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A cognitive-behavioral and mindfulness-based group sleep intervention improves behavior problems in at-risk adolescents by improving perceived sleep quality

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A R T I C L E   I N F O

A B S T R A C T

Objective: The aim of this study was to test whether a cognitive-behavioral and mindfulness-based group sleep intervention would improve behavior problems in at-risk adolescents, and whether these improvements were specifically related to improvements in sleep.

Method: Secondary analysis of a randomized controlled trial conducted with 123 adolescent participants (female = 60%; mean age = 14.48, range 12.04–16.31 years) who had high levels of sleep problems and anxiety symptoms. Participants were randomized into either a sleep improvement intervention (n = 63) or an active control "study skills" intervention (n = 60). Participants completed sleep and behavior problems questionnaires, wore an actiwatch and completed a sleep diary for five school nights, both before and after the intervention.

Results: Parallel multiple mediation models showed that postintervention improvements in social problems, attention problems, and aggressive behaviors were specifically mediated by moderate improvements in self-reported sleep quality on school nights, but were not mediated by moderate improvements in actigraphy-assessed sleep onset latency or sleep diary-measured sleep efficiency on school nights.

Conclusion: This study provides evidence, using a methodologically rigorous design, that a cognitive-behavioral and mindfulness-based group sleep intervention improved behavior problems in at-risk adolescent by improving perceived sleep quality on school nights. These findings suggest that sleep interventions could be directed towards adolescents with behavior problems.

Clinical Trial Registration: This study was part of The SENSE Study (Sleep and Education: learning New Skills Early). URL: ACTRN12612001177842; http://www.anzctr.org.au/TrialSearch.aspx?searchTxt=ACTRN12612001177842&isBasic=True.

1. Introduction

Many adolescents obtain insufficient and/or poor quality sleep, which is increasingly regarded as an important public health problem (American Medical Association, 2010). Adolescents are thought to optimally require approximately nine hours of sleep per night (Fuligni, Arruda, Krull, & Gonzales, 2017). However, a recent meta-analysis found that 53% of adolescents obtain less than 8 h of sleep on school nights, and 36% report difficulty falling asleep (Gradisar, Gardner, & Dohnt, 2011). Physiological maturation processes (Colrain & Baker, 2011) and

social/cultural factors (Bartel, Gradisar, & Williamson, 2015; Maume, 2013) interact in adolescence so that reduced sleep propensity in the late evening becomes permissive of continued waking activities and delayed bedtimes (BT). This delay in sleep onset results in sleep restriction, because school starts early in the morning. Further, sleep has reduced restorative value, because recovery sleep tends to occur at an inappropriate circadian phase (Carskadon, 2011). Adolescents are also vulnerable to the same processes that cause insomnia in adults, such as susceptibility to hyperarousal (Alfano, Pina, Zerr, & Villalta, 2010; Blake et al., 2017a; Riemann et al., 2010).

Sleep disturbance is an important contributor to increased vulnerability and risk among young people (Harvey, 2015). There is emerging evidence that adolescent sleep disturbance may precipitate and maintain many emotional and behavioral problems (Dahl & Harvey, 2007). Indeed, recent reviews have concluded that sleep problems, particularly wakefulness in bed (e.g., prolonged sleep onset latency [SOL] and poor sleep efficiency [SE]), precede the development of anxiety and depression in adolescence more than the reverse (Lovato & Gradisar, 2014; McMakin & Alfano, 2015). However, in comparison to internalizing symptoms, relatively few studies have examined the role of sleep disturbance in adolescent behavior problems (Becker, Langberg, & Byars, 2015).

Cross-sectional, experimental, naturalistic, and longitudinal studies have consistently shown that adolescent sleep disturbance is associated with social problems, attention problems, and aggressive behaviors, including school non attendance (Shochat, Cohen-Zion, & Tzischinsky, 2014), social withdrawal (Carney, Edinger, Meyer, Lindman, & Istre, 2006), loneliness (Mahon, 1994), difficulties in peer relationships (Roberts, Roberts, & Chen, 2002; Sarchiapone et al., 2014), inattentive behaviors (Gregory & O'Connor, 2002; O'Callaghan et al., 2010), academic problems (Shochat et al., 2014), oppositionality (Beebe et al., 2008), and hostile behaviors (Gregory & O'Connor, 2002; Gregory, Van der Ende, Willis, & Verhulst, 2008; Ireland & Culpin, 2006), which may mimic Attention Deficit Hyperactivity Disorder (ADHD) and Conduct Disorder (Dahl, 1996). However, further high quality longitudinal and treatment outcome studies are needed that examine the prospective and causal associations between poor sleep and behavior problems in adolescents (Becker et al., 2015; Dewald, Meijer, Oort, Kerkhof, & Bögels, 2010; Shochat et al., 2014).

Adolescents with concomitant sleep and internalizing problems may be particularly vulnerable to behavior problems. Young people with anxiety disorders exhibit exaggerated hypoconnectivity between the prefrontal cortex (PFC) and amygdala (Hamm et al., 2014), and adolescents with depression show elevated activity in extended medial networks regions, including the anterior cingulate cortex, ventromedial and orbitofrontal cortices, and amygdala (Kerestes, Davey, Stephanou, Whittle, & Harrison, 2014). Adolescents with internalizing symptoms are also prone to cognitive biases, including interpretational biases, judgment biases, negative attributional styles, and hypervigilance for threat (Garber & Weersing, 2010; Price et al., 2016). These physiologic and cognitive/emotional vulnerabilities are likely to further compromise their behavior regulation, especially under conditions of sleep deprivation. In support of this, children and adolescents with anxiety and depressive disorders have been shown to use maladaptive ways of regulating their behavior, including avoidance, excessive reassurance seeking, and less effective problem-solving (Thompson et al., 2010; Garber & Weersing, 2010; Thompson et al., 2010; Tsypes, Aldao, & Mennin, 2013; Weems, Silverman, & Greca, 2000). Furthermore, adolescents with internalizing problems may have particular difficulties adhering to good sleep hygiene behaviors (Blake et al., 2017a), as they may spend more time in their bedroom and delay sleep as a means of avoiding disorder-specific stressors and cognitions.

