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Adolescent daytime sleepiness as a risk factor for adult crime

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Background: While recent cross-sectional research has documented a relationship between sleep problems and antisocial behavior, the longitudinal nature of this relationship is unknown. This study tests both the hypothesis that adolescent daytime sleepiness is associated with later adult criminal offending, and also tests a biopsychosocial mediation model in which social adversity predisposes to sleepiness, which in turn predisposes to attentional impairment, and to adult crime. **Methods:** Schoolboys aged 15 years rated themselves on self-report sleepiness. Age 15 antisocial behavior was assessed by teacher ratings and self-reports, while convictions for crime were assessed at age 29. Attentional capacity at age 15 was assessed by autonomic orienting, with arousal assessed by the electroencephalogram (EEG). **Results:** Sleepy adolescents were more likely to be antisocial during adolescence, and were 4.5 times more likely to commit crime by age 29. The sleepiness–adult crime relationship withstood control for adolescent antisocial behavior. Self-report sleepiness predicted to adult crime over and above objective measures of daytime sleepiness (EEG theta activity) and age 15 antisocial behavior. Poor daytime attention partly mediated the sleep–crime relationship. Mediation analyses also showed that social adversity predisposed to daytime sleepiness which was associated with reduced attention which in turn predisposed to adult crime. **Conclusions:** Findings are the first to document a longitudinal association between sleepiness in adolescence and crime in adulthood. The longitudinal nature of this relationship, controlling for age 15 antisocial behavior, is consistent with the hypothesis that adolescent sleepiness predisposes to later antisociality. Findings are also consistent with the notion that the well-established link between social adversity and adult crime is partly explained by sleepiness. Results suggest that a very brief and simple assessment of subjective daytime sleepiness may have prognostic clinical value, and that interventions to reduced sleepiness could be a useful avenue for future crime prevention. **Keywords:** Sleepiness; sleep; antisocial; crime; attention; electroencephalogram; prefrontal; adolescence; adversity; intervention.

Introduction

There is increasing evidence that poor sleep is associated with antisocial and criminal behavior in adults. Night restlessness as measured by actigraphy has been associated with increased aggression in 19 Dutch psychotic prisoners (Meijers, Harte, & Scherder, 2015). Similarly, poorer self-reported sleep quality and insomnia are associated with increased self-reported aggression in 96 Dutch forensic psychiatric patients (Kamphuis, Dijk, Spreen, & Lancel, 2014). Male soldiers with antisocial personality disorder who reported poor sleep also reported higher levels of aggression (Semiz et al., 2008). As such, initial cross-sectional evidence from clinical populations suggest that sleepiness is plausibly associated with antisocial behavior.

Sleep problems are not restricted to adult aggression, and also developmentally extend downwards into child and adolescent externalizing behavior problems and conduct disorder. Externalizing behavior problems have been associated with sleep problems in preschool children (Scharf, Demmer, Silver, & Stein, 2013), adolescents (Pieters et al., 2015), and young adults (Barclay, Eley, Maughan, Rowe, & Gregory, 2011). Furthermore, teenagers who self-report sleep problems also report more conduct problems (Lin & Yi, 2015). Developmentally, adolescence is a period when sleep–antisocial relationships may be particularly salient given the increase in antisocial behavior during this period when teenagers are particularly susceptible to having less sleep than required (Dahl & Lewin, 2002). Furthermore, adolescent daytime sleepiness increases throughout adolescence and is associated with a range of negative health outcomes (Owens, 2014).

Although these prior studies have been invaluable in empirically establishing a sleep – externalizing behavior relationship, there has been relatively less attention to the mechanisms by which sleepiness predisposes to antisocial behavior, and in embedding this relationship in a broader conceptual framework. We suggest that the sleep–antisocial behavior relationship can be understood within a biopsychosocial conceptual framework. Social adversity is a source of stress, and stress results in impaired sleep and daytime sleepiness (Akerstedt, 2006; Owens, 2014). Furthermore, low SES including low income has been quite strongly (odds ratio 2.84) associated with poor sleep quality, as has a lower level of education (Patel, Grandner, Xie, Branas, & Gooneratne, 2010). Sleeplessness robustly produces impairments in attentional capacity (Killgore, 2010). Impaired

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attentional functioning is in turn a risk factor for adult crime (Raine, Venables, & Williams, 1990a, 1990b). As such, daytime sleepiness and attentional dysfunction (measured biologically through electrodermal orienting) could mediate the social adversity–adult criminality relationship. One goal of this study therefore was to test this biopsychosocial model which proposes that adversity predisposes to daytime sleepiness, which is itself associated with reduced attentional capacity, which in turn predisposes to crime.

