Protective and Risk Factors for Adolescent Sleep Health

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Summary

There is consensus among the scientific community that adolescence is a unique developmental period, and that good sleep health is required for optimal functioning and positive development. Factors associated with bedtime, the time it takes to fall asleep (sleep latency), and sleep duration have been studied, particularly in relation to weekday sleep, when school start time and biological sleep patterns conflict with adolescents' sleep need. Generally, these factors may be categorised as promoting (protective) or disrupting (risk) sleep health. Yet, often, studies are correlational, a limited number of protective and risk factors are studied at one time, and samples are contained within country, or continent.

To address this gap in literature, this thesis introduced the topic of adolescent sleep, before looking in detail at behavioural protective and risk factors for bedtime, sleep latency and total sleep time, with a focus on weekday sleep. Firstly, in Chapter 2, this was done through a comprehensive meta-analysis, whereby multiple behavioural factors were examined in one chapter. This allowed comparative assessment of the strength of association between each factor and adolescent sleep. Based on these findings, the third and fourth chapters examined factors found to be associated with adolescent sleep, through an international, online survey. Chapters 3 and 4 enabled assessment of these associations, after controlling for other possibly related variables, across continents and hemispheres.

As technology use was found to be a risk factor for bedtimes in the earlier chapters, Chapter 5 experimentally manipulated pre-bed mobile phone use. Restriction of mobile phone use in the hour before bed tested the causal relationship between pre-bed phone use and adolescent sleep, with earlier lights out time (17 min) and longer sleep (19 min) resulting during the intervention week. In contrast, Chapter 6 focussed on protective factors determined in earlier chapters, as good pre-sleep cognitive emotional arousal was related to shorter sleep latency. Adolescents were allocated to one of three conditions (mindfulness body scan, constructive worry, control) to determine the effects of brief, 15 min interventions on decreasing pre-sleep worry, and thus sleep latency. Mindfulness decreased sleep latency by 31 min among adolescents with a baseline sleep latency of 30 min or longer, but no other significant effects were found.

Findings are summarised in Chapter 7, giving consideration to methodological, theoretical and clinical implications. An emergent theme throughout the thesis was that of good sleep hygiene being a strong helpful factor for advancing bedtime, decreasing sleep latency, and increasing sleep duration. Technology use, particularly close to bedtime, was related to later bedtimes, yet not to sleep latency. It can thus be considered a contributor to poor sleep, but not a sole focus. This thesis gives guidance into the most meaningful ways to assist adolescents in the general population to improve their sleep, through advancing bedtimes, decreasing sleep latency, and increasing sleep duration. This can be through reducing risk factors (e.g., pre-bed mobile phone use, evening light) or implementing protective factors (e.g., good sleep hygiene, mindfulness body scan at bedtime). Findings as they pertain to practical assistance for adolescents, as well as their caregivers, are discussed.

Declaration

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed… Date……….

Kate Bartel, B. Psych (Hons)

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Glossary of Abbreviations

ASHS-r	Adolescent Sleep Hygiene Scale – revised
AUDIT	alcohol use disorders identification test
BT	bedtime
CHAOS	Confusion Hubbub and Order Scale
CI	confidence interval
EEG	electroencephalography
EMG	electromyography
EOG	electrooculography
FOMO	fear of missing out
LMMR	linear mixed model regression
M	mean
MBCT	mindfulness-based cognitive therapy
MBSR	mindfulness-based stress reduction
MT	movement time
N1	non-rapid eye movement stage 1
N2	non-rapid eye movement stage 2
N3	non-rapid eye movement stage 3
NREM	non-rapid eye movement
PSG	polysomnography
PSQI	Pittsburgh sleep quality index
PTQ-C	Perseverative Thinking Questionnaire – Child Version
PVT	Psychomotor Vigilance Task
REM	rapid eye movement
SAAQ	sleep anticipatory anxiety questionnaire

SD	standard deviation
SE	standard error
SL	sleep latency
SOL	sleep onset latency
SCN	suprachiasmatic nuclei
SRSQ	Sleep Reduction Screening Questionnaire
SSHS	school sleep habits survey
TST	total sleep time
TV	television
UK	United Kingdom
USA	United States of America
VG	video gaming
WASO	wake after sleep onset

List of Manuscripts and Publications in thesis

List of Refereed Conference Proceedings & Book Chapters Resulting from Thesis

Bartel, K.A. and Gradisar, M.S. (2017). New Directions in the Link Between Technology Use and Sleep in Young People. In Sona Nevšímalová & Oliviero Bruni, ed. Sleep Disorders in Children. Switzerland: Springer International Publishing, pp. 69-80.

Huang, I., Bartel, K.A., O'Shea, A.E., Hiller, R.M.B., Lovato, N., Micic, G., et al. (2016). Sleep difficulties and depressed mood in adolescents: The roles of repetitive negative thinking and perfectionism. 23rd Congress of the European Sleep Research Society. Bologna, Italy. Sep 2016.

Bartel, K.A., Gradisar, M.S. and Huang, C. (2016). Helping adolescents with prolonged sleep latency through a brief school-based intervention. 23rd Congress of the European Sleep Research Society. Bologna, Italy. Sep 2016.

Bartel, K.A. and Gradisar, M.S. (2016). An Adolescent's worst nightmare?: Altering pre-bedtime phone use to achieve better sleep health. 23rd Congress of the European Sleep Research Society. Bologna, Italy. Sep 2016.

Bartel, K.A., Gradisar, M.S., van Maanen, A., Cassoff, J., Williamson, P.J., Meijer, A.M., et al. (2016). Differences in evening screen use between Australian, Canadian and Dutch Adolescents. 4th International Pediatric Sleep Congress. Taipei, Taiwan. Mar 2016.

Bartel, K.A., Gradisar, M.S., van Maanen, A., Cassoff, J. and Williamson, P.J. (2015). The long and short of adolescent sleep: The Unique impact of day length. 7th Quadrennial Congress of the World Sleep Federation World Sleep and Health. Instanbul, Turkey. Oct 2015.

Bartel, K., Gradisar, M. and Williamson, P. (2014). Meta-analysis of protective and risk factors for adolescent sleep. 22nd Congress of the European Sleep Research Society. Tallinn, Estonia. Sep 2014.

CHAPTER 1. Introduction to Sleep Across Adolescence

Introduction to Sleep Across Adolescence

Sleep Across Adolescence

Adolescence is an important period of transition from childhood to adulthood. Hormonal changes and brain maturation result in much cognitive, social and emotional learning (e.g., Laursen & Hartl, 2013; Lerner, Boyd, & Du, 1998; Spear, 2000). For example, adolescents become more autonomous, may learn to drive, obtain paid work, and have increased academic demands. They often spend more time with peers and less time with adults, and their risk-taking behaviour may increase, including the exploration of alcohol, tobacco and drugs use (Laursen & Hartl, 2013; Spear, 2000). Sleep is one of many areas impacted during this transition period. As the brain is not immune to the physical changes which occur during puberty (Ohayon, Carskadon, Guilleminault, & Vitiello, 2004; Tarokh & Carskadon, 2010), not only is sleep impacted from a biological perspective, but also from a social and psychological standpoint (Carskadon, 2011; Crowley, Acebo, & Carskadon, 2007).

From a physiological standpoint, sleep architecture changes in early adolescence, predominantly through a reduction in deep sleep (i.e., theta and delta waves in stages 3 and 4 sleep; Baker et al., 2016; Carskadon et al., 1980; Ohayon et al., 2004; Tarokh, & Carskadon, 2010; Scholle et al., 2011; see Figure 1.1). A 40% decrease in deep sleep occurs as adolescents mature, however, rapid-eye movement (REM) sleep remains stable (Carskadon et al., 1980). Overall sleep duration on school days also declines (see Ohayon et al., 2004 for meta-analysis).