These findings suggest that quality sleep in childhood and adolescence is critical for optimizing emotional health, social functioning, and cognitive development. Moreover, early treatment programs for sleep problems might reduce the risk for developing internalizing disorders and behavior problems and can be considered a helpful general preventive strategy. Sleep disturbance in adolescents can be treated using a range of approaches. Recent reviews have suggested that while school-based sleep education programs are effective for improving students' knowledge about sleep and insomnia, they are less effective for improving sleep behavior or mental health (Blunden & Rigney, 2015; Blunden, Chapman, & Rigney, 2012; Gruber, 2017). This is consistent with research showing that targeted interventions are more effective than universal interventions in preventing child and adolescent mental health problems (Rohde, 2015), and that simple sleep hygiene instruction does not guarantee positive outcomes in adults (Irish, Kline, Gunn, Buysse, & Hall, 2015).

There is emerging evidence that adolescent sleep problems can be treated more effectively using cognitive-behavioral therapies. Cognitive-behavioral therapy for insomnia (CBT-I) is recommended as a front-line treatment for adult insomnia (Qaseem, Kansagara, Forciea, Cooke, & Denberg, 2016), based on evidence from multiple systematic reviews and meta-analyses that the intervention improves sleep and mental health in adults, usually with medium-large effect sizes (Ballesio et al., 2017; Taylor & Pruiksma, 2014; Trauer, Qian, Doyle, Rajaratnam, & Cunnington, 2015; Van Straten et al., 2017). CBT-I involves behavioral techniques such as sleep hygiene instruction, stimulus control, sleep restriction therapy, and relaxation training, but also addresses unhelpful beliefs and attitudes about sleep (for a review, see Edinger & Means, 2005). There is also emerging evidence that sleep problems can be treated successfully using protocols that include a mindfulness component (for a meta-analytic review, see Gong et al., 2016). Mindfulness meditation is especially indicated for sleep-related problems because it aims to reduce the hyperarousal and negative emotional states that are frequently reported by individuals with sleep problems (Harvey, 2002; Riemann et al., 2010).

Research on adolescent cognitive-behavioral and mindfulness-based sleep interventions is not as developed as the adult literature. A recent systematic review and meta-analysis found that only nine trials ($n = 357$) have examined the efficacy of face-to-face cognitive-behavioral sleep interventions among adolescents with self-identified sleep problems or a diagnosis of a sleep disorder (mean age = 14.97 years, range 11–20 years; Blake, Sheeber, Youssef, Raniti, & Allen, 2017b). Two of the studies evaluated "manualized" CBT-I, whereas the other interventions included added treatment components (e.g., mindfulness, anxiety/depression specific modules). The results showed that the sleep interventions produced marked and statistically significant improvements in objective and self-reported indices of sleep, daytime sleepiness, anxiety, and depression at post-intervention time points. Moreover, gains were generally maintained over time. As with adults, improvements tended to be stronger for wakefulness in bed variables (SOL and SE) compared to sleep duration variables, and self-reported sleep variables compared to objective sleep variables (Trauer et al., 2015). However, the trials included in the meta-analysis were limited in several ways, including small sample sizes, lack of control groups, waitlist control groups, high attrition rates, low generalizability, lack of follow-ups, short follow-ups, failure to differentiate between weekday and weekend sleep, and/or reliance on self-reported measures of sleep. Therefore, high quality, large-scale controlled treatment outcome studies are needed to confirm the findings; in particular, studies are needed that comprehensively assess sleep and functional outcomes. No previous randomized controlled trials (RCTs) have examined the effects of a cognitive-behavioral sleep intervention on adolescent behavior problems, so we know relatively little about these outcomes. Therefore, secondary analyses of non-primary outcomes may be beneficial.

The SENSE Study is an RCT investigating whether a 7-week, cognitive-behavioral and mindfulness-based group sleep intervention can prevent the emergence of Major Depressive Disorder (MDD) at 2-year follow-up among a group of adolescents (aged 12–17) who were experiencing high levels of sleep problems and anxiety symptoms (Waloszek et al., 2015). Strengths of the SENSE study are the large sample size, the well-defined manual-driven treatment consisting of

components demonstrated to improve sleep in prior research, the time- and format-equated active control 'study skills' condition, and the use of both self-reported and objective measures of sleep duration and quality. We have previously reported the postintervention effects of the intervention on sleep and internalizing symptoms (Blake et al., 2017a; Blake et al., 2016). The results showed that the sleep intervention condition ("Sleep SENSE") was associated with significantly greater improvements in actigraphy-measured SOL, sleep-diary measured SE, perceived sleep quality, daytime sleepiness, and anxiety compared to the active control condition ("Study SENSE"), with small to medium effect sizes. The aim of the present study was to examine the effects of the intervention on behavior problems at postintervention. We predicted that the Sleep SENSE intervention would improve social problems, attention problems, and aggressive behaviors in adolescents who were experiencing high levels of sleep problems and anxiety symptoms, and that these improvements would be specifically mediated by the measured improvements in objective and self-reported sleep that resulted from the interventions.

2. Methods

The full methods of the SENSE Study were reported in Waloszek et al. (2015), Blake et al. (2016), and Blake et al. (2017a). Here, we focus on the methods relevant to the present analyses.