In addition to the relative lack of studies examining mechanisms of action in the sleep–antisocial behavior relationship, several other important gaps in the literature exist. First, from a developmental perspective, is sleepiness in adolescence associated with crime in adulthood? To our knowledge, there have been no longitudinal studies on adolescent sleep and adult antisocial behavior. Second, while sleep problems have been linked to aggressive behavior, does this association extend to antisocial and criminal behavior in general? Third, the presumption is that sleep problems predispose to daytime sleepiness which then predispose to antisocial behavior, but to date there have been no studies on daytime sleepiness per se and antisocial behavior. Does subjective daytime sleepiness predict to later antisociality over and above objective measures of sleepiness such as increased electroencephalographic (EEG) theta activity, a validated measure of daytime sleepiness (Kaida et al., 2006)? Fourth, even if longitudinal associations could be established from sleepiness at time A to antisociality at time B, that would not rule out the possibility that antisociality at time A is predisposing both the sleepiness at time A as well as the antisociality at time B. The question to be resolved concerns whether sleep problems predispose to antisocial behavior, or whether antisocial behavior instead predisposes to sleep problems?

The present study set out to address these gaps in the literature by making use of existing longitudinal data in which subjective daytime sleepiness was assessed alongside EEG in adolescents, with outcome for criminal behavior assessed 14 years later (Raine, Venables, & Williams, 1995; Raine et al., 1990a, 1990b). A psychophysiological measure of attention (orienting) allowed for the testing of a mediation model in which sleepiness results in attentional impairment which in turn relates to later criminal offending. A measure of adolescent antisocial behavior taken concurrently with daytime sleepiness allowed for controlling adolescent antisociality when testing the longitudinal sleepiness–crime relationship. We hypothesized that: (a) adolescent sleepiness predisposes to adult crime, (b) reduced attention mediates this relationship, (c) social adversity predisposes to sleepiness which in turn predisposes to attention problems and thence to adult crime, (d) the sleepiness–crime relationship is not explained by social or academic confounds or by adolescent antisocial behavior, and (e) subjective sleepiness provides added predictive value over and above objective sleepiness measures.

Methods

Participants

Participants came from a longitudinal study on psychophysiological predictors of crime (Raine et al., 1990a, 1990b). Participants consisted of 101 (15-year-old) schoolchildren (range 14–16 years, mean age 14.6 years) from three schools in York, England. School A was a 'secondary modern' school (taking academically less able children), school B was a 'grammar' school (taking academically more able children), while school C was a 'comprehensive' (unselected) school. Participants were sampled from these three schools (31%, 14%, and 55%, respectively) in order to obtain a representative cross-section of children in terms of academic and social background. The catchment area for school A was largely lower/middle-working class neighborhoods, for school B residential and rural neighborhoods, and for school C mixed neighborhoods.

Fifteen-year olds were chosen for study because (a) this is a peak age for antisocial behavior, (b) teenagers are particularly prone to sleep problems (Owens, 2014; Pieters et al., 2015), and (c) as some children leave school at 16, this age allows for a more representative, unselected sample. All but 1 of the 101 teenagers were Caucasian. Full details of all study variables are given in Table 1. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975. The written, informed consent was obtained from both the adolescent and their parent.

Daytime sleepiness

Sleepiness during the day was assessed by a Likert-scale item that assessed degree of sleepiness on a 7-point scale ranging

Table 1 Means, *SD*s (in parentheses), and *t*-test comparisons (two-tailed) for criminal and control groups on key study measures

	Controls	Criminals	*t*	*df*	*p*	*d*
Age	14.57 (0.50)	14.82 (0.39)	2.29	99	.029	.51
Academic/peer status	2.12 (0.65)	2.41 (0.61)	1.71	99	.090	.45
Social class	2.93 (1.38)	3.47 (1.06)	1.68	99	.105	.41
Area of residence	0.24 (0.42)	0.41 (0.51)	1.48	99	.143	.39
Total adversity	−0.08 (0.98)	0.43 (1.03)	1.85	99	.067	.52
Adolescent antisociality	−0.12 (0.94)	0.61 (1.11)	2.85	99	.005	.76
Daytime sleepiness	3.83 (0.80)	4.59 (1.21)	3.23	99	.002	.86
Attention (orienting)	1.94 (2.46)	0.90 (0.91)	1.72	99	.004	.46
Auditory thresholds	5.44 (8.48)	9.54 (7.51)	1.85	99	.067	.49

from 7 ('sleepy') to 1 ('unusually alert'). This question was assessed at both the start and at the end of the 2-hr laboratory testing session. Scores on the two questions were averaged to obtain one summary sleepiness measure ($M = 3.96$, $SD = 0.91$). All participants were tested at the same time of day (from 1.10 pm to 3.15 pm), within a start-time variation of 5–15 min.

Adult criminal status

Participants underwent psychophysiological and sleepiness assessment during the period 1978–1979. A computerized search was made in May 1993 at the Central Criminal Records Office in London when the participants were aged 29 years. Only participants found guilty and sentenced at court were classified as 'criminal'. Using this criteria, 17 of the 101 participants were found to possess a criminal record. Crimes recorded in the Criminal Records Office are synonymous with 'serious' offending (Farrington, 1983), and do not include trivial offenses such as traffic offenses.

Adolescent antisocial behavior

Self-report psychopathic/impulsive antisocial behavior was assessed at school using the Socialization Scale (Gough, 1969), the Criminal Propensity Scale (Allsopp & Feldman, 1976), the Unsocialized-Psychopathic, Neurotic-Disturbed, Socialized-Subcultural scales of the Personal Opinion Study (Quay & Parsons, 1970), and the Impulsivity scale of the Eysenck Impulsivity Inventory (Eysenck & Eysenck, 1978).