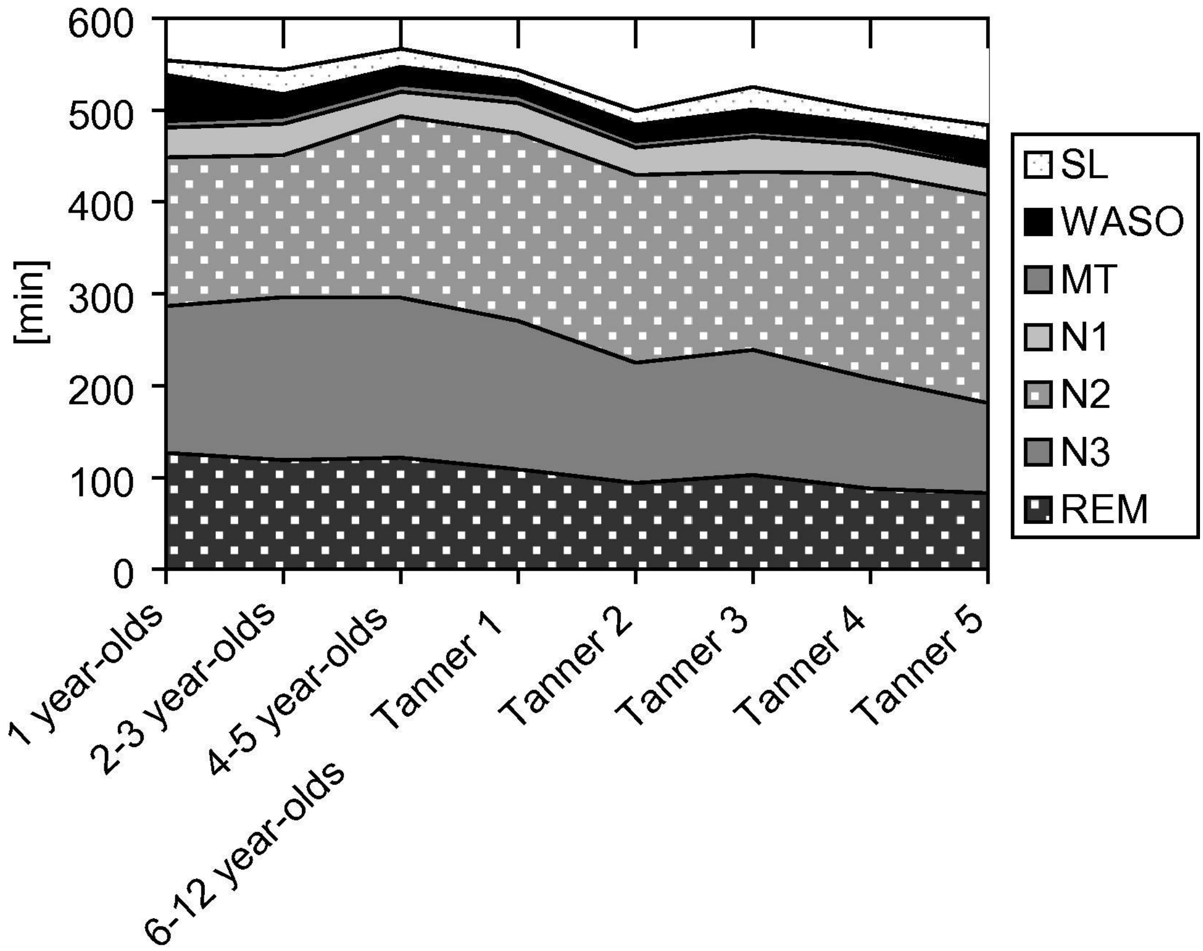


Figure 1.1. Age related trends from 1st year of age to 18th year of age for sleep latency (SL), wake after sleep onset (WASO), movement time (MT), non-rapid eye movement (NREM) stage 1 (N1), NREM stage 2 (N2), NREM stage 3 (N3) and REM sleep in minutes. Note: Tanner stages are developmental stages, with the number of participants, means age and range of each Tanner stage in Figure 1.1 as follows: Tanner 1 n = 34, 8.1 years old (6.0–11.6); Tanner 2 n = 33, 11.5 years old (9.4–13.4); Tanner 3 n = 23, 12.8 years old (9.5–16.1); Tanner 4 n = 24, 15.2 years old (13.0–17.9); Tanner 5 n = 25, 16.9 years old (14.0–18.0). Taken from Scholle et al., 2011.

Prevalence of sleep problems.

Worldwide, most adolescents are not receiving optimal sleep (i.e., they obtain less than 9 hr; Gradisar et al., 2011). In fact, sleep restriction may be quite severe, with survey data reporting adolescents acquiring an average of only 6.5 hr sleep on weekdays in Norway

(Hysing, Pallesen, Stormark, Lundervold, & Sivertsen, 2013) and 7.2 hr per night in Saudi Arabia (Al-Hazzaa, Musaiger, Abahussain, Al-Sobayel, & Qahwaji, 2012). Fifty-six percent of parents participating in the USA National Sleep Foundation (NSF) 2014 poll reported their 15-17 year old sleeping 7 hr or less (NSF, 2014). Even conservative figures demonstrate that the average American adolescent, and 36% of Australian adolescents, obtain less than 8 hr sleep per week night (Zhang et al., 2017; Short, Gradisar, Gill, & Camfferman, 2013). Furthermore, there appears to be an overall trend for sleep decreasing over time (Matricciani, Olds, & Petkov, 2012; Singh & Kenney, 2013). In addition to having shortened total sleep time, many adolescents (e.g., 65%) report taking longer than 30 min to fall asleep (Hysing et al., 2013), or report having trouble falling asleep (32% prevalence reported by Australian adolescents; Short, Gradisar, Gill, et al., 2013). Two thirds of adolescents displayed at least one 'clinical indicator' of a sleep problem (e.g., 26% reported difficulty waking in the morning, 21.5% reported having a delay in their weekend bedtime of ≥2 hr), although only 23.1% self-reported a sleep problem (Short, Gradisar, Gill, et al., 2013).

In the home environment, adolescents show a decrease in total sleep time compared to children (e.g., Borisenkov, 2011; Carskadon, 2011; Gradisar, Gardner, & Dohnt, 2011; Ohayon et al., 2004; Scholle et al., 2011), however, a meta-analysis has demonstrated the trend for a decrease in sleep only appears during school days, suggesting environmental demands, such as school start times, impinge on adolescents' sleep opportunity (Ohayon et al., 2004). In fact, when given longer opportunities to sleep, such as school holidays, adolescents actually obtain over 9 hr (Carskadon, Acebo, & Seifer, 2001; Warner, Murray, & Meyer, 2008), and sleep duration remains constant across puberty (Carskadon et al., 1980). To further support the notion of environmental pressures on sleep, in countries where academic pressure is high, particularly in Asia, a further reduction in total sleep is witnessed on weekdays, mostly through a delay in bedtimes (Carskadon, 2011; Gradisar et al., 2011;

Olds, Blunden, Petkov, & Forchino, 2010). Earlier school start times (by an average of 47 min in the United States of America [USA] compared to Australia; Short, Gradisar, Lack et al., 2013), may explain why adolescents in the USA obtain less total sleep than their Australian and European peers (Gradisar, Gardner, & Dohnt, 2011; Olds, Blunden, et al., 2010; Olds, Maher, Blunden, & Matricciani 2010; Short, Gradisar, Lack et al., 2013). The effects of earlier school start times may be exacerbated by high extracurricular and study load, early morning sports practise, and the absence of parent-set bedtimes (Short, Gradisar, Lack et al., 2013).

Early school start times create a desire to acquire more sleep on weekends, when sleep parameters are less dictated by external factors (Gradisar et al., 2011). Sleeping-in on weekends creates discontinuity between school and weekend sleep, with the resulting irregular sleep patterns more prevalent among 10-17 year olds than any other age group (Borisenkov et al., 2016). A review of problems associated with poor adolescent sleep has shown that sleep is closely connected to many aspects of psychological, physical, social and cognitive functioning, with the potential for many of the relationships between sleep and health to be bi-directional (Shochat, Cohen-Zion, & Tzischinsky, 2014). Among adolescents, this ‘sleep irregularity’ has been linked to mental health disorders, suicidality, poorer perceived mental and physical health and increased tobacco consumption (Zhang et al., 2017). It is also associated with more conflict with mothers, less time at school (Sally et al., 2015); increased calorie intake (He et al., 2015); obesity (Chuang, Fehr, Ievers-Landis, Narasimhan, Uli, & O’Riordan, 2015); and, early adolescents’ aggression (Lemola, Schwarz, & Siffert, 2012). Sleep/wake problems, including sleep irregularity, also moderate the relationship between peer victimisation and internalising and externalising problems (Tu, Erath, & El-Sheikh, 2015).

Regarding mental health, meta-analytic data have revealed that among longitudinal studies, sleep disturbances (i.e., long sleep latency, increased night time wakening, lower sleep efficiency) are likely to precipitate adolescent depression, however, symptoms of depression at baseline do not necessarily predict future sleep disturbance (Lovato, & Gradisar, 2014). Furthermore, sleeping less than 8 hr per night is associated with increased suicide attempts (Liu, 2004); and trouble sleeping between the ages of 12 to 14 years increases the odds of suicidal thoughts 3 years later (Wong, Brower, & Zucker, 2011). Concordantly, gradual sleep extension among chronically sleep restricted adolescents, in combination with sleep hygiene advice, decreases depressive symptoms (Dewald-Kaufmann, Oort, & Meijer, 2014).

In terms of sleep and school performance, a meta-analysis has highlighted that increased sleepiness, poorer sleep quality and shorter sleep duration are all related to poorer performance (Dewald, Meijer, Oort, Kerkhof, & Bögels, 2010). Experimentally, even one night of total sleep deprivation in a laboratory setting is sufficient to decrease attention and processing speed, while causing increases in subjective sleepiness (Louca & Short, 2014).