2.1. Design

The study used a parallel RCT design that followed all CONSORT RCT requirements for non-pharmacological trials in order to ensure the quality, accuracy, and integrity of the trial (Moher et al., 2012). The study utilized appropriate randomization sequence generation and allocation concealment, attempted to minimize interventional contamination and operator bias, provided blinded assessment of study endpoints, and included a detailed record of participant flow (see Fig. 1). The experimental group took part in a cognitive-behavioral and mindfulness-based sleep intervention (Sleep SENSE) and the active control group took part in a study skills educational program (Study SENSE). The control intervention was chosen to have strong face validity as an intervention that addresses salient issues for adolescents and to entail similar delivery format, levels of effort, and engagement with facilitators, as did the sleep intervention.

2.2. Ethics, consent and permissions

Participants were recruited from secondary schools in the Melbourne Metropolitan Area, Australia. Preintervention and postintervention data collection was conducted in the Melbourne School of Psychological Sciences at the University of Melbourne, Australia. Interventions were also held after school at the University, except for one group that was held at the participants' school. The study and all procedures were approved by the University of Melbourne Human Research Ethics Committee (HREC#1237312), the Department of Education and Early Childhood Development (DEECD) (2012_001659), and the Catholic Education Office Melbourne (CEOM) (GE12/000091819). It also complied with the Australian National Health and Medical Research Council guidelines. All participants and their guardians gave written informed consent before participating in the study. The trial is registered with the Australian New Zealand Clinical Trials Registry (ACTRN12612001177842; http://www.anzctr.org.au/TrialSearch.aspx?searchTxt=ACTRN12612001177842&isBasic=True).

2.3. Procedure

The overall study has five data collection phases (Waloszek et al., 2015). The present paper reports on the first four phases (school recruitment/screening, diagnostic interview, pre-intervention assessments,

and post-intervention assessments), which were completed in 2013–14. Phase five (2-year follow-up) will be completed in 2017. Details of phases 1–4, the recruitment process, and participant numbers can be found in Fig. 1. Participants were reimbursed for their time and travel expenses with a department store voucher for each assessment phase.

2.4. Participant recruitment

Participants were recruited using a two-stage procedure, consisting of an in-school screening followed by a diagnostic interview for those meeting screening criteria, to identify students with high levels of anxiety and sleeping difficulties but without a history of MDD. One hundred and one schools were contacted via letters or emails describing the study. Schools who did not wish to participate in the study ($n = 78$) indicated they did not have enough time due to a full curriculum, were already participating in other research studies (i.e., decline, $n = 47$) or the school coordinator was not contactable (i.e., passive decline, $n = 29$). One school consented but did not participate and another school withdrew consent after participating. All students in Years 7 through 10 were invited to participate in the study. Seventeen hundred and thirty-seven students provided written parental consent to participate in the screening and were asked to attend the screening assessment session. Fourteen hundred and ninety-one students completed the screening questionnaire. Two hundred and seventy participants declined to participate after their parents had provided consent, and 246 participants were absent from school during the screening.

2.5. Inclusion & exclusion criteria

Participants whose ratings on the screening questionnaire indicated high anxiety (Spence Children's Anxiety Scale ([SCAS] total score > 32 and > 38 for males and females respectively; [84th percentile or above, based on population norms described at www.scas.webiste.com]; Spence, 1998), as well as the likely presence of sleep problems (Pittsburgh Sleep Quality Index [PSQI] global score > 4; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989), were invited to take part in a face-to-face diagnostic interview based on DSM-IV-TR criteria (the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version [K-SADS-PL]; Axelson, Birmaher, Zelazny, Kaufman, & Kay Gill, 2009) with trained interviewers. Three hundred and ninety-seven participants met criteria after the school screening and were invited to participate in the interview; 218 consented to participate. Participants who scored above the cut-off in the SCAS and PSQI in the screening assessment, indicating high levels of anxiety symptoms and sleep problems, but not necessarily the presence of an anxiety or sleep disorder, and who had never met criteria for MDD, as assessed using the KSADS-PL, were invited to participate in the intervention stage of the study. Those with a history of MDD ($n = 30$, 13.7%) were excluded because the study's ultimate goal was to prevent first incidence of MDD at 2-year follow-up (Blake et al., 2016; Waloszek et al., 2015). Other exclusion criteria were current or past diagnoses of bipolar or psychotic disorder, and inadequate comprehension of written and spoken English. No participants were excluded for these reasons. Medication use was also assessed at preintervention and postintervention. No participants reported taking psychiatric medication during the interventions (e.g., hypnotics, anxiolytics, anti-depressants, stimulants).