Teacher ratings of conduct disorder were made on each child by 2–3 teachers who in all cases had extensive teaching experience of each individual (in most cases an average of 2.5 hr/week over a 4-year period). Children were rated on the Unsocialized-Psychopathic scale of the Behavior Problem Checklist (Quay & Parsons, 1970) which assesses behavior such as destructiveness, swearing, disobedience, and fighting. Interrater reliability was acceptable, with 32 cross-rater correlation coefficients having a mean of 0.64 and median of 0.75.

The seven self-report and teacher rating measures were subjected to a principal component analysis. All measures intercorrelated in the predicted direction between .36 and .69. All factor loadings ranged from .72 to .83. Factor scores from the single principal component were saved using the regression method, with higher scores indicating higher antisocial behavior.

Electroencephalogram

Increased theta power was recorded as an objective measure of daytime sleepiness. Full details are given in Raine et al., (1990b). Briefly, resting EEG was recorded from the vertex site. Power spectral density curves during a 2-minute rest period yielded spectral values for a 0- to 30-Hz frequency range with the theta band covering 3.52–7.42 Hz. Full details are reported in online Appendix S1.

Skin conductance orienting response

Full details of assessment of skin conductance orienting are given in Raine et al., (1990a). Briefly, the orienting paradigm consisted of a sequence of 9 pure tones delivered binaurally to the subject over headphones. Skin conductance was measured from bipolar leads on each hand using silver–silver chloride electrodes.

In addition to a total of all orienting responses amplitudes ($M = 1.76$ μs, $SD = 2.30$) on all nine stimuli, a dichotomy of skin conductance orienting response (SCOR) responding–nonresponding was constructed for one analysis below by dividing participants into those who gave no SCORs to any of the orienting stimuli ('nonresponders') as opposed to those who gave at least one response ('responders'; Boucsein, 2012).

Absolute auditory thresholds

Briefly this measure of signal detection was assessed using an audiometer with thresholds measured in each ear. For each ear, two ascending and two descending series of tones were presented, with auditory thresholds being based on the average of the eight readings. Full methodological details are given in the Appendix S1.

Social adversity

A residential classification was made on the basis of whether participants were residents in areas of relatively higher crime (housing estates – coded 1) or of relatively lower crime (residential areas and rural areas – coded 0). Socioeconomic status was assessed on the Office of Population Censuses and Survey's 6-point classification of occupations (Office of Population Censuses and Surveys, 1970). A broad measure of school quality and peer group affiliation was derived from a 3-point rating scale of the quality of school they attended (1 = grammar school, 2 = comprehensive, 3 = secondary modern). All measures were intercorrelated .44 to .61 (all p values < .001). After z transformation, they were summed to produce an overall measure of adversity.

Statistical analyses

Logistic regression (with criminality status as the dichotomous outcome) was used to assess if daytime sleepiness predicted to future offending over and above an objective indicator of sleepiness (increased daytime EEG theta activity) and adolescent antisocial behavior, using the Nagelkerke's R^2 statistic to assess predictive power and the amount of variance in group membership explained by predictors. A receiver operating characteristic curve (ROC) analysis was conducted on the prediction algorithm derived from logistic regression to assess strength of prediction to future offending.

To assess if attention mediated any association between sleepiness and crime, the PROCESS macro (Hayes, 2013) was used to test the significance of indirect (mediating) effects using a bootstrapping procedure which improves estimates of standard errors to identify any mediation effect (Hayes, 2013). Extent of mediation was assessed using a two-step logistic regression, calculating the reduction in variance (Nagelkerke R^2) explained by sleepiness after controlling for attention. All effect sizes from t-test and correlations were all two-tailed and effect sizes were calculated using Cohen's d (Cohen, 1988).

Results

Means, SDs, results of t-test comparisons between criminals and controls, and effect sizes for all key study variables are presented in Table 1.

Validation of the subjective sleep measure

The self-report sleepiness measure was significantly associated with skin conductance orienting amplitudes ($r = -.21$, $p = .04$), indicating that sleepy adolescents were less likely to allocate attentional resources to process auditory stimuli. Participants who failed to give any orienting responses ('nonresponders' – $N = 13$) were more sleepy compared to

those who gave orienting responses ('responders' – $N = 87$; $t = 2.2$, $df = 98$, $p = .03$).

Self-report sleepiness was also associated with increased absolute auditory thresholds ($r = .336$, $p < .001$, $d = .71$), indicating poorer signal detection in more sleepy children.

Adolescent sleepiness, adolescent antisocial behavior, and adult crime

Daytime sleepiness was positively associated with increased antisocial behavior at age 15 ($r = .21$, $p = .03$, $d = .43$).

Sleepy adolescents were more likely to commit crime in adulthood (see Table 1). Future criminals at age 29 had higher daytime sleepiness scores at age 15 compared to controls ($p = .002$, $d = .86$). Because groups differed in age, age was controlled for in a logistic regression. Increased sleepiness at age 15 still predicted to future crime at age 29 ($\chi^2 = 8.11$, $p = .004$, $R^2 = .19$).