In reality, sleep during the school week is restricted, rather than completely denied, a phenomenon which has been subject to recent experimental investigation. Acute sleep restriction, such as one night of only 4 hr sleep, after a well-rested baseline sleep, does not appear to impact adolescents' declarative memory (Kopasz et al., 2010). However, it does appear to interfere with adolescents' ability to safely cross a road (Davis, Avis, & Schwebel, 2013). Adolescents who are required to wake in time for school, and only obtain 6.5 hr sleep for as little as one week, are more inattentive at school, experience increased daytime sleepiness and tiredness, and perform worse on academic tests, than adolescents who obtain over 9 hr of sleep during a 10 hr sleep opportunity (Beebe et al., 2008; Beebe, Field, Milller, Miller, & LeBlond, 2016; Beebe, Rose, & Amin, 2010). The same experimental procedure also revealed poorer emotional and mood regulation and metacognition, reported by both adolescents and their parents, as well as increased feelings of anxiety (Baum et al., 2013; Beebe et al., 2008). Negative consequences of sleep loss across the school week are further substantiated by experimental studies which restricted sleep to 5 hr per night across the school week (Agostini, Carskadon, Dorrian, Coussens, & Short, 2017; Huang et al., 2016; Lo, Ong, Leong, Gooley, & Chee, 2016). Subjective sleepiness and lapses in attention, measured by the Psychomotor Vigilance Task (PVT), increased during restriction (Agostini et al., 2017). Similarly, working memory, sustained attention, executive functioning and positive mood all decreased across the restriction period (Lo et al., 2016), and recall of large amounts of information was impaired (Huang et al., 2016). Furthermore, 2 recovery nights of a 10 hr sleep opportunity (i.e., on the weekend) did not allow PVT performance to return to baseline levels (Agostini et al., 2017), nor did subjective sleepiness and sustained attention return to baseline levels after 2 nights of 9 hr of time in bed (Lo et al., 0216). Alternatively, sleep extension, through the delaying of school start time by 1 hr, or increasing of time in bed, decreased the rates of motor vehicle accidents, and self-reported driving violations among those who also reported improved cognitive tempo (e.g., faster thinking; Danner & Phillips, 2008; Garner et al., 2017). This suggests sleep extension may improve reaction time, attention and concentration.

Regarding the influence of sleep on diet, when school night sleep is restricted to a 6.5 hr opportunity, adolescents consume higher kilojoule sweet foods and dessert than when they sleep for 9 hr per night during the school week (Beebe et al., 2013). Interestingly, adolescents’ choices in beverages, fatty foods, processed foods, and fruits and vegetables did not differ between the experimental weeks (Beebe et al. 2013). High sugar foods have been linked to serious metabolic and cardiovascular health conditions, thus the tendency for sleep deprived adolescents to choose such foods may have serious long-term health consequences

(Beebe et al., 2013). Additionally, short sleep duration among adolescents predicts high cholesterol levels when they reach young adulthood, particularly for females (Gangwisch, Malaspina et al., 2010), supporting the seriousness of short sleep on health consequences.

Increased adolescent autonomy.

Despite the apparent need for consistent sleep duration throughout adolescence, there are several factors, other than schooling, which interrupt the amount of sleep adolescents obtain on school nights. One of these is increased autonomy (Carskadon, 2011). Older adolescents less frequently have parent set bedtimes (Carskadon, 1990; Carskadon, 2011; Gangwisch, Babiss, et al., 2010; Randler, Bilger, & Díaz-Morales, 2009; Short, Gradisar, Lack et al., 2013; Short, Gradisar, Wright, Lack, Dohnt, & Carskadon, 2011), hence are increasingly free to choose their own (later) bedtime. As discussed in further detail later in this chapter, set school start times limit them from choosing their own rise time, resulting in less total sleep on school days, and attempted catch-up sleep on weekends, in an effort to satisfy homeostatic sleep pressure (Carskadon, 2011). Many would argue that perhaps it would be wise for adolescents to attempt sleep earlier (e.g., parents, teachers). Yet, maybe it is not just poor choices on behalf of adolescents that lead to later bedtimes and subsequent sleep loss.

Biology of Adolescent Sleep

Circadian rhythm delay.

A major reason adolescents are prone to choosing a later bedtime (and rise time) is due to the delay in their circadian rhythm timing (Borisenkov, 2010; Borisenkov, 2011; Carskadon, 2011; Crowley et al., 2007; Randler et al., 2009; Roenneberg & Merrow, 2007). The circadian rhythm is a roughly 24-hr cycle, regulated by the suprachiasmatic nuclei (SCN), located in the hypothalamus (see Refinetti & Menaker, 1992, for a review). Synchronisation of sleep to night and wake cycles to day predominantly occurs through daylight exposure, although synchronisation can also be manipulated through other external zeitgebers (e.g., Roenneberg & Merrow, 2007). This biological process commences when light hits photoreceptors (ganglion cells) in the eye, which then transmit information through the optic nerve to the SCN (Berson, Dunn, & Takao, 2002; Moore, Heller, Wurtman, & Axelrod, 1967; Scheer, Pirovano, Van Someren, & Buijs,, 2005). Two key aspects of the circadian rhythm, melatonin and core body temperature, are both affected by light and darkness (Kubota et al., 2002; Shanahan & Czeisler, 1991). Melatonin, a hormone produced by the pineal gland, increases in dim light, and decreases in bright light in normally-entrained individuals (Kubota et al., 2007; Shanahan & Czeisler, 1991; Moore et al., 1967). During regular sleep schedules, melatonin is secreted 2-3 hr before bedtime, is highest just after the mid-point of sleep, and begins to decrease to daytime levels 2 hr before usual wake-time (Shanahan & Czeisler, 1991). Furthermore, circadian rhythms of melatonin and core body temperature are inversely coupled. That is, as melatonin increases, core body temperature decreases, and vice versa (Cagnacci, Elliott, & Yen 1992; Kubota et al., 2007; Shanahan & Czeisler, 1991). Thus, core body temperature increases in response to daylight and decreases in darkness, in a similar reciprocal pattern to that of melatonin (Kubota et al., 2007; Shanahan, & Czeisler; Scheer et al., 2005). These regulatory processes are important, as increases in melatonin and decreases in core body temperature encourage sleep (Kubota et al., 2007), thus allowing night time to be a time of sleep and restoration and metabolically demanding activities to occur during daylight hours. Consequently, social and biological body clocks align.

Adolescents have a predisposition to delayed circadian rhythms (see Figure 1.2; Carskadon, 2011; Crowley et al., 2007; Randler et al., 2009; Roenneberg & Merrow, 2007). In other words, during puberty, and up until the age of 20 years, adolescents have a biological tendency to exhibit a later chronotype (i.e., to go to bed later and sleep in), as this is what the timing of their body clock naturally desires (Roenneberg & Merrow, 2007). As this conflicts with their normal school schedule, a delay in school start times has been proposed. Indeed, adolescents who have later school start times obtain longer sleep and feel less sleepy during the day (Beebe, 2011; Boergers, Gable, & Owens, 2014; Dexter, Bijwadia, Schilling, & Applebaugh, 2003; Gariépy, Janssen, Sentenac, & Elgar, 2017; Wheaton, Chapman, & Croft, 2016; Wolfson & Carskadon, 2003; Wolfson, Spaulding, Dandrow, & Baroni, 2007) indicating that a delay in circadian rhythms can at least be accommodated in part by adapting school times to favour adolescents' sleep timing.

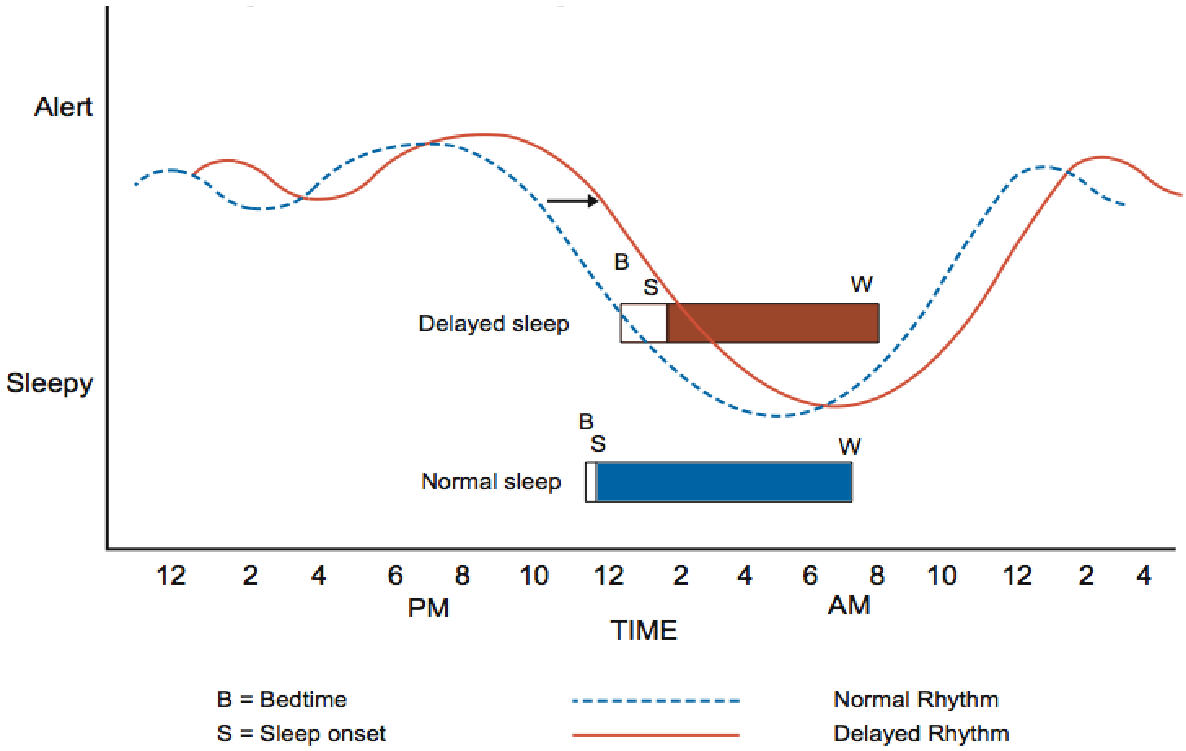


Figure 1.2. Delayed and "normally-entrained" circadian rhythm. Dotted line depicts an example of a "normally-entrained" circadian rhythm of an adolescent who wakes and falls asleep in line with social requirements. Solid line depicts an example of an adolescent with a delayed circadian rhythm. Horizontal solid bars represent the respective adolescents' sleep period. Transparent bars represent time in bed awake between bedtime and sleep onset. Note that the core body temperature oscillates in the same manner as the rhythms displayed above.