2.6. Data collection

One hundred and eighty-eight participants met inclusion criteria after the diagnostic interview. Participants who met inclusion criteria after the diagnostic interview and who consented to participate in the intervention stage of the trial ($n = 144$) were asked to complete a number of assessments. At each assessment phase, participants completed sleep and behavior problems questionnaires, and wore an Actiwatch and completed a sleep diary for five school nights. We analyzed school night sleep because
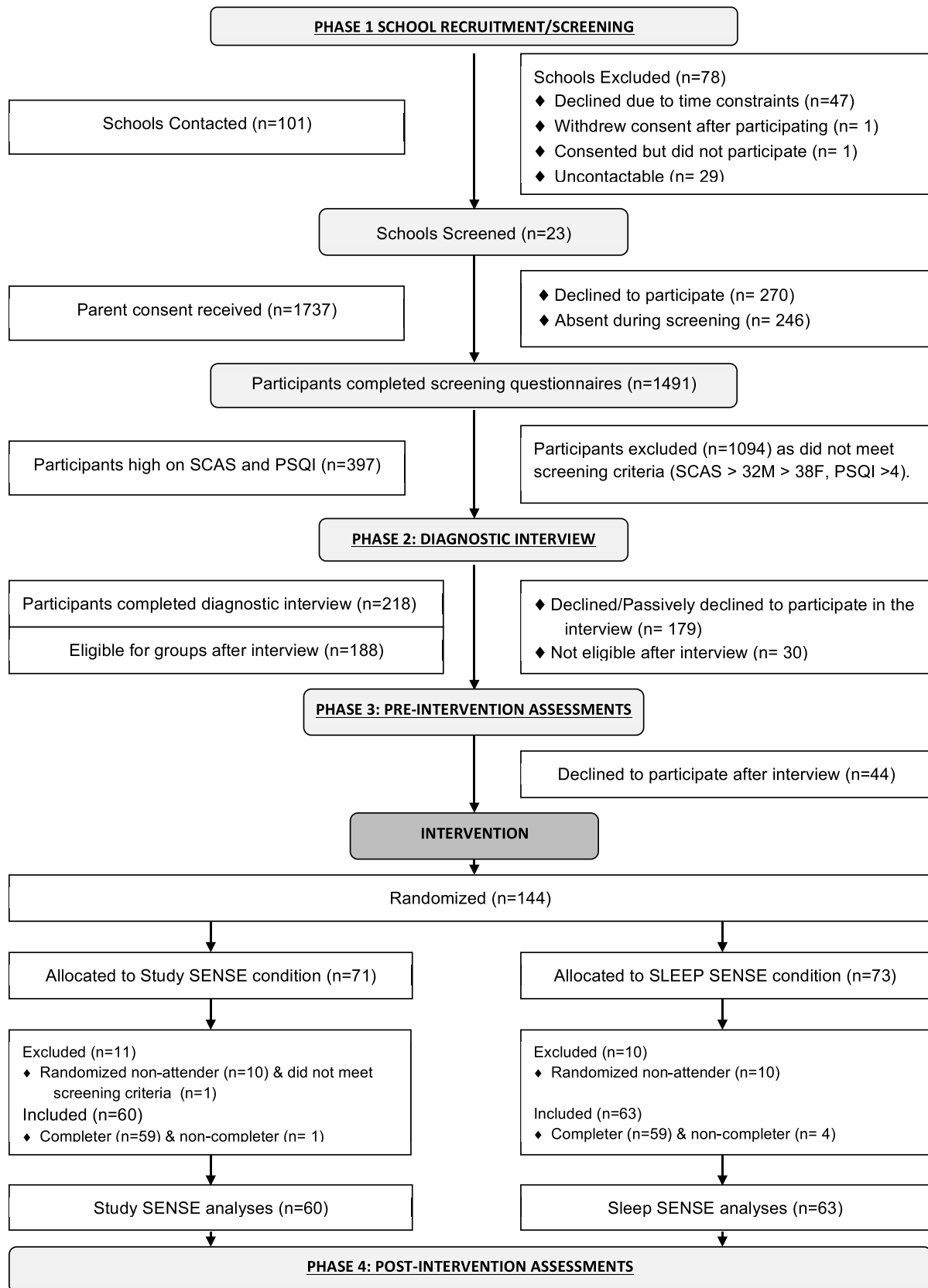
PHASE 1 SCHOOL RECRUITMENT/SCREENING

Schools Contacted (n=101)

Schools Excluded (n=78)
- ◆ Declined due to time constraints (n=47)
- ◆ Withdrew consent after participating (n= 1)
- ◆ Consented but did not participate (n= 1)
- ◆ Uncontactable (n= 29)

Schools Screened (n=23)

Parent consent received (n=1737)

- ◆ Declined to participate (n= 270)
- ◆ Absent during screening (n= 246)

Participants completed screening questionnaires (n=1491)

Participants high on SCAS and PSQI (n=397)

Participants excluded (n=1094) as did not meet screening criteria (SCAS > 32M > 38F, PSQI >4).

PHASE 2: DIAGNOSTIC INTERVIEW

Participants completed diagnostic interview (n=218)

Eligible for groups after interview (n=188)

- ◆ Declined/Passively declined to participate in the interview (n= 179)
- ◆ Not eligible after interview (n= 30)

PHASE 3: PRE-INTERVENTION ASSESSMENTS

Declined to participate after interview (n=44)

INTERVENTION

Randomized (n=144)

Allocated to Study SENSE condition (n=71)

Allocated to SLEEP SENSE condition (n=73)

Excluded (n=11)
- ◆ Randomized non-attender (n=10) & did not meet screening criteria (n=1)

Included (n=60)
- ◆ Completer (n=59) & non-completer (n= 1)

Excluded (n=10)
- ◆ Randomized non-attender (n=10)

Included (n=63)
- ◆ Completer (n=59) & non-completer (n= 4)

Study SENSE analyses (n=60)

Sleep SENSE analyses (n=63)

PHASE 4: POST-INTERVENTION ASSESSMENTS

Fig. 1. Flowchart of participants through the SENSE Study (Phases 1–4).

of the well-established discrepancy between weekday and weekend/holiday sleep habits in adolescents (Gradisar et al., 2011), and because social problems, attention problems, and aggressive behaviors are more likely to occur at school.

2.7. Randomization and blinding

Eligible participants who consented to participate in the intervention stage of the trial were randomly allocated to receive either the

2.10.4. Anxiety

At the screening, preintervention and postintervention phases, participants also completed the *Spence Children's Anxiety Scale* (SCAS; Spence, 1998). The SCAS is a 44 item self-report measure designed to measure the frequency with which children and adolescents experience anxiety symptoms. It has been shown to have good internal consistency ($\alpha = 0.92$) and 3-month temporal stability ($r = 0.63$) among 12–15 year olds (Muris, Schmidt, & Merckelbach, 2000; Spence, Barrett, & Turner, 2003), as well as strong convergent validity with other measures of anxiety and good divergent validity with measures of depression (Spence et al., 2003). Internal consistency statistics for the total score in the current sample were excellent (preintervention $\alpha = 0.89$; postintervention $\alpha = 0.91$).