The 7-point self-report sleepiness scale was used to dichotomize participants with a score of 5 or more ('somewhat drowsy' to 'sleepy') and those with a score of 4 or less ('averagely alert' to 'unusually alert'). A χ^2 analysis documented a significant relationship between sleepiness and crime ($\chi^2 = 6.76$, $df = 1$, $p = .009$), with an odds ratio of 4.54 (CI = 1.35–15.26).

Subjective sleepiness predicting to crime above objective sleepiness

To assess if subjective sleepiness ratings predicted to future adult crime over and above the objective measure of daytime sleepiness (EEG), a logistic regression was run with EEG entered on block 1, and subjective sleepiness on block 2. EEG alone predicted significantly to future crime ($\chi^2 = 8.23$, $p = .001$, $R^2 = .13$; see Raine et al., 1990b). After controlling for objective sleepiness, subjective sleepiness significantly predicted to future crime, $\chi^2 = 8.50$, $p = .004$, increase in $R^2 = .14$. The total variance in group membership explained by both variables was $R^2 = .27$.

Controlling for age 15 antisocial behavior

As a stricter test of the utility of subjective sleepiness in predicting future crime, the logistic regression was repeated entering adolescent antisocial behavior on block 1, EEG theta activity on block 2, and subjective sleepiness on block 3. Adolescent antisocial behavior predicted to future crime, $\chi^2 = 7.59$, $p = .006$, $R^2 = .12$. Theta activity significantly added to the prediction of crime (Raine et al., 1990b), $\chi^2 = 10.30$, $p = .001$, R^2 change = .15, total $R^2 = .27$. Self-report sleepiness predicted to crime over and above the combination of adolescent antisocial behavior and objective sleepiness, $\chi^2 = 6.23$, $p = .013$, R^2 change = .09, total $R^2 = .36$.

Receiver operating characteristic curve analysis in predicting crime

Probabilities of group membership from the above logistic regression based on the three predictors were used as a predictor test variable of crime in ROC analyses using the actual criminal/noncriminal grouping as the state variable. The area under the curve was .83 ($p < .0001$), indicating good prediction, with the predictor score having a sensitivity of .88 and specificity of .77. Using this cut-point to dichotomize the test variable to create a sleepy/alert grouping in a χ^2 analysis of actual criminal outcome produced a significant $\chi^2 = 6.81$, $df = 1$, $p = .009$, with an odds ratio of 10.04 (CI = 1.27–79.04).

Attention as a mediator of the sleepiness–crime relationship

Because sleepiness was associated with poor attention as measured by skin conductance orienting, and because reduced orienting has been associated with later crime in this sample (Raine et al., 1990a), we examined whether the sleepiness–crime relationship could be partly explained by reduced attention.

Paths for the PROCESS mediation model are shown in Figure 1. All paths between *X*, *M*, and *Y* were statistically significant ($p < .05$). The indirect effect (the effect of sleepiness on crime operating through attention) was also significant ($\beta = .133$, CI = 0.006–0.435, $p < .05$), indicating significant mediation. As the direct effect (the effect of sleepiness on crime independent of attention) remained significant ($\beta = .758$, CI = 0.0153–1.363, $p = .014$), the mediating effects of attention were partial, and not full. Using logistic regression, controlling for attention reduced the total effect of sleepiness on crime by 20.4% (Nagelkerke R^2 reducing from .144 to .115).

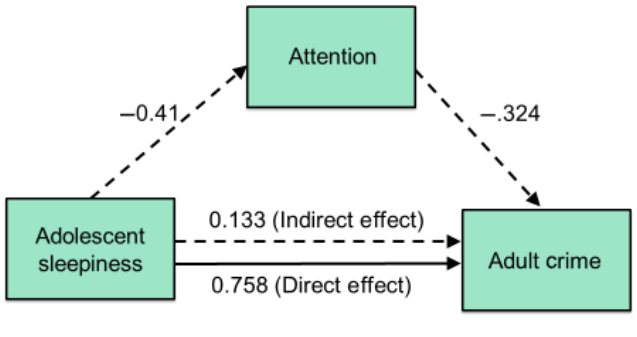

Figure 1 Poor attention (skin conductance orienting) partly mediates the effect of daytime sleepiness at age 15 on crime at age 29. All coefficients (unstandardized beta weights) are statistically significant, including the indirect and direct effects. Indirect paths are signified by dashed lines, the direct effect by a solid line [Colour figure can be viewed at wileyonlinelibrary.com]

Sleepiness and inattention as mediators of the social adversity–crime relationship

To test the biopsychosocial model outlined above in which social adversity predisposes to daytime sleepiness, a serial mediation model was run. Adversity was the independent variable, sleepiness was the first mediator, inattention was the second mediator, and crime was the dependent variable (see Figure 2).