Homeostatic sleep drive.

Further adding to adolescents' woes of finding it difficult to achieve optimal weekday sleep (via an early bedtime), is their new found ability to accumulate sleep pressure at a slower rate, relative to childhood (Crowley et al., 2007; Jenni, Achermann, & Carskadon, 2005; Taylor, Jenni, Acebo, & Carskadon, 2005). Upon waking, and throughout the day, sleep pressure continues to build until, in conjunction with the circadian rhythm timing, it is strong enough to help a person sleep (see Figure 1.3). Pre-pubescent children find it difficult to ignore this homeostatic sleep drive, meaning that when they are sufficiently tired in the evening they find it difficult to maintain wakefulness (Crowley et al., 2007; Jenni et al., 2005; Taylor et al., 2005). During adolescence (and pubertal development), however, the ability to prolong sleep onset increases (Crowley et al., 2007; Jenni et al., 2005; Taylor et al., 2005), and combines with adolescents' social desires, school pressure, autonomy to stay up later, and delayed circadian rhythm, to enable later bedtimes and less total school day sleep (Crowley et al., 2007).

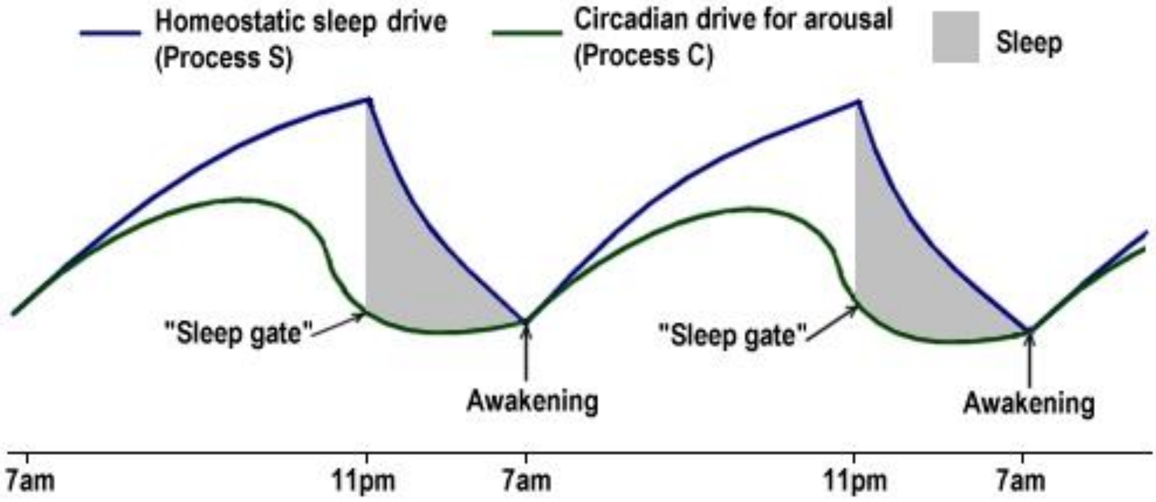


Figure 1.3. The interaction between the homeostatic sleep drive (Process S) and the circadian drive for arousal (Process C) in relation to sleep and wake states (Mastin, 2013). Blue line represents homeostatic sleep drive, which continues to increase from waking until sleep initiation. Green line represents circadian rhythm, which oscillates in approximately 24-hr cycles. Sleep (represented by grey shading) is most likely to occur when sleep propensity is high (i.e., there is high sleep pressure after a day of wakefulness) and the core body temperature rhythm starts to decrease/melatonin starts to increase (Kubota et al., 2002).

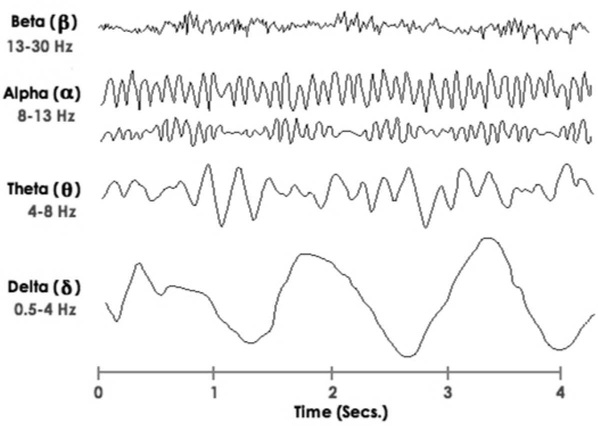
Although the accumulation of sleep pressure is slower in adolescents than children, electroencephalograms (EEG) demonstrate adolescents still require a similar amount of sleep in order for sleep pressure to dissipate (Baker et al., 2016; Carskadon, 2011; Jenni & Carskadon, 2004). In fact, the reduction in slow wave sleep seen in adolescents may be due to developmental changes in the brain, rather than changes in sleep as a restorative function (Carskadon, 2011; Jenni & Carskadon, 2004; Kurth et al., 2010). This once again lends itself to adolescents' desire to sleep in on weekends, as sleep pressure is likely to be high after a week of shortened sleep during the school week (Gradisar et al., 2011), thus exacerbating the tendency to sleep in due to their delayed circadian rhythm. Considering the dynamic changes that occur during adolescence, and the multiple factors influencing their sleep, it is important to understand the various methods of measuring adolescent sleep (or lack of), thereby facilitating research to improve it.

Measurement of Night Time Sleep

Polysomnography.

Polysomnography (PSG) is the "gold standard" for measuring sleep, giving an accurate account of sleep-wake timing, as well as sleep architecture (i.e., the cycles and stages of sleep; Martin & Hakim, 2011). Polysomnography identifies sleep and wake states and sleep stages by measuring electrical currents to record brain waves (electroencephalography), as well as eye movements (electrooculography [EOG]) and muscle tone (electromyography [EMG]; Hirshkowitz, 2014; See Figures 1.4a & 1.4b). For these reasons, PSG is referred to as an objective measure of sleep (Short, Gradisar, Lack, Wright, & Chatburn, 2013).

(a)



(b)

Figure 1.4(a). Example of brain waves which occur during different sleep stages, and *(b)* A young person with EEG and EOG leads attached, in order to measure brain waves.

Although PSG is the most accurate way to measure sleep and wake, specialised technicians are required to score the sleep data (Grigg-Damberger, 2016), necessitating time for training, as well as scoring, reading and analysing PSG data. Unfortunately, it is thus quite expensive, and often requires an overnight stay in a sleep laboratory. One of its limitations is that it does not provide information about other aspects of sleep, including perceived sleep difficulties and sleeping habits in the home (Martin & Hakim, 2011; Short et al., 2012). Moreover, first night effects (i.e., whereby sleep is different to usual due to the unfamiliarity of the laboratory environment) commonly occur for adolescents (Grigg-Damberger, 2016), meaning that researchers may be unable to attribute effects of an experiment to the experimental condition, but rather to the experience of being in a sleep laboratory.

The feasibility of using PSG decreases in large scale studies where the measurement of sleep of hundreds of adolescents is required, due to the logistics of time, expense and equipment required. However, there are other means to measure sleep when high participant numbers are required.

Actigraphy.

An increasingly popular means of objectively measuring sleep among adolescents is actigraphy (Meltzer, Montgomery-Downs, Insana, & Walsh, 2012). Actigraphy devices sense movement when worn (e.g., on the wrist), and use automatic scoring algorithms built into software to identify sleep-wake patterns (see Figure 1.5 for example output). Algorithms used to score actigraphy are based on research where individuals’ sleep has been simultaneously recorded with PSG (Johnson et al., 2007; Sadeh, 2011; Sadeh & Acebo, 2002; Sadeh, Sharkey, & Carskadon, 1994). They assume that activity is associated with wakefulness, and lack of movement is related to sleep (Galland, Meredith-Jones, Terrill, & Taylor, 2014; Martin & Hakim, 2011). This method has advantages compared to PSG, in that it can be used in their natural home environment for multiple nights without it being burdensome, does not require a lengthy time to set up, and is more cost effective (Martin & Hakim, 2011). Similar to PSG, it is not prone to recall bias, nor influenced by expectations, misperceptions of sleep, or participants forgetting when they fell asleep and woke (Martin & Hakim, 2011).