2.10.5. Affective and psychotic disorders

At the screening phase, participants were also administered the *Kiddie Schedule of Affective Disorders and Schizophrenia Children's Version - Present and Lifetime Version* (K-SADS-PL; Axelson et al., 2009). The K-SADS-PL is a semi-structured diagnostic interview designed to identify past or present psychopathology in children and adolescents. It has been shown to be a reliable and valid measure of Diagnostic and Statistical Manual of Mental Disorders, fourth edition (DSM–IV) Axis I disorders among children and adolescents (Kaufman et al., 1997). The following modules were administered: depression, mania, psychosis, panic disorder, social phobia, specific phobia/agoraphobia, generalized anxiety, obsessive-compulsive disorder, separation anxiety, and post-traumatic stress disorder. Graduate clinical psychology students and research assistants administered the interviews. A clinical psychologist provided regular clinical supervision to all interviewers. Approximately 20% of interviews were double-scored by another interviewer who listened to a de-identified audio recording of the interview. Inter-rater reliability was assessed using Byrt, Bishop, and Carlin's (1993) prevalence-adjusted and bias adjusted kappa (PABAK) statistic. Analyses were conducted at the item level, which included symptoms and diagnoses. PABAK kappa was calculated at 0.98 for this study.

2.11. Data processing

2.11.1. Actigraphy variables

BT and RT were determined by visually screening the actograms using the collective information of movement, light (when available), event markers (when available) and sleep diary (when available). A recent study suggests this procedure ("human scoring") has a good correlation with polysomnography and a superior correlation to automated machine algorithms in determining BT and RT among adolescent samples (Boyne, Sherry, Gallagher, Olsen, & Brooks, 2013). The following school night actigraphy sleep variables were calculated: total sleep time (TST [minutes]), SOL (minutes), SE (percent), wake after sleep onset (WASO [minutes]), and BT [hh:mm]). Actigraphy variables are objective and use the suffix "obj" (e.g., SOL$_{obj}$).

2.11.2. Self-reported variables

The following school night sleep diary variables were calculated: TST (minutes), SOL (minutes), SE (percent), WASO (minutes), and BT (hh:mm). Sleep diary variables use the suffix "subj" (e.g., SE$_{subj}$). PSQI global, SCAS total, and CBCL subscale scores were calculated using the standard methods recommended by the authors of the scales (Achenbach, 1991; Buysse et al., 1989; Spence, 1998).

2.12. Statistical analyses

A "modified intention to treat" approach was taken; intervention completers ($n = 118$) and non-completers ($n = 5$) were included in analyses, but randomized non-attenders ($n = 20$; defined above) were excluded. Missing data were imputed using the multiple imputation procedure with five imputation data sets in SPSS. There was a low incidence of missing data for the questionnaire (5.5% average) and actigraphy (6.1%) variables. On average, participants wore the actiwatch on 4.5 of the 5 school nights at preintervention and postintervention. There was a higher incidence of missing data for the sleep diaries variables (14.6%). On average, participants completed the sleep diaries on 3.75 of the 5 school nights at preintervention and postintervention.

A series of parallel multiple mediation analyses were conducted using the statistical program PROCESS (Model 4; Hayes, 2013) to examine the effects of the two treatment conditions (X; 0 = Study SENSE, 1 = Sleep SENSE) on the behavior outcomes (Y's: postintervention scores for the CBCL-SP, CBCL-AP, CBCL-AB variables) through the putative treatment mechanisms (M's: postintervention scores for the objective and self-reported sleep variables). All analyses used ordinary least squares path analysis and bias corrected bootstraps based on 10,000 resamples. Preintervention scores for the mediating and outcome variables were included as covariates in the respective models to control for individual differences.

The effects of treatment condition on the behavior problem variables (Y's) were the *direct effects*. The direct effects quantified the estimated difference in the behavior problem variables between participants in the Sleep SENSE and Study SENSE conditions at postintervention independent of the mediating (sleep) variables. The effects of treatment condition (X) on the behavior problem variables (Y's) through the sleep variables as a whole (M's) were the *total indirect effects*. The total indirect effects quantified how much participants in the Sleep SENSE and Study SENSE conditions differed on the behavior problem variables at postintervention as a result of the influence of the treatment conditions on the sleep variables as a whole, which in turn influenced the behavior problem variables. The effects of treatment condition (X) on the behavior problem variables (Y's) through specific sleep variables (M's) were the *specific indirect effects*. The specific indirect effects quantified how much participants in the Sleep SENSE and Study SENSE conditions differed on the behavior problem variables at postintervention as a result of the influence of the treatment conditions on the specific sleep variables, holding scores on the other mediators constant (i.e., controlling for scores on the other mediators), which in turn influenced the behavior problem variables. The sums of the direct and total indirect effects were the *total effects*. There is growing consensus among quantitative methodologists that a total effect of X on Y should not be a prerequisite for searching for evidence of indirect effects, as the total effect is not always a good estimator of X 's effect on Y (Hayes & Rockwood, 2016; Hayes, 2013). In other words, X may exert its influence on Y through multiple pathways (i.e., direct effects, total indirect effects, and/or specific indirect effects). Specifically, because the total effect of X on Y is an aggregation of various direct and indirect effects, which may be in different directions, requiring an initial significant total effect before testing mediation may mask important significant indirect effects.