There are three indirect paths through the two mediators. The first (from higher adversity to increased sleepiness to poorer attention to crime) was statistically significant (β = .009, CI = 0.001–0.135, $p < .05$). The second (from higher adversity to increased sleepiness to crime) was also statistically significant (β = .051, CI = 0.004–0.268, $p < .05$). The third (from higher adversity to poor attention to crime) was not significant (β = .031, CI = −0.005 to 0.237, $p > .05$). Combining all three indirect paths, the total indirect effect was significant (β = .090, CI = 0.023–0.345, $p < .05$). As the direct effect from social adversity to crime was not significant (β = .104, CI = −0.120 to 0.328, $p > .05$), the mediating effects of sleepiness and inattention were full.

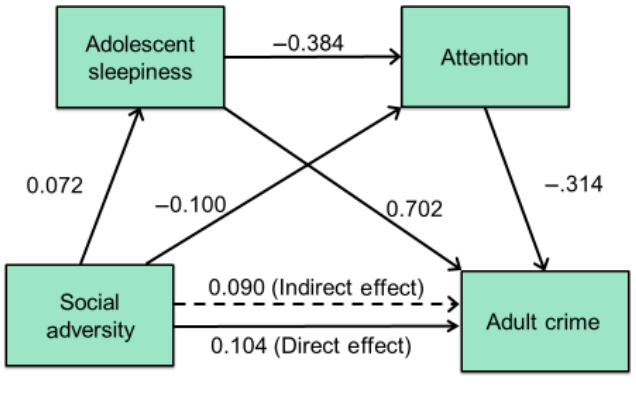

Figure 2 Mediation model with unstandardized beta weights indicating that higher social adversity predisposes to increased adolescent daytime sleepiness that impairs attention and predisposes to later crime [Colour figure can be viewed at wileyonlinelibrary.com]

Using logistic regression, controlling for sleepiness and attention reduced the total effect of adversity on crime by 75.4% (Nagelkerke R^2 reducing from .053 to .013). As such, some support was found for social adversity predisposing to the sleepiness risk factor for adult crime, and for sleepiness and inattention partly explaining the social adversity–crime relationship.

Discussion

This study assessed whether daytime subjective sleepiness is a risk factor for future crime. Adolescents who reported being more sleepy during the afternoon were more antisocial at age 15, and were 4.5 times more likely to go on to become convicted criminals by age 29. Subjective sleepiness predicted more future crime over and above both an objective physiological measure of daytime sleepiness (EEG) and also age 15 antisocial behavior. The combination of subject and objective daytime sleepiness measures, together with adolescent antisocial behavior, were associated with a 10-fold increase in the likelihood of adult crime. The sleep–crime relationship (d = .86) was partly mediated by a psychophysiological measure of attention. Support was found for a causal model starting with psychosocial adversity predisposing to sleepiness, which in turn was associated with reduced attention, and ultimately adult crime. To the authors' knowledge, these are the first findings to document a relationship between any measure of sleepiness (or sleep problems more generally) and later criminal offending. It is tentatively hypothesized that sleepiness results in reduced attentional capacity, an indirect indicator of frontolimbic functioning, which predisposes to offending.

Mechanisms of action

Reduced attention (autonomic orienting) mediated the relationship between daytime sleepiness and crime, accounting for 29.2% of the sleepiness–crime relationship. While mediation effects have been hypothesized on the sleep–antisocial relationship, they have not to our knowledge been empirically tested using mediation models. Subjective sleepiness has been associated with both reduced electrodermal activity and disrupted sleep (El-Sheikh & Arsiwalla, 2011). Furthermore, sleep deprivation has been associated with reduced skin conductance orienting (Michael, Passmann, & Becker, 2012) which is a sensitive measure of attention and information processing (Boucsein, 2012; Ohman, Hamm, & Hugdahl, 2000) and has been associated (r = .61) with cognitive measures with a high working memory load (Raine, 1987). Attentional and neurocognitive impairments are in turn a well-replicated risk factor for antisocial behavior (Dolan & Lennox, 2013). As such, the mediation result is broadly consistent with a broader literature on sleep, attention, and antisocial behavior.

Attentional impairment could predispose to later criminal behavior in a number of ways. At a broad social level, poor attention could predispose to school failure, occupational failure, and a criminal way of life (Raine et al., 1990a). At a neurophysiological level, these attention deficits may be a marker for neural structures which are associated with both antisocial behavior and sleep disruption. For example, electrodermal orienting is associated with activation in the ventromedial and bilateral prefrontal cortex and also the amygdala (Williams et al., 2007), regions which are structurally and functionally impaired in antisocial populations (Fairchild et al., 2011; Yang & Raine, 2009). Furthermore, sleep deprivation results in reduced connectivity between the prefrontal cortex and the amygdala (Shao et al., 2014), and reduced orbitofrontal-amygdala

connectivity has been observed in antisocial youths (Marsh et al., 2011). The mediational effect of attention consequently provides some initial support for the provisional hypothesis that sleepiness may predispose to crime via disruption to fronto-limbic functioning, although alternative models that involve cognitive, affective, and behavioral mediators are worthy of further testing (Dahl & Lewin, 2002).

