
- Gregory, A. M., & O'Connor, T. G. (2002). Sleep problems in childhood: A longitudinal study of developmental change and association with behavioral problems. *Journal of the American Academy of Child and Adolescent Psychiatry*, 41(8), 964–971.
- Gregory, A. M., Rijdsdijk, F. V., Lau, J. Y., Dahl, R. E., & Eley, T. C. (2009). The direction of longitudinal associations between sleep problems and depression symptoms: A study of twins aged 8 and 10 years. *Sleep*, 32(2), 189–199.
- Grenard, J. L., Ames, S. L., Wiers, R. W., Thush, C., Sussman, S., & Stacy, A. W. (2008). Working memory capacity moderates the predictive effects of drug-related associations on substance use. *Psychology of Addictive Behaviors*, 22(3), 426.
- Hahn, C., Cowell, J. M., Wiprzycka, U. J., Goldstein, D., Ralph, M., Hasher, L., et al. (2012). Circadian rhythms in executive function during the transition to adolescence: The effect of synchrony between chronotype and time of day. *Developmental Science*, 15(3), 408–416.
- Harakeh, Z., Scholte, R. H., De Vries, H., & Engels, R. C. (2006). Association between personality and adolescent smoking. *Addictive Behaviors*, 31(2), 232–245.
- Hasler, B. P., Smith, L. J., Cousins, J. C., & Bootzin, R. R. (2012). Circadian rhythms, sleep, and substance abuse. *Sleep Medicine Reviews*, 16(1), 67–81.
- Hingson, R. W., Heeren, T., & Winter, M. R. (2006). Age at drinking onset and alcohol dependence: Age at onset, duration, and severity. *Archives of Pediatrics and Adolescent Medicine*, 160(7), 739–746.
- Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences*, 16, 174–180.
- Holm, S. M., Forbes, E. E., Ryan, N. D., Phillips, M. L., Tarr, J. A., & Dahl, R. E. (2009). Reward-related brain function and sleep in pre-early pubertal and mid/late pubertal adolescents. *Journal of Adolescent Health*, 45(4), 326–334.
- Holmen, T. L., Barrett-Connor, E., Holmen, J., & Bjerner, L. (2000). Health problems in teenage daily smokers versus nonsmokers, Norway, 1995–1997 The Nord-Trøndelag Health Study. *American Journal of Epidemiology*, 151(2), 148–155.
- Horne, J. A. (1988). Sleep loss and “divergent” thinking ability. *Sleep*, 11, 528–536.
- Johnson, E. O., & Breslau, N. (2001). Sleep problems and substance use in adolescence. *Drug and Alcohol Dependence*, 64(1), 1–7.
- Johnson, E. O., Roth, T., Schultz, L., & Breslau, N. (2006). Epidemiology of DSM-IV insomnia in adolescence: Lifetime prevalence, chronicity, and an emergent gender difference. *Pediatrics*, 117(247), 256.
- LeBourgeois, M. K., Giannotti, F., Cortesi, F., Wolfson, A. R., & Harsh, J. (2005). The relationship between reported sleep quality and sleep hygiene in Italian and American adolescents. *Pediatrics*, 115(1 Suppl), 257–265.
- Liu, X., & Zhou, H. (2002). Sleep duration, insomnia and behavioral problems among Chinese adolescents. *Psychiatry Research*, 111, 75–85.
- Mayes, S. D., Calhoun, S. L., Bixler, E. O., Vgontzas, A. N., Mahr, F., Hillwig-Garcia, J., et al. (2009). ADHD subtypes and comorbid anxiety, depression, and oppositional-defiant disorder: Differences in sleep problems. *Journal of Pediatric Psychology*, 34(3), 328–337.
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*, 41, 49–100.
- Muris, P., Meesters, C., & Van den Berg, F. (2003). The Strengths and Difficulties Questionnaire (SDQ): Further evidence for its reliability and validity in a community sample of Dutch children and adolescents. *European Child and Adolescent Psychiatry*, 12(1), 1–8.
- Muthén, L. K., & Muthén, B. O. (1998–2007). *Mplus user's guide*. 5th edn. Los Angeles, CA: Muthén & Muthén.
- Negriff, S., Dorn, L. D., Pabst, S. R., & Susman, E. J. (2011). Morningness/eveningness, pubertal timing, and substance use in adolescent girls. *Psychiatry Research*, 185(3), 408–413.
- Ohayon, M. M., Roberts, R. E., Zully, J., Smirne, S., & Priest, R. G. (2000). Prevalence and patterns of problematic sleep among older adolescents. *Journal of the American Academy of Child and Adolescent Psychiatry*, 39, 1549–1556.
- Pagel, J. F., Forister, N., & Kwiatkowiak, C. (2007). Adolescent sleep disturbance and school performance: The confounding variable of socioeconomic status. *Journal of Clinical Sleep Medicine*, 3, 19–23.
- Pasch, K. E., Latimer, L. A., Cance, J. D., Moe, S. G., & Lytle, L. A. (2012). Longitudinal bi-directional relationships between sleep and youth substance use. *Journal of Youth and Adolescence*, 41(9), 1184–1196.