Sleep variables that did not show statistically significant treatment effects (i.e., one-way between groups ANCOVAs that were not statistically significant, as reported in Blake et al., 2017a; Blake et al., 2016) were not included as mediating variables in the analyses. Therefore, mediating variables were SOL$_{obj}$, SE$_{subj}$, and PSQI global. Outcome variables were CBCL-SP, CBCL-AP, and CBCL-AB. Fig. 2 shows a conceptual diagram of the parallel multiple mediation models. Parallel multiple mediation has several advantages: (a) the likelihood of bias due to correlated or omitted variables is reduced; (b) spurious association can be separated from potential causal association; and (c) competing theories can be compared (i.e., comparison of specific indirect effects; Hayes & Rockwood, 2016; Hayes, 2013).
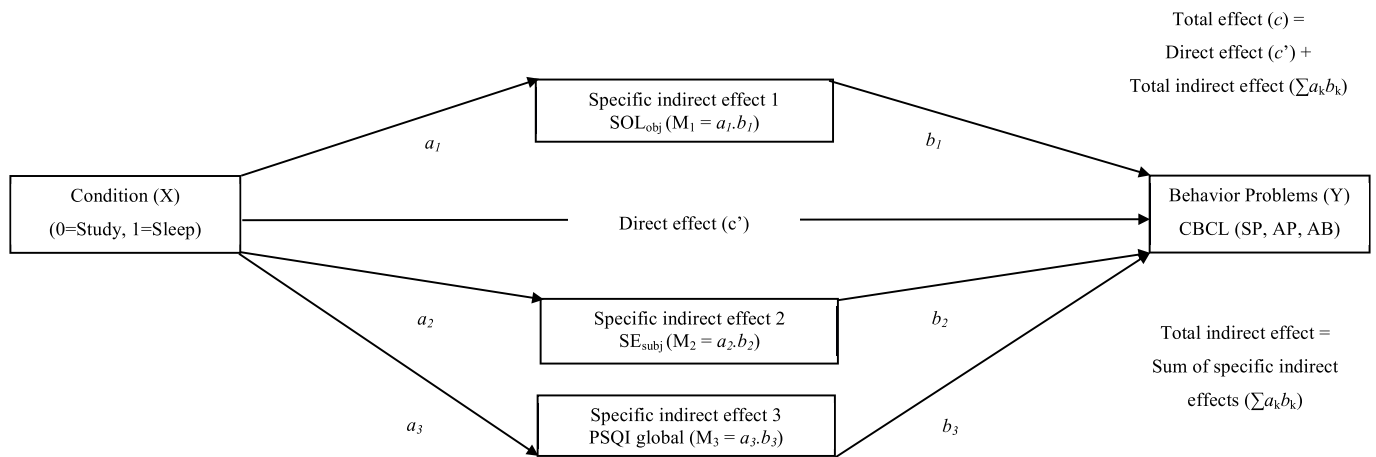
Fig. 2. Conceptual diagram of the parallel multiple mediation models. *AB* Aggressive Behaviors subscale, *AP* Attention Problems subscale, *CBCL* Child Behavior Checklist – Youth Self Report Version, *PSQI global* Pittsburgh Sleep Quality Index global score on school nights, *SEsubj*, sleep diary measured sleep efficiency on school nights (percentage), *SOLobj*, actigraphy measured sleep onset latency on school nights (minutes), *SP* Social Problems subscale.

3. Results

3.1. Demographic and descriptive statistics

One hundred and twenty-three participants began the interventions (female = 60%; mean age = 14.48, standard deviation = 0.95, range 12.04–16.31 years), with 60 in the Sleep SENSE condition and 63 in the Study SENSE condition. Full demographic and descriptive statistics for the sleep and anxiety variables were previously reported in Blake et al. (2016) and Blake et al. (2017a). Consistent with the inclusion criteria, the intervention sample was characterized by short sleep duration, wakefulness in bed, and poor sleep quality on school nights prior to the interventions (i.e., at phase 3). Average TST_{obj} was 6:47 h, SOL_{obj} 29.78 min, SE_{obj} 79.25, $WASO_{obj}$ 59.42 min, and PSQI global score 6.3. Although no specific quantitative parameters define insomnia disorder, TST less than 6:30 h, SOL greater than 30 min, and SE less than 85% are common manifestations of insomnia (Lichstein, Durrence, Taylor, Bush, & Riedel, 2003) and PSQI global greater than 5 indicates sleeping problems in adults (Buysse et al., 1989). The intervention sample was also characterized by anxiety symptoms prior to the interventions. Average SCAS was 28.5 for males and 36.17 for females – scores greater than 32 for males and 38 for females are indicative of sub-clinical anxiety (Spence, 1998). Descriptive statistics for the CBCL-SP, CBCL-AP and CBCL-AB are provided in Table 2. Prior to the interventions, social problems, attention problems, and aggressive behavior scores were within normal ranges for adolescents (approximately 72nd, 72nd–74th, and 54th–58th percentiles respectively; Achenbach, 1991). There were no statistically significant differences between the Sleep SENSE and Study SENSE conditions on the behavior problems variables prior to the interventions (all $p > 0.05$; Table 2).

3.2. Mediation models

A summary of the parallel multiple mediation results is provided in Table 3. Postintervention improvements in CBCL-SP, CBCL-AP, and CBCL-AB were specifically mediated by the moderate improvements in PSQI global (but not SOL_{obj} or SE_{subj}) that resulted from the interventions. That is, postintervention improvements in social problems, attention problems, and aggressive behaviors were specifically associated with postintervention improvements in self-reported sleep quality on school nights, the only specific indirect paths to show evidences of effects (-0.44, -0.50, and -0.64 units respectively). Thus, even though the *direct and total effects* of treatment condition on social problems, attention problems, and aggressive behaviors were not statistically different from zero, there was clear evidence of *specific indirect effects* of treatment condition on behavior problems through perceived sleep quality.