Causation, confounds, and the etiology of sleepiness

Do sleep problems predispose crime, or does antisocial behavior result in poor sleep? Antisocial adolescents are more likely to stay out late and break bed-time sleep rules, actions that can result in daytime sleepiness. There are no prior longitudinal studies on sleep and crime, and cross-sectional studies on child antisocial behavior and sleep have not resolved this issue. We addressed this issue in the current study by showing that adolescent daytime sleepiness still predisposed to adult crime after controlling for adolescent antisociality. This dictates against the counterhypothesis that antisocial behavior results in poor sleep, and instead suggests that sleepiness per se predisposes to crime. We nevertheless caution that while mediation analysis tests causal models, it does not prove them. We cannot rule out the dual possibility that sleepiness predisposes to crime, and also that antisociality may at some point make some contribution to daytime sleepiness. Cross-lagged models which include the measurement of sleep at age 29 could usefully address this issue (Preacher, 2015).

Findings provide support for the contribution of social factors as possible etiological candidates for daytime sleepiness. The serial mediation analyses provided support for a biopsychosocial model in which social adversity results in daytime sleepiness that impairs attention and predisposes to crime. While this is the first attempt in the antisocial–sleep literature to empirically identify a putative etiological basis for the sleeplessness associated with antisocial behavior, other sources clearly need to be pursued in future research, including comorbid mental health conditions that are associated with sleep disruption (Dahl & Lewin, 2002), and also parenting and housing conditions.

Limitations

Limitations of this study need to be acknowledged. First, the sample size was small, although this biases toward Type II error, whereas the current results were statistically significant, in the predicted direction, and predicated on prior findings (Kamphuis, Meerlo, Koolhaas, & Lancel, 2012). Second, daytime subjective sleepiness was based on one short question on two occasions. Nevertheless, very similar single-item assessments of sleepiness–alertness such as the Karolinska Sleepiness Scale have been extensively validated (Brown et al., 2014). Furthermore, these measures received some validation against two objective indicators of attention and vigilance and have the advantage of simplicity in application in a clinical self-report context. Third, we emphasize that much of the supporting literature is predicated on sleep problems/deprivation rather than daytime sleepiness per se. At the same time, daytime sleepiness increases during pubertal development, even with optimal levels of sleep (Dahl & Lewin, 2002), and consequently the construct of daytime sleepiness has ecological validity in the context of adolescent development.

Fourth, we recognize that our causal modeling cannot claim a causal association from adolescent sleepiness to adult crime. Furthermore, because we cannot assess all constructs at each time-point, a half-longitudinal design is not possible and causal inference from our findings is inevitably limited (Preacher, 2015). Sleepiness and attention are also measured at the same point in time. Findings are however consistent with one randomized trial showing that sleep restriction in 15-year olds increased self-reported and parent-reported anger, hostility, and irritability (Baum et al., 2014). Fifth, we had no additional measures of psychopathology which would have allowed us to examine their role in association with sleepiness and crime. Sixth, being based on an entirely male sample, this study cannot speak to the issue of sleepiness and female crime. Seventh, factors other than sleep problems, such as health problems, could be an alternative source of daytime sleepiness (Owens, 2014). Eighth, our electrode montage at the time (Cz) is very limited compared to more recent multichannel EEG research. Ninth, because attention and sleepiness were concurrently measured, it is theoretically possible that poor attention could cause sleepiness, rather than vice-versa.

Clinical implications

One clinical implication of this study is that a simple self-report question on daytime sleepiness may be predictive of a future salient negative outcome (crime) that affects both the perpetrator, their families, and their victims. Given that this subjective measure predicts to crime as well as more expensive and time-consuming objective measures of sleepiness, posing this question to children and adolescents during daytime therapy could have some prognostic utility.

Sleep disturbance has been documented in many psychiatric conditions affecting adolescents, including ADHD, depression (Dahl & Lewin, 2002), alcohol abuse, and schizophrenia (Fazel, Langstrom, Hjern, Grann, & Lichtenstein, 2009). Given raised rates of antisocial/aggressive behavior in these groups (Fazel et al., 2009, 2009) such elevations could be attributable to sleep problems. Given the availability of brief but effective behavioral sleep interventions for

adolescents (Paavonen, Huurre, Tilli, Kiviruusu, & Partonen, 2016), there exists a promising opportunity for prevention and interventions studies to reduce externalizing behavior problems in both clinical and nonclinical adolescent samples.

From a forensic psychology standpoint, daytime sleepiness and sleep measures have never been incorporated into risk assessment tools to predict future dangerousness. Inclusion of one simple question on daytime sleepiness in such instruments could ascertain whether this risk factor has utility in improving recidivism prediction. Relatedly, there exists the potential to reduce future crime by screening high-risk adolescents for sleep problems and providing them with sleep hygiene education to attenuate this risk factor.