- Patton, G. C., McMorris, B. J., Toumbourou, J. W., Hemphill, S. A., Donath, S., & Catalano, R. F. (2004). Puberty and the onset of substance use and abuse. *Pediatrics*, 114(3), e300–e306.
- Pelayo, R. P., Thorpy, M. J., & Glovinsky, P. (1998). Prevalence of delayed sleep phase syndrome among adolescents. *Sleep Research*, 17, 391.
- Pieters, S., Van der Vorst, H., Burk, W. J., Wiers, R. W., & Engels, R. C. M. E. (2010). Puberty-dependent sleep regulation and alcohol use in adolescents. *Alcoholism, Clinical and Experimental Research*, 34(9), 1512–1518.
- Pine, D. S., Cohen, P., Gurley, D., Brook, J., & Ma, Y. (1998). The risk for early-adulthood anxiety and depressive disorders in adolescents with anxiety and depressive disorders. *Archives of General Psychiatry*, 55(1), 56–64.

- Roane, B. M., & Taylor, D. J. (2008). Adolescent insomnia as a risk factor for early adult depression and substance abuse. *Sleep, 31*(10), 1351.
- Roberts, R. E., Roberts, C. R., & Duong, H. T. (2009). Sleepless in adolescence: Prospective data on sleep deprivation, health and functioning. *Journal of Adolescence, 32*(5), 1045–1057.
- Roehrs, T., Carskadon, M. A., Dement, W. C., & Roth, T. (2005). Daytime sleepiness and alertness. In: M. H. Kryger, T. Roth, C. Dement, (Eds.), *Principle and practice of sleep medicine*, 4th ed. Philadelphia: Elsevier Saunders, pp. 39–51.
- Russo, P. M., Bruni, O., Lucidi, F., Ferri, R., & Violani, C. (2007). Sleep habits and circadian preference in Italian children and adolescents. *Journal of Sleep Research, 16*(2), 163–169.
- Saraceno, L., Munafó, M., Heron, J., Craddock, N., & Van den Bree, M. B. (2009). Genetic and non-genetic influences on the development of co-occurring alcohol problem use and internalizing symptomatology in adolescence: A review. *Addiction, 104*(7), 1100–1121.
- Steele, R. G., Forehand, R., Armistead, L., & Brody, G. (1995). Predicting alcohol and drug use in early adulthood. *American Journal of Orthopsychiatry, 65*(3), 380–388.
- Stordal, K. I., Lundervold, A. J., Egeland, J., Mykletun, A., Asbjørnsen, A., Landrø, N. I., et al. (2004). Impairment across executive functions in recurrent major depression. *Nordic Journal of Psychiatry, 58*(1), 41–47.
- Storfer-Isser, A., Lebourgeois, M. K., Harsh, J., Tompsett, C. J., & Redline, S. (2013). Psychometric properties of the Adolescent Sleep Hygiene Scale. *Journal of Sleep Research, 22*(6), 707–716.
- Teunissen, H. A., Adelman, C. B., Prinstein, M. J., Spijkerman, R., Poelen, E. A., Engels, R. C., et al. (2011). The interaction between pubertal timing and peer popularity for boys and girls: An integration of biological and interpersonal perspectives on adolescent depression. *Journal of Abnormal Child Psychology, 39*(3), 413–423.
- Thorpy, M. J., Korman, E., Spielman, A. J., & Glovinsky, P. B. (1988). Delayed sleep phase syndrome in adolescents. *Journal of Adolescent Health Care, 9*, 22–27.
- Thush, C., Wiers, R. W., Ames, S. L., Grenard, J. L., Sussman, S., & Stacy, A. W. (2008). Interactions between implicit and explicit cognition and working memory capacity in the prediction of alcohol use in at-risk adolescents. *Drug and Alcohol Dependence, 94*(1–3), 116–124.
- Tynjälä, J., Kannas, L., & Levälähti, E. (1997). Perceived tiredness among adolescents and its association with sleep habits and use of psychoactive substances. *Journal of Sleep Research, 6*(3), 189–198.
- Vignau, J., Bailly, D., Duhamel, A., Vervaecke, P., Beuscart, R., & Collinet, C. (1997). Epidemiologic study of sleep quality and troubles in French secondary school adolescents. *Journal of Adolescent Health, 21*(5), 343–350.
- Wiers, R. W., Bartholow, B. D., van den Wildenberg, E., Thush, C., Engels, R. C., Sher, K. J., et al. (2007). Automatic and controlled processes and the development of addictive behaviors in adolescents: A review and a model. *Pharmacology, Biochemistry and Behavior, 86*(2), 263–283.
- Wong, M. M., Brower, K. J., Fitzgerald, H. E., & Zucker, R. A. (2004). Sleep problems in early childhood and early onset of alcohol and other drug use in adolescence. *Alcoholism, Clinical and Experimental Research, 28*(4), 578–587.
- Wong, M. M., Brower, K. J., Nigg, J. T., & Zucker, R. A. (2010). Childhood sleep problems, response inhibition, and alcohol and drug outcomes in adolescence and young adulthood. *Alcoholism, Clinical and Experimental Research, 34*(6), 1033–1044.
- Wong, M. M., Brower, K. J., & Zucker, R. A. (2009). Childhood sleep problems, early onset of substance use and behavioral problems in adolescence. *Sleep Medicine, 10*(7), 787–796.

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