Notably, there was also some evidence of a countervailing effect of the Sleep SENSE intervention on social problems – the direct effect for this model was in the positive direction. This suggests that the Sleep SENSE intervention increased social problems after controlling for the indirect effect on social problems through perceived sleep quality. While the direct effect was sizeable (0.62) it was non-significant, possibly because power to detect a direct effect is significantly lower than power to detect indirect effects (Kenny & Judd, 2014).

Finally, reverse mediation models, in which outcomes were used as mediators, were conducted, to examine the possibility of bi-directional improvements between sleep and behavior problems. However, the results showed that postintervention improvements in PSQI global, SOL_{obj}, and SE_{subj} were not specifically related to changes in CBCL-SP,

Table 2
Descriptive statistics for the behavior problem variables.

Domain	Variable	Intervention Sample $n = 123$		Sleep SENSE $n = 63$				Study SENSE $n = 60$			
		Preintervention (Phase 3)		Preintervention (Phase 3)		Postintervention (Phase 4)		Preintervention (Phase 3)		Postintervention (Phase 4)	
		M	SD	M	SD	M	SD	M	SD	M	SD
Behavior Problems	CBCL-SP	3.79	2.29	3.96[ns]	2.41	3.82	2.43	3.61[ns]	2.17	3.65	2.68
	CBCL-AP	6.81	2.87	6.74[ns]	2.80	6.25	3.07	6.89[ns]	2.97	6.67	2.81
	CBCL-AB	8.44	4.29	8.80[ns]	4.61	8.24	4.84	8.05[ns]	3.93	8.34	4.52

AB Aggressive Behaviors subscale, *AP* Attention Problems subscale, *CBCL* Child Behavior Checklist – Youth Self Report Version, *SP* Social Problems subscale.
ns Independent samples t-tests indicated that the differences in CBCL-SP ($t = (121) = 0.86$, $p = 0.39$), CBCL-AP ($t = (121) = -0.29$, $p = 0.78$) and CBCL-AB ($t = (121) = 0.97$, $p = 0.34$) between the Sleep SENSE and Study SENSE conditions prior to the interventions were not statistically significant.

Table 3
Summary of the results from the parallel multiple mediation models.

Dependent Variable	Total Effect (CI)	Direct Effect (CI)	Total Indirect Effect (CI)	Specific Indirect Effects (CI)		
				SOL_{obj}	SE_{subj}	PSQI global
CBCL-SP	0.10 (−0.65, 0.86)	0.62 (−0.17, 1.41)	−0.52 (−1.00, −0.15)*	−0.03 (−0.25, 0.10)	−0.04 (−0.29, 0.16)	−0.44 (−0.86, −0.18)*
CBCL-AP	−0.42 (−1.34, 0.50)	0.05 (−0.90, 1.01)	−0.47 (−1.04, −0.02)*	0.13 (−0.06, 0.45)	−0.11 (−0.48, 0.12)	−0.50 (−0.94, −0.21)*
CBCL-AB	−0.57 (−2.00, 0.86)	−0.04 (−1.57, 1.49)	−0.53 (−1.39, 0.12)	0.17 (−0.10, 0.62)	−0.07 (−0.56, 0.36)	−0.64 (−1.26, −0.22)*

AP Attention Problems subscale, *AB* Aggressive Behaviors subscale, *CBCL* Child Behavior Checklist - Youth Self Report Version, *CI* confidence interval, *PSQI global* Pittsburgh Sleep Quality Index global score on school nights, SE_{subj}, sleep diary measured sleep efficiency on school nights, SOL_{obj}, actigraphy measured sleep onset latency on school nights, *SP* Social Problems subscale.
*Evidence of an effect (95% bias corrected bootstrap confidence interval did not include zero).

Table 4
Summary of the results from the reverse parallel multiple mediation models.

Dependent Variable	Total Effect (CI)	Direct Effect (CI)	Total Indirect Effect (CI)	Specific Indirect Effects (CI)		
				CBCL-SP	CBCL-AP	CBCL-AB
SOL_{obj}	−9.71 (−16.79, −2.62)*	−10.43 (−17.57, −3.31)*	0.72 (−0.68, 3.47)	−0.20 (−2.59, 1.14)	0.39 (−0.52, 3.17)	0.54 (−0.28, 3.72)
SE_{subj}	0.03 (0.01, 0.04)*	0.03 (0.01, 0.04)*	0.00 (−0.00, 0.01)	0.00 (−0.00, 0.00)	0.00 (−0.00, 0.01)	−0.00 (−0.01, 0.00)
PSQI global	−1.14 (−1.77, −0.51)*	−1.05 (−1.63, −0.46)*	−0.09 (−0.37, 0.14)	−0.02 (−0.25, 0.10)	−0.06 (−0.30, 0.03)	−0.01 (−0.20, 0.04)

AP Attention Problems subscale, *AB* Aggressive Behaviors subscale, *CBCL* Child Behavior Checklist - Youth Self Report Version, *CI* confidence interval, *PSQI global* Pittsburgh Sleep Quality Index global score on school nights, SE_{subj}, sleep diary measured sleep efficiency on school nights, SOL_{obj}, actigraphy measured sleep onset latency on school nights, *SP* Social Problems subscale.
*Evidence of an effect (95% bias corrected bootstrap confidence interval did not include zero).

CBCL-AP, and CBCL-AB that resulted from the interventions (Table 4).