Conclusions

We show here that daytime sleepiness during adolescence is associated with adult criminal offending. Adolescence is a developmental time-window during which teenagers have relatively poor sleep, with at least one third getting less than the 8–9 hr of sleep per night that is recommended (Eaton et al., 2010), resulting in daytime sleepiness and fatigue. Sleep researchers have for over a decade argued that early starting times in secondary schools exacerbates sleep problems in adolescents, and the current findings suggest that negative consequences extend well beyond poorer attention, sleepiness, and motivation (Dahl & Lewin, 2002). Sleep is an alterable risk factor for crime, and crime is an enormously costly international public health problem. As such, from a public health perspective greater attention to this neglected health risk factor for crime could have significant beneficial societal and clinical implications beyond better school performance.

Supporting information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Sensitivity analysis for the daytime sleepiness–crime relationship.

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Key points

- Cross-sectional studies have documented associations between sleep problems and antisocial behavior, but longitudinal research is lacking.
- This study documents for the first time an association between daytime sleepiness in adolescence and crime in adulthood.
- Mediation analyses showed that social adversity was associated with increased sleepiness which was associated with poor attention which was in turn associated with later crime.
- A very brief assessment of subjective daytime sleepiness in clinical practice may help to predict future antisocial behavior.
- Behavioral sleep interventions for at-risk children and adolescents could help reduce externalizing problems and adult crime.

References

Akerstedt, T. (2006). Psychosocial stress and impaired sleep. *Scandinavian Journal of Work Environment and Health*, *32*, 493–501.

Allsopp, J.F., & Feldman, M.P. (1976). Personality and Anti-Social Behavior in Schoolboys – Item Analysis of Questionnaire Measures. *British Journal of Criminology*, *16*, 337–351.

Barclay, N.L., Eley, T.C., Maughan, B., Rowe, R., & Gregory, A.M. (2011). Associations between diurnal preference, sleep quality and externalizing behaviours: A behavioural genetic analysis. *Psychological Medicine*, *41*, 1029–1040.

Baum, K.T., Desai, A., Field, J., Miller, L.E., Rausch, J., & Beebe, D.W. (2014). Sleep restriction worsens mood and emotion regulation in adolescents. *Journal of Child Psychology and Psychiatry*, *55*, 180–190.

Boucsein, W. (2012). *Electrodermal activity* (2nd edn). New York: Springer.

Brown, J.G., Wieroney, M., Blair, L., Zhu, S.J., Warren, J., Scharf, S.M., & Hinds, P.S. (2014). Measuring subjective sleepiness at work in hospital nurses: Validation of a modified delivery format of the Karolinska Sleepiness Scale. *Sleep and Breathing*, *18*, 731–739.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd edn). Hillsdale, NJ: Lawrence Erlbaum.

Dahl, R.E., & Lewin, D.S. (2002). Pathways to adolescent health: Sleep regulation and behavior. *Journal of Adolescent Health*, *31*, 175–184.

Dolan, M., & Lennox, C. (2013). Cool and hot executive function in conduct-disordered adolescents with and without co-morbid attention deficit hyperactivity disorder: Relationships with externalizing behaviours. *Psychological Medicine*, *43*, 2427–2436.

Eaton, D.K., McKnight-Eily, L.R., Lowry, R., Perry, G.S., Presley-Cantrell, L., & Croft, J.B. (2010). Prevalence of insufficient, borderline, and optimal hours of sleep among high school students – United States, 2007. *Journal of Adolescent Health*, *46*, 399–401.

El-Sheikh, M., & Arsiwalla, D.D. (2011). Children's sleep, skin conductance level and mental health. *Journal of Sleep Research*, *20*, 326–337.

Eysenck, S., & Eysenck, H.J. (1978). Impulsiveness and venturesomeness: Their position in a dimensional system of personality description. *Psychological Reports*, *43*, 1247–1255.

Fairchild, G., Passamonti, L., Hurford, G., Hagan, C.C., von dem Hagen, E.A., van Goozen, S.H. & Calder, A.J. (2011). Brain structure abnormalities in early-onset and adolescent-onset conduct disorder. *American Journal of Psychiatry*, *168*, 624–633.

Farrington, D. P. (1983). Offending from 10 to 25 years of age. In van Dusen K., & S. A. Mednick (Eds.), *Prospective studies of crime and delinquency* (pp. 17–37). Boston: Kluwer/Nijhoff.

Fazel, S., Langstrom, N., Hjern, A., Grann, M., & Lichtenstein, P. (2009). Schizophrenia, substance abuse, and violent crime. *Journal of the American Medical Association*, *301*, 2016–2023.

Gough, H.G. (1969). *Manual of the California Personality Inventory*. Palo Alto, CA: Consulting Psychologists Press.

Hayes, A.F. (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. New York: Guilford Press.

Kaida, K., Takahashi, M., Akerstedt, T., Nakata, A., Otsuka, Y., Haratani, T. & Fukasawa, K. (2006). Validation of the Karolinska sleepiness scale against performance and EEG variables. *Clinical Neurophysiology*, *117*, 1574–1581.

Kamphuis, J., Dijk, D.J., Spreen, M., & Lancel, M. (2014). The relation between poor sleep, impulsivity and aggression in forensic psychiatric patients. *Physiology and Behavior*, *123*, 168–173.