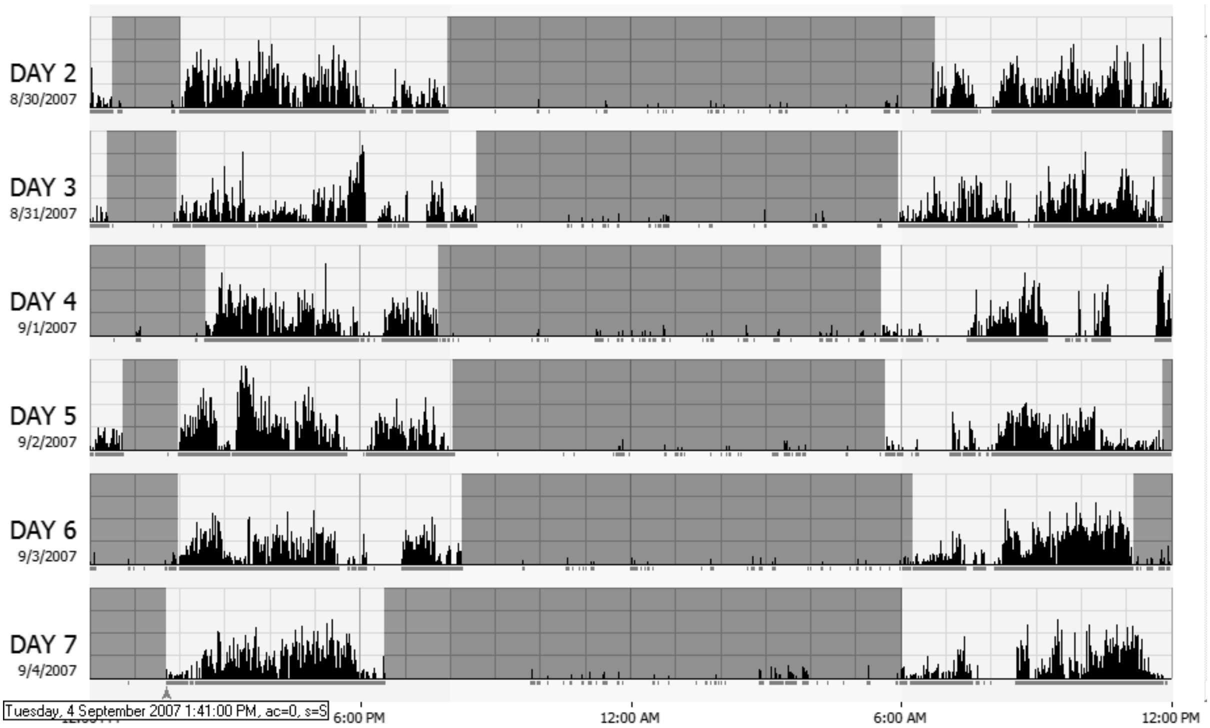


Figure 1.5. Example output of wrist actigraphy. Black vertical columns indicate movement. Grey horizontal bars indicate periods of sleep. White horizontal background indicates periods of wakefulness.

Despite these advantages of actigraphy, it may underestimate total sleep time compared with PSG (Johnson et al., 2007). Depending on the algorithm used when scoring the sleep data, it may also be more accurate for adolescent girls rather than boys (Short et al., 2012), and for adolescents without sleep disordered breathing (Johnson et al., 2007). That is, actigraphy tends to overestimate sleep latency in adolescents experiencing sleep disordered breathing (by 12 minutes; Toon, Davey, Hollis, Nixon, Horne, & Biggs, 2016).

A recent review of actigraphy found that it was consistently accurate at identifying sleep periods among adolescents, however, failed to adequately measure wake after sleep onset (i.e., the time awake during the period between initially falling asleep, and the final wake time in the morning, WASO; Meltzer et al., 2012). This was regardless of where on the body it was worn, or the algorithm used to calculate sleep/wake time (Meltzer et al., 2012). Although actigraphy is typically more accurate at measuring sleep, rather than wake (Meltzer et al., 2012; Sadeh, Sharkey, & Carskadon, 1994), it can also inaccurately identify lack of movement as sleep (Galland et al., 2014), when in fact an adolescent may be lying still (e.g., at the beginning of the night, prior to sleep onset; Martin & Hakim, 2011). Thus, actigraphy is inconsistent when measuring sleep latency (Martin & Hakim, 2011).

Individual variability between PSG and some devices used to measure movement may also be high (e.g., the SenseWear Pro$_3$Armband™ body monitor, [BodyMedia Inc], a type of sleep monitoring armband; Soric et al., 2013), leading authors to advise against using the armband for accurate measurement of sleep (Soric et al., 2013).

Unfortunately, there is a dearth of standardised scoring between devices (Galland et al., 2014; Meltzer et al., 2012), as hardware is accompanied by device specific sleep-wake scoring algorithms (Galland et al., 2014). Nonetheless, in terms of measuring the start of the sleep period, the number of minutes asleep, the number of minutes awake and sleep efficiency, the reliability of actigraphy increases when measurement occurs across multiple nights within a week (Acebo et al., 1999). Even with 7 nights of data, however, sleep period (i.e., the time from the start to end of the sleep period) does not achieve acceptable reliability (Acebo et al., 1999).

Furthermore, although actigraphy allows for larger scale objective measurement of total sleep compared to PSG, it does not accurately indicate the duration of awakenings throughout the night, nor sleep latency (Meltzer et al., 2012; Short et al., 2012). Despite increased feasibility for larger scale studies of actigraphy compared to PSG, it still requires the logistics of dissemination of the device to participants, hence is not a realistic measurement tool for studies collecting hundreds of participants' data within a short period of time (Gradisar et al., 2011; Wolfson et al., 2003). Furthermore, actigraphy is unable to capture the subjective experience of sleep, or how tired adolescents feel (Morgenthaler et al., 2007). For example, to determine the length of time an adolescent perceives themselves to be lying in bed attempting to sleep, questionnaires or sleep diaries are more appropriate. Self-conceptualised sleep latency is important, as regardless of objective sleep duration, people who perceive their sleep quality to be poor are more likely to feel sleepy during the day, have negative thoughts and mood, engage in safety behaviours (e.g., cancelling social arrangements or decreasing exercise due to feeling tired) and monitor their body for somatic feelings of fatigue (Bei, Wiley, Allen, & Trinder, 2015; Semler & Harvey, 2005).

Self-report measures.

Using self-report measures is a further way to measure sleep, either in the form of a sleep diary, or via questionnaires. These methods are easy to administer, useful when assessing sleep for hundreds of adolescents, cheaper than actigraphy and PSG, and can be used for in home assessment (Gradisar et al., 2011; Martin & Hakim, 2011; Wolfson et al., 2003). Moreover, these methods are useful for measuring bedtime, which is a behavioural measure of sleep (Kline, 2013), and can give insight into a person's perception of their sleep (as opposed to actual amount of sleep obtained). A major downfall of self-report measures is recall bias – in that a person may have an inaccurate memory or perception of their sleep (Martin & Hakim, 2011).

Sleep diary.

Sleep diaries may be more accurate than questionnaires due to daily documentation (Martin & Hakim, 2011), although this is not always the case, as moderate-to-strong correlations between the measures do exist in some studies (Matricciani, 2013). Recently, reliability of sleep diaries as a measurement tool has been assessed among Australian, American, British and Qatari adolescents (Short, Arora, Gradisar, Taheri, & Carskadon, in press). The authors concluded that as a conservative approach, it was necessary for adolescents to complete 5 nights of data for a reliable estimate of bedtime, sleep latency and total sleep ubiquitously across countries, for school nights. However, reliability could often be obtained with fewer nights' data (often 3-4 nights), depending on the country and sleep parameter measured. For example, as a minimum, Australian adolescents required only 2 nights of data for a reliable estimate of weekday bedtime, and for adolescents in the USA, United Kingdom (UK) and Qatar, 2 nights of weekday data was sufficient to measure sleep latency. Sleep diaries completed continuously over 12 weeks also demonstrated adequate week-to-week stability for measuring weekday bedtime, sleep latency and total sleep, using sleep diaries with 3 nights of weekday data. Conversely, 4, 8 and 13 weekend nights of sleep diary information were required to obtain reliable weekend sleep latency, sleep duration and bedtime information, respectively (Short et al., in press). Furthermore, diaries are able to show day-to day variability in sleep, yet unfortunately are more onerous than questionnaires completed at a single time point (Martin & Hakim, 2011).

Sleep questionnaires.

In contrast, 'once off' questionnaires are short, and thus are less inconvenient for adolescents to complete (Gradisar et al., 2011; Martin & Hakim, 2011; Wolfson et al., 2003).

One of the most widely used surveys for assessing adolescent sleep is the School Sleep Habits Survey (SSHS; Gradisar et al., 2011; Wolfson et al., 2003). The survey asks about "usual" sleep habits over the preceding 2 weeks, separately for school and weekend nights, and has been validated against 8-day sleep diaries and actigraphy (Wolfson et al., 2003). All SSHS responses were strongly correlated with diary and actigraphy data for school days, with weekend SSHS responses positively correlated with diary and actigraphy data to a lesser extent (Wolfson et al., 2003). School day responses did not differ from sleep diary or actigraphy data for total sleep time or wake time (Wolfson et al., 2003). However, adolescents slightly underestimated bedtime, weekend total sleep time and weekend wake up times, when giving survey answers (Wolfson et al., 2003). Thus, survey reports can be considered appropriate and feasible for measuring adolescent sleep when requiring measurement to occur in large groups, particularly during the week (Wolfson et al., 2003).