4. Discussion

This study provides evidence, using a methodologically rigorous design, that a cognitive-behavioral and mindfulness-based group sleep intervention improved behavior problems (social problems, attention problems, and aggressive behaviors) in at-risk adolescents by improving perceived sleep quality on school nights. There was no evidence of the reverse association.

These findings suggest that improvements in perceived sleep quality may change adolescents' behaviors in ways that increase the likelihood of experiencing positive social interactions, and decrease the likelihood of experiencing cognitive difficulties and externalizing problems. Good quality sleep may optimize adolescents' attention, decision-making, impulse control, motivation, reward processing, and emotion expression and recognition. In support of this, neurobiological research has shown that poor sleep disrupts the function of mesolimbic and corticolimbic brain circuitry, principally the PFC, which is critical in executive functioning and the regulation of affective systems (Palmer & Alfano, 2017). In particular, adolescents who sleep poorly may find it difficult to recognize an emotion as problematic, to choose a suitable emotion regulation approach, and/or to use that strategy in an effective way (Palmer & Alfano, 2017). Sleep problems may be especially damaging for adolescents with internalizing disorders, who are already vulnerable to exaggerated physiologic response (Hamm et al., 2014; Kerestes et al., 2014) and cognitive/emotional biases (Garber & Weersing, 2010; Price et al., 2016). Adolescents with sleep and internalizing problems, such as those in the current study, may prioritize sleep over other important waking activities, have reduced energy for and motivation to seek out complex and enjoyable social and cognitive activities, and be more prone to irritability and oppositionality. This has particular relevance for social interactions, including social intelligence, social competence, affiliative behaviors, theory of mind, and empathy (Beattie, Kyle, Espie, & Biello, 2014). For example, sleep driven emotional dysregulation may increase the likelihood of adolescents experiencing both peer rejection and disciplinary problems at school, which may lead to feelings of loneliness, devaluation, low

self-worth, sadness, and hopelessness (McMakin et al., 2016). This is especially important given the salience of the peer group and school context in adolescence (Blakemore & Mills, 2014).

CBT-I and mindfulness-based sleep interventions may be particularly effective for improving social, cognitive, and externalizing problems in at-risk adolescents, as they may decrease sleepiness during the day and optimize emotional regulation. For example, CBT-I focuses on improving emotion regulation via re-appraisal, labeling, and distraction. Similarly, mindfulness-based sleep interventions encourage a detached and decentered view of emotions and thoughts. Additionally, group programs may improve resilience and self-regulatory skill in social situations, normalize the experience of sleep and mental health problems, emphasize peer support and positive interactions between group members, and provide opportunities to practice interpersonal communication skills. Indeed, Sleep SENSE can be considered a general wellbeing enhancing intervention and a novel approach to resiliency. It has an emphasis on strengths-based, dynamic, mental wellbeing; participants learn to apply core skills of cognitive restructuring, acceptance and mindfulness that may not only improve sleep, but also generalize to healthier relationships with self, others, and the environment.

However, in the present study, improvements in social problems, attention problems, and aggressive behaviors were not specifically related to the moderate improvements in objective SOL and self-reported SE on school nights that resulted from the interventions. There are several possible explanations for this result: (a) improvements in sleep-wake behaviors were insufficient to improve behavior problems considerably; (b) improvements in sleep-wake behaviors do not immediately translate into improvements in the self-reported experience of behavior problems; and (c) common method variance accounted for some of the relationship between the questionnaire variables.

Finally, there was some evidence that the Sleep SENSE intervention increased social problems in the at-risk adolescents after controlling for the indirect effect through perceived sleep quality. Future studies could explore the possible reasons for this countervailing effect. For example, other mediators may result in significant indirect effects in the opposite direction to the one through perceived sleep quality.

4.1. Limitations and strengths

The study was not without limitations. First, although we provided evidence using a methodologically rigorous design, and appropriate statistical tests, that improvement in perceived sleep quality lead to improvements in behavior problems, we did not provide firm temporal links between treatment, processes, and outcomes. Studies utilizing frequent assessments during the study period and/or multiple follow-up time points would more firmly establish temporal relations between sleep and behavior outcomes (Nock, 2007). Second we relied on self-report measures of behavior problems. Self-report questionnaires cannot definitively rule out the influence of extraneous processes, such as inaccuracies introduced due to poor recall, and assume an individual is able to accurately introspect. Future studies could consider using objective measures of behavior problems as outcome measures, such as clinical interviews. Third, participants in the present study were not characterized by high levels of behavior problems prior to the commencement of the interventions. It is possible that stronger treatment effects would be found in trials among adolescents experiencing clinical levels of sleep and behavior problems (e.g., diagnosis of Insomnia, ADHD and/or Conduct Disorder). Fourth, studies are needed that incorporate additional indictors of behavior and functioning, including risk-taking behaviors, school attendance, and academic performance. Finally, one notable feature of the sample was the low rate of medication use during the interventions, which may limit the generalizability of the findings to some other samples.

The SENSE Study has a number of strengths. First, it included a large sample size compared to other similar studies (Blake et al., 2017a). Second, it utilized an RCT design following all CONSORT protocols, including a multi-component group sleep intervention specifically designed for use with high-risk adolescents, and an active control study skills intervention with good face validity as an intervention that can address salient issues for adolescents. Third, it included self-reported and objective indices of sleep.

5. Conclusion

This study provides evidence, using a methodologically rigorous design, that a cognitive-behavioral and mindfulness-based group sleep intervention improved behavior problems (social problems, attention problems, and aggressive behaviors) in at-risk adolescents by improving perceived sleep quality on school nights. These findings suggest that cognitive-behavioral and mindfulness-based sleep interventions could be directed towards adolescents with vulnerability towards behavior problems.

Institution where work was performed

The University of Melbourne.

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Conflicts of interest

There are no conflicts of interest to disclose.

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