Kamphuis, J., Meerlo, P., Koolhaas, J.M., & Lancel, M. (2012). Poor sleep as a potential causal factor in aggression and violence. *Sleep Medicine*, *13*, 327–334.

Killgore, W.D.S. (2010). Effects of sleep deprivation on cognition. *Progress in Brain Research*, *185*, 105–129.

Lin, W.H., & Yi, C.C. (2015). Unhealthy sleep practices, conduct problems, and daytime functioning during adolescence. *Journal of Youth and Adolescence*, *44*, 431–446.

Marsh, A.A., Finger, E.C., Fowler, K.A., Jurkowitz, I.T., Schechter, J.C., Yu, H.H., ... & Blair, R.J. (2011). Reduced amygdala-orbitofrontal connectivity during moral judgments in youths with disruptive behavior disorders and psychopathic traits. *Psychiatry Research: Neuroimaging*, *194*, 279–286.

Meijers, J., Harte, J.M., & Scherder, F.V. (2015). Disturbed sleep as a risk factor for aggression in prisoners with a psychotic illness: A brief report. *Psychology Crime and Law*, *21*, 968–972.

Michael, L., Passmann, S., & Becker, R. (2012). Electrodermal lability as an indicator for subjective sleepiness during total sleep deprivation. *Journal of Sleep Research*, *21*, 470–478.

Office of Population Censuses and Surveys (1970). *Classification of occupations*. London: Her Majesty's Stationery Office.

Ohman, A., Hamm, A., & Hugdahl, K. (2000). Cognition and the autonomic nervous system: Orienting, anticipation, and conditioning. In J.T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (pp. 533–575). Cambridge, UK: Cambridge University Press.

Owens, J. (2014). Insufficient sleep in adolescents and young adults: An update on causes and consequences. *Pediatrics*, *134*, E921–E932.

Paavonen, E.J., Huurre, T., Tilli, M., Kiviruusu, O., & Partonen, T. (2016). Brief behavioral sleep intervention for adolescents: An effectiveness study. *Behavioral Sleep Medicine*, *14*, 351–366.

Patel, N.P., Grandner, M.A., Xie, D.W., Branas, C.C., & Gooneratne, N. (2010). "Sleep disparity" in the population: Poor sleep quality is strongly associated with poverty and ethnicity. *BMC Public Health*, *10*, Advanced online publication. doi: 10.1186/1471-2458-10-475.

Pieters, S., Burk, W.J., Van der Vorst, H., Dahl, R.E., Wiers, R.W., & Engels, R.C.M.E. (2015). Prospective relationships between sleep problems and substance use, internalizing and externalizing problems. *Journal of Youth and Adolescence*, *44*, 379–388.

Preacher, K.J. (2015). Advances in mediation analysis: A survey and synthesis of new developments. *Annual Review of Psychology*, *66*, 825–852.

Quay, H.C., & Parsons, L.B. (1970). *The differential classification of the juvenile offender*. Washington, DC: Bureau of Prisons.

Raine, A. (1987). Effect of early environment on electrodermal and cognitive correlates of schizotypy and psychopathy in criminals. *International Journal of Psychophysiology*, *4*, 277–287.

Raine, A., Venables, P.H., & Williams, M. (1990a). Autonomic orienting responses in 15-year-old male subjects and criminal behavior at age 24. *American Journal of Psychiatry*, *147*, 933–937.

Raine, A., Venables, P.H., & Williams, M. (1990b). Relationships between central and autonomic measures of arousal at age 15 years and criminality at age 24 years. *Archives of General Psychiatry*, *47*, 1003–1007.

Raine, A., Venables, P.H., & Williams, M. (1995). High autonomic arousal and electrodermal orienting at age 15 years as protective factors against criminal behavior at age 29 years. *American Journal of Psychiatry*, *152*, 1595–1600.

Scharf, R.J., Demmer, R.T., Silver, E.J., & Stein, R.E. (2013). Nighttime sleep duration and externalizing behaviors of preschool children. *Journal of Developmental and Behavioral Pediatrics*, *34*, 384–391.

Semiz, U.B., Algül, A., Başoğlu, C., Ateş, M.A., Ebrinç, S., Cetin, M., ... & Günay, H. (2008). The relationship between subjective sleep quality and aggression in male subjects with antisocial personality disorder. *Turk Psikiyatri Dergisi*, *19*, 373–381.

Shao, Y.C., Lei, Y., Wang, L.B., Zhai, T.Y., Jin, X., Ni, W., ... & Yang, Z. (2014). Altered resting-state amygdala functional connectivity after 36 hours of total sleep deprivation. *PLoS One*, *9*. Advanced online publication. doi: 10.1371/journal.pone.0112222.

Williams, L.M., Felmingham, K., Kemp, A.H., Rennie, C., Brown, K.J., Bryant, R.A., & Gordon, E. (2007). Mapping frontal-limbic correlates of orienting to change detection. *NeuroReport*, *18*, 197–202.

Yang, Y.L., & Raine, A. (2009). Prefrontal structural and functional brain imaging findings in antisocial, violent, and psychopathic individuals: A meta-analysis. *Psychiatry Research: Neuroimaging*, *174*, 81–88.

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