A recent review has highlighted the importance of considering the wording of questions when measuring adolescents' sleep using questionnaires (Matricciani, 2013). Firstly, there is a difference between school and non-school days, thus this should be defined in the questions (e.g., Sunday to Thursday night = school nights) and asked separately for the two time frames (Matricciani, 2013). Moreover, for non-school days, lower correlations exist between self-report and objective sleep measures, such as actigraphy, compared to school days (Matricciani, 2013), emphasising the need to request information separately for the two periods.

Accuracy of self-report measures compared to objective measures can be further improved by defining sleep duration and specifying a recent period from which participants are to recall their sleep (Matricciani, 2013). Specifically, stipulating the sleep period as sleep start to sleep end (not taking account of periods of wakefulness after sleep onset) provides the highest correlation between sleep duration and actigraphy (Matricciani, 2013).

It should be cautioned, however, that parents may misrepresent their adolescent's sleep, reporting more total school night sleep than actigraphy measures, as well as adoelscent reported sleep diaries and surveys, as well as earlier bedtimes (Short et al., 2012; Short, Gradisar, Lack, Wright, & Chatburn, 2013). Thus, as parents may report an idealised version of their child's sleep, adolescent self-report is preferable to parent report.

Mobile applications.

An emerging area of sleep monitoring is the use of mobile applications and wearable devices for “everyday” consumers (Galland, Meredith-Jones, Terrill, & Taylor, 2014). The use of these applications for sleep research is currently cautioned, due to inconsistency in results and lack of scientific validation (Galland et al., 2014). For example, in a sample of children and adolescents, with sleep disordered breathing, an application (MotionX 24/7) underestimated sleep latency and wake after sleep onset (WASO; reported 0min compared to 63min by PSG), and overestimated total sleep and sleep efficiency, compared to PSG (Toon et al., 2016). Jawbone (a wrist wearable device which synchronises to smartphones), accurately measured adolescents’ time in bed and sleep latency, compared to PSG, yet overestimated total sleep and sleep efficiency, and underestimated WASO and total wake time (de Zambotti, Baker, & Colrain, 2014).

Fitbits are another popular device on the market (“Why Your Fitness Tracker Thinks You’re Lazy” n.d.), yet depending on the settings used, they are prone to either overestimate or underestimate total sleep, WASO and sleep efficiency, compared with PSG and actigraphy - therefore they are not recommended for use to measure sleep (Meltzer, Hiruma, Avis, Montgomery-Downs, & Valentin, 2015). Furthermore, a recent review, mostly focussing on adult studies, found low validity when using Fitbit and Jawbone for sleep (Evenson, Goto, & Furberg, 2015).

Summary of measuring sleep.

Overall, PSG is preferable in terms of its accuracy, followed by actigraphy, however, sleep diaries and questionnaires may at times be the only feasible way to measure adolescent sleep, and are the only measure by which the subjective experience of sleep can be captured (e.g., bedtime). Mobile applications and consumer wearables, it appears, should be avoided until further research determines them to be reliable and accurate. The means by which adolescent sleep is measured is an important consideration when designing research dedicated to this topic. To this end, the series of studies in the present thesis investigated various risk and protective factors for adolescents' bedtimes, sleep onset latency, and sleep duration. For the most part, these studies were performed on large sample sizes, and at times, across continents, making objective measures of sleep difficult to use. Furthermore, bedtime is a behavioural sleep parameter that is not best measured with PSG or actigraphy. Therefore, sleep questionnaires and sleep diaries were used when appropriate.

Role of Measuring Behavioural Factors

Added to the melange of intrinsic, biological factors affecting adolescent sleep, extrinsic factors also contribute (Carskadon, 1990; Carskadon, 2011). As mentioned earlier, autonomy during adolescence increases, thus adolescents have an increase in demands on their time, such as homework, paid work, social and extracurricular opportunities, yet they also need to learn to juggle commitments and prioritise their time as they transition into adulthood (Carskadon, 1990; Carskadon, 2011; Short, Gradisar, Lack et al., 2013). Overall, the prevalence of suboptimal sleep duration among adolescents is high. This is perhaps unsurprising, given that biologically speaking, adolescents are at risk of developing poor sleeping patterns (Carskadon, 2011; Crowley et al., 2007). As there are significant negative consequences associated with short sleep, it is imperative to both determine which environmental factors increase the risk of problematic sleep developing, and to assist the development of targeted interventions. Knowledge of what *to do,* and what to *avoid*, is pertinent, especially as biology, in conjunction with school start times, are seemingly opposed to adolescents' natural sleep tendencies (Carskadon, 2011). Thus, having techniques to counteract these precursors to insufficient sleep is vital. Although broad interventions, such as delaying school start times, may be one response, these policy changes can be controversial as policy makers, parents and school staff, may not realise the necessity of adequate sleep, with further debates raised due to the impact on morning extracurricular activities, the costs of altering bus timetables and the inconvenience for working staff and parents (Wheaton et al., 2016). Fortunately, some contributing factors are under direct behavioural control, hence adolescents are likely to be able to make changes to their behaviour to improve their sleep. Understanding the importance of sufficient sleep, adolescent motivation, time commitment and ease of access to the intervention, all need to be considered when attempting to improve adolescents' sleep through behavioural change (Cassoff, Knäuper, Michaelsen, & Gruber, 2013). Less invasive techniques, underpinned with sound theory and evidence-base, would likely enhance the probability of adolescents undertaking such changes to improve their sleep.

Adolescence is a time of physical, emotional and cognitive change, plagued with challenges (Lerner et al., 1998). Being able to positively contribute to adolescent health through clear, simple sleep advice can broadly assist adolescents, as well as their care providers, to effectively manage their sleep and enhance daytime functioning (Shochat et al., 2014). Hopefully, if the guidance is indeed clear and simple, adolescents will have an increased chance of successfully implementing advice in their routine, empowering them during this developmental stage of increased independence to progressively manage their own sleep.

Thesis Aims

In an effort to further understand the behavioural risk and protective factors for adolescents' sleep, this dissertation first aimed to review and quantify the influence of individual factors on adolescents' bedtime, sleep latency and total sleep. Chapter 2 therefore presented a systematic review and meta-analysis on protective and risk factors for adolescent sleep (Bartel, Gradisar, & Williamson 2015).

Through the process of performing this systematic review and meta-analysis, it became clear that there were not enough studies measuring multiple contributing factors to adolescent sleep. This makes it difficult to distinguish the unique contribution of each protective and risk factor relative to others. Sleep problems during adolescence are widespread (i.e., across continents), therefore, Chapter 3 measured both protective and risk factors and sleep of adolescents across continents. This allowed for the assessment of some contributing factors that are not under behavioural control (e.g., length of daylight hours). Chapter 4 aimed to further replicate results from the meta-analysis when multiple behavioural factors were measured simultaneously across multiple countries (i.e., Australia, Canada and The Netherlands; Bartel et al., 2016). At this point, contributing factors were identified. However, as questionnaire designs cannot infer cause and effect (i.e., whether a factor is a contributor or consequence), experimental studies were employed, in the hope that findings will contribute towards broad interventions to improve the sleep health of many adolescents. Chapter 5 thus examined the effects of limiting adolescents' pre-bedtime technology use and the resultant effect on sleep. Chapter 6 then examined the effects of two brief cognitive interventions to reduce arousal in the evening and the subsequent effects on adolescents' sleep. Finally, Chapter 7 presented a Discussion of this thesis' findings, how these new data added to the body of knowledge about adolescents' sleep, and outlined directions for future research.

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CHAPTER 2. Protective and Risk Factors for Adolescent Sleep: A Meta-Analytic Review

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Author Contributions

KB contributed to study design, literature search, emailing authors for unpublished results, statistical analysis, results interpretation and manuscript preparation. PW contributed to statistical analysis, results interpretation and manuscript preparation. MG contributed to study design, literature search, statistical analysis, results interpretation and manuscript preparation.

*Please note referencing style for this chapter only has remained as in the published article for aesthetic purposes.

*Supplementary data were too large for this thesis, but can be obtained from the following weblink http://www.sciencedirect.com/science/article/pii/S1087079214000926

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Abstract

Teenagers need sufficient sleep to function well daily, yet consolidated evidence advising which factors protect, or harm, adolescents' sleep is lacking. Forty-one studies, published between 2003 and February, 2014, were meta-analysed. Mean weighted r values were calculated to better understand the strength of protective and risk factors for 85,561 adolescents' (age range = 12-18 years) bedtime, sleep onset latency (SOL) and total sleep time (TST). Results showed good sleep hygiene and physical activity were associated with earlier bedtimes. Video gaming, phone, computer and internet use, and evening light related to delayed bedtimes. Good sleep hygiene negatively correlated with sleep latency. Alternatively, sleep latency lengthened as a negative family environment increased. Tobacco, computer use, evening light, a negative family environment and caffeine were associated with decreased total sleep, whereas good sleep hygiene and parent-set bedtimes related to longer sleep length. Good sleep hygiene appears to be protective, whereas a negative home environment and evening light appear to be risk factors. Cautious use of technology (other than television), caffeine, tobacco and alcohol should be considered. These factors, along with pre-sleep worry, are likely to have some negative impact on sleep. Parent-set bedtimes and physical activity may be beneficial. Future research directions are discussed.

Protective and Risk Factors for Adolescent Sleep: A Meta-Analytic Review

The Importance of Sleep and Sleep Habits for Adolescents

Sleep is an essential part of everyday functioning, therefore restricting it can have multiple, negative consequences [1]. Longitudinal and survey data indicate that adolescents with unrestricted sleep opportunities obtain over 9 hr of sleep [2] and [3]. However, systematic reviews and meta-analyses show millions of adolescents worldwide achieve insufficient sleep (e.g., less than 8 h), especially on school nights [4] and [5].

Considering only 14% [6] to 27% [1] of adolescents obtain over 9 hr of sleep on school nights, and worse still, up to 25% [1] acquire *less than* 6 hr, it is hardly surprising that most teenagers wake feeling unrefreshed at least a few times per week [6]. Additionally, the consequences of insufficient sleep extend far beyond morning tiredness [7]. Less than 8 hr sleep increases sleepiness throughout the day, and decreases mood, motivation and scores on intelligence tasks [8] and impairs daytime functioning [3]. Conversely, longer sleep duration, better sleep quality and lower daytime sleepiness have been associated with better school performance [9]. Severe restriction of sleep during the week (i.e., less than 6 hr/night) is associated with increased interpersonal problems at school, psychological problems, such as lower life satisfaction, lower self-esteem, higher incidence of drug use [1] and a higher rate of motor vehicle accidents [10].

A lack of sleep on school nights is a transcontinental phenomenon, with adolescents' bedtimes delaying during development. Despite later bedtimes, school start times remain constant, resulting in insufficient sleep duration during the school week [11], and catch up sleep when given extended opportunities (i.e., weekends; [5] and [12]). Given that a lack of sleep is detrimental to healthy functioning and performance [1], it is crucial to identify factors which affect sleep in order to minimise subsequent negative consequences.

Bedtimes and sleep onset latency (i.e., the time it takes to fall asleep; SOL) have been found to negatively correlate with total sleep time (i.e., night time sleep duration; TST) and are also associated with fatigue, anxiety and depressed mood [13]. It therefore appears important to investigate not only sleep duration, but also bedtime and sleep latency.

Possible Reasons why Adolescents do not get Enough Sleep

"Risk" factors.

Many internal and external factors have been identified as detrimental to teens' sleep (e.g., [14]). Although this paper will primarily focus on factors under behavioural control, internal, biological mechanisms also contribute to adolescents' sleep (e.g., [2], [14] and [15]). Physiological sleep pressure takes longer to rise in adolescents than in children, thus it takes longer for adolescents to feel sleepy and prolongs sleep onset [16] and [17]. Additionally, sleep/wake rhythms naturally drift later in adolescents than in children, meaning their natural inclination is to go to bed later and sleep later [15].

Melatonin, a hormone released by the body in the evening in preparation for sleep, is released later in the evening for older adolescents than younger adolescents, which prolongs the onset of evening sleepiness [14]. Together, these biological mechanisms drive adolescents' tendency to stay up later.

Although not a biological mechanism, teenagers are unable to control their school start time, which remains the same or becomes earlier with increased age. This works against teenagers' inclination to sleep later and results in sleep restriction [14]. Conversely, when adolescents are given the opportunity to start school later in the morning they obtain more sleep and feel less tired throughout the day [11].

Looking to external contributors, much hype surrounds the use of electronic media and its detrimental impact on sleep [18]. However, results from studies concerning the effect of television (e.g., [19]), computer use (e.g., [19] and [20]), video gaming (e.g., [20]), mobile phone use (e.g., [21]) and internet use (e.g., [22]) have not exclusively nor consistently stated that all these media have a negative impact on adolescent bedtime, sleep latency or duration - nor that the impact is large. Similarly, the effects of substance use, such as caffeine, alcohol and tobacco have shown a variety of effects on sleep, ranging from no relationship of cigarette use [23] and caffeine [24] on weekday sleep, to medium negative effects from alcohol and smoking [25].

Other factors hypothesized to affect adolescent sleep include; time spent with their peers [26]; whether they are worried close to bedtime (e.g., [27]), and; involvement in extracurricular activities, such as sport and work (e.g., [12]). All these factors have been surveyed in relation to sleep habits, and have presented mixed results in terms of the presence and size of the effect. Another external factor proposed to lead to less sleep and later bedtimes is longer day length, which is affected by longitude, latitude and season (e.g., [28] and [29]). Although day length is not under behavioural control, using room lighting in the evening is. For example, Brazilian adolescents in homes with electric lighting have later bedtimes than those without electric lighting [30].

Despite many factors theorised to negatively impact adolescent sleep, it is difficult to reach conclusions between studies regarding the consequences and severity of these risk factors. Thus, this review aims to consolidate and quantify these research findings using a meta-analytic approach.

Protective factors.

A neglected ‘half’ of the adolescent sleep research field is the investigation of factors benefiting adolescent sleep. Several variables consistently show a protective relationship to adolescents' sleep, bedtime and sleep latency. For instance, adolescents in Australia [31], the United States [12] and Germany [32] all had longer sleep durations when their bedtimes were set by their parents. Better sleep hygiene, such as rarely using one's bed for things other than sleep and relaxing before bed, are positively correlated with sleep duration and negatively correlated with sleep latency [33] and [34]. A positive family environment, with low conflict [35] or chaos [33], has also been shown to benefit adolescents' sleep patterns.

Although it appears that some factors are harmful, or at least not beneficial, there also seems to be protective factors present. Furthermore, most external factors can be modified through changes in people's behaviour (e.g., restricting caffeine intake, avoiding television before bed, etc.). Understanding these relationships simultaneously will be helpful in shaping teenagers' activities in order to improve their sleep.

Current Research and the Need for Consolidation

Although many studies have looked at the impact of individual risk and protective factors on adolescent sleep, no meta-analysis exists to consolidate or quantify these data. Reliance on individual studies may lead to assumptions and misunderstandings concerning the relationship between sleep and risk or protective factors [36], among both the scientific community and the general population. As the magnitude and consistency of these relationships are currently unknown, synthesis of data could provide assurance that risk factors are actually harmful, and to what extent. Moreover, the importance of actively promoting protective factors, rather than simply decreasing unfavourable behaviour, will be a useful addition to therapy, education programs and developments within the field. A research field often needs collaboration of existing data, rather than more studies, to find consistency, minimise variance, and provide new direction for future research [36]. As such, a meta-analytic approach to consolidate existing data will be used to gain information on protective and risk factors for adolescent sleep.

Method

Literature Search

Databases (e.g., Proquest Central, Flinders University search engine, Sage, PubMed, Google Scholar) were searched for articles relating to adolescent sleep. Combinations of keywords, such as ‘adolescent,’ ‘teenage,’ ‘sleep,’ ‘parent monitoring,’ ‘bedtimes,’ ‘electric light,’ ‘media use,’ ‘technology use,’ ‘sunrise,’ ‘sunset,’ ‘longitude,’ ‘latitude,’ ‘anxiety,’ ‘worries,’ ‘stress,’ ‘delayed,’ ‘late,’ ‘sleep hygiene,’ ‘substance use,’ ‘caffeine,’ ‘adequate sleep’ and ‘consequences’ were used to search for articles which relate to relevant factors on sleep duration, sleep onset latency and bedtime. Reference lists of studies found through databases were also searched, and articles found when searching literature for related research were considered.

Inclusion Criteria

Peer reviewed articles, with a mean sample age between 12 and 18 y were considered for inclusion. Articles needed to measure bedtime, SOL and/or TST, and have collected data within the last 11 y (i.e., 2003 to February, 2014), due to rapid changes in technology during this time period, which may make older findings obsolete. For studies where the year of data collection was not stated, year of publication was used. Language of publication was not an inclusion criteria, however, no non-English publications were found.

Exclusion Criteria

Studies were excluded if they were not peer reviewed; if the study focused on an abnormal population (other than delayed sleep phase disorder or insomnia), or; was a review article. Where relevant variables were measured but not reported, authors were emailed requesting the appropriate correlation coefficients. If relevant variables were not measured, or authors did not respond to emails, the study was excluded. Further data offered from emailed authors was accepted if they met all other inclusion criteria.

Coding

Studies were coded by KB, with support from MG. Discrepancies were discussed until consensus was met. A total of 147 studies were identified. Of these, 41 were included in final analyses (see Fig. 2.1 and Table 2.1).

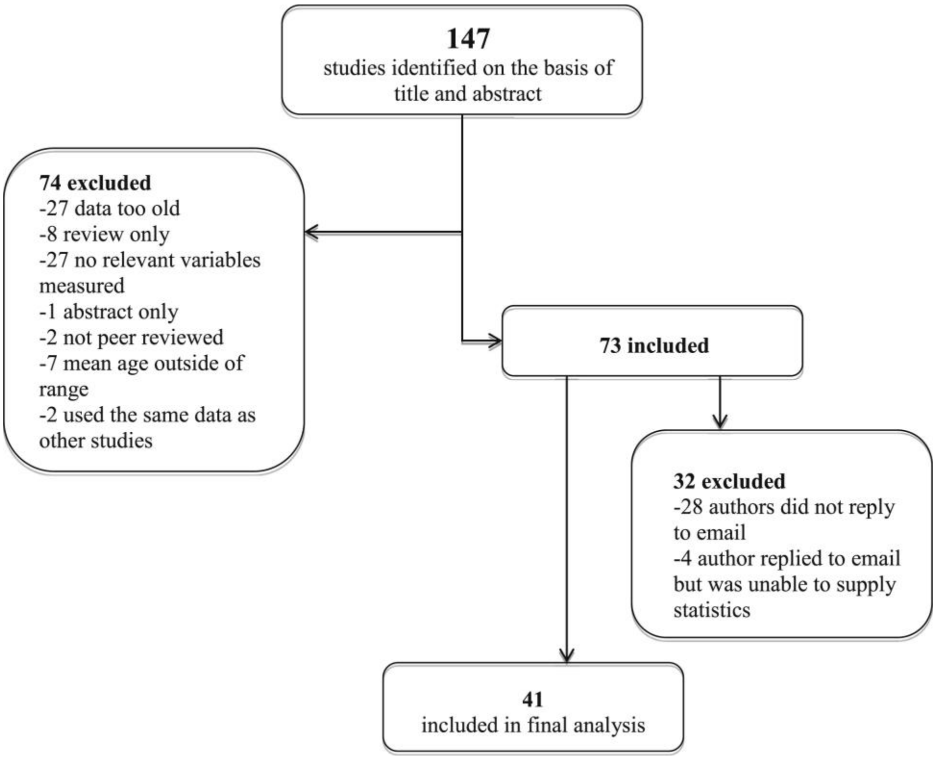

Figure 2.1. Flow chart of articles.

Table 2.1.

Summary of Articles Included in the Meta-Analyses

Author. Year	**Sample size (%male)**	**Country**	**Age range (mean, standard deviation)**	**Measure (sleep); weekend/weekday**	**Measure (protective/risk factors)**
Arora et al., 2013. [60]	632 (36.1)	England	11–18 (13.9, 2.0)	SSHS (SOL, TST); weekday	SSHS (extracurricular); technology use questionnaire (VG, TV, computer, phone)
Billows et al., 2009. [33]	217 (43)	Australia	13–18 (14.9, 1.0)	Self-report questions (SOL, TST); weekday	Confusion hubbub and order scale (family environment); sleep hygiene index (sleep hygiene, caffeine, pre-sleep worry), parental monitoring questionnaire (parent-set BT)
Borisenkov et al., 2010. [52]	1101 (49)	Russian Federation	11–23 (16.1, 3.1)	Munich chronotype questionnaire (BT, SOL, TST); weekday	Longitude & latitude (southern Komi Republic [KR]; Syktyvkar, KR; Inta, KR, & Apatity, Murmansk Region, Russian Federation)
Brand et al., 2009. [40]	246 (24)	Switzerland	(17.58, 1.62)	Sleep log based on PSQI (BT, TST, SOL); weekday	Questionnaire (caffeine, tobacco, alcohol)

Brand et al., 2010. [49]	434 (40)	Switzerland	(17.2, 1.4)	Sleep log based on PSQI (BT, SOL, TST); weekday	Exercise log (physical activity)
Bryant Ludden & Wolfson. 2010. [58]	197 (49)	USA	Grades 9–12	Questionnaire (BT, SOL, TST); weekday	Questionnaire (caffeine)
Chung & Cheung. 2008. [44]	1629 (50)	China	12–19 (14.8, 1.7)	Sleep-wake habit questionnaire, modified from PSQI (BT, TST), sleep quality index (SOL); weekday	Questionnaire (work, physical activity, tobacco, alcohol, caffeine)
Collado Mateo et al., 2012. [47]	2649 (51)	Spain	12–16 (14.09, 1.33)	SSHS (BT, SOL, TST); weekday	SSHS (parent-set bedtime)
Condén et al., 2013. [27]	5012 (50)	Sweden	15–18	Questionnaire (TST); weekday	Questionnaire (tobacco, computer, physical activity); AUDIT (alcohol)
Drescher et al., 2011. [57]	319 (52)	USA	10–17 (13.3, 1.8)	Sleep habits questionnaire (BT, TST, SOL); weekday	Questionnaire (VG, caffeine, work)
Dworak et al., 2007. [62]	11 (100)	Germany	12–14 (13.45, 1.04)	PSG (SOL, TST)	Experiment (VG, TV, control)
Engelhardt et al., 2013. [67]	41 typically developing (100)	USA	8–17 (12.2, 2.4)	Parent report (TST); combined	Parent report (TV, VG)
Figueiro & Rea. 2010. [28]	16 (63)	USA	13–14	Sleep log (sleep onseta, TST); Wednesday	Sleep log b(evening light)

Fuligni & Hardway. 2006. [65]	761	USA	14–15	Questionnaire (TST); weekday	Questionnaire (homework, peers, TV, computer)
Gaina et al., 2005. [19]	643 (48)	Japan	12–15	Questionnaire (BT, TST; weekday, SOL; combined)	Questionnaire (physical activity, homework, TV, VG)
Garmy et al., 2012. [53]	Grade 8 = 782, grade 10 = 1026	Sweden	Grade 8 (14), grade 10 (16)	questionnaire regarding sleep and lifestyle (BT, TST); weekday	Questionnaire (TV, computer)
Gradisar et al., 2011. [43]	49 (53)	Australia	11–18 (14.6, 1.0)	Sleep diary (BT, SOL, TST); weekday	Questionnaire (caffeine use, alcohol, tobacco)
Gradisar et al., 2013. [7]	171	USA	13–18	Questionnaire (BT, SOL, TST); weekday	Questionnaire (caffeine, TV, computer, phone, VG)
Heath et al., 2014. [59]	16 (44)	Australia	14–19 (17.4, 1.9)	Subjective SOL – direct question	Lux meter (evening light)
Hiller et al., 2014. [61]	40 (53)	Australia	11–19 (15.2, 1.5)	Seven day sleep diary (SOL); weekdays	Sleep anticipatory anxiety questionnaire (SAAQ; pre-sleep worries), questionnaire (caffeine)
Honda et al., 2008. [50]	2160 (100)	Japan	Grades 10–12	Questionnaire (BT), calculated (TST [from BT & risetime]); weekday	Questionnaire (TV, internet, evening light, homework, phone, physical activity)

Huang et al., 2013. [45]	33390 (45)	China	11–18	Questionnaire (BT); weekday	Questionnaire (physical activity, alcohol, smoking)
Kalak et al., 2012. [64]	80 (55)	Switzerland	12–20 (16.28, 2.0)	EEG (SOL, TST); not specified	Family climate questionnaire (family environment)
King et al., 2013. [63]	17 (100)	Australia	15–17 (16, 1)	PSG (SOL, TST)	Experiment (VG)
King et al., 2014. [55]	1287 (50)	Australia	12–18 (14.9, 1.5)	Sleep activity and media questionnaire (BT, SOL, TST calculated); weekday	Questionnaire (internet, VG, TV)
Loessl et al., 2008. [42]	601 (50)	Germany	12–18 (15.4, 1.7)	SSHS (BT, SOL, TST); weekday	SSHS (parent-set bedtime, physical activity, work, extracurricular, alcohol, tobacco)
Megdal & Schernhammer. 2007. [46]	131 (45)	USA	13–18 (15.6)	PSQI (BT, SOL, TST); combined	Questionnaire (tobacco, physical activity)
Ortega et al., 2010. [51]	2179 (48)	Spain	13–18.5	Questionnaire (BT), calculated (TST [from BT & rise time]); weekday	Questionnaire (physical activity, TV)
Oshima et al., 2012. [66]	17920 (31)	Japan	Grades 7–12	Self-report (TST); combined	Questionnaire (mobile phone, alcohol)
Pasch et al., 2012. [23]	704 (49)	USA	10–17 (14.7, 1.83; at wave	Questionnaire (BT) calculated (TST [from BT & wake	Questionnaire (alcohol, tobacco)

			1)	time]); weekday	
Peixoto et al., 2009. [30]	37 (38)	Brazil	11–16 (13.1, 1.7)	Actigraphy (sleep onseta, TST); weekday	Electric/non electric home lighting; lux (evening light)
Pieters et al., 2012. [54]	1926 (45)	Belgium	13–20 (16.9, 1.5)	SSHS (BT, SOL); weekday	Questionnaire (TV, computer, phone, VG)
Randler. 2008. [29]	674 (49)	Germany	11–16 (13.3,1.66)	Questionnaire (BT), calculated (TST [from BT & risetime]); weekday	Locality (East Germany [Leipzig], West Germany [Stuttgart, Ludwigsburg])
Randler et al., 2009. [32]	784 (45)	Germany	11–20 (15.18, 2.14)	Questionnaire (BT), calculated (TST [from BT & risetime]); weekday	Adapted SHSS (parent-set BT)
Saxvig et al., 2012. [25]	1285 (52)	Norway	16–19 (17.3, .9)	Questionnaire (BT, SOL, TST); weekday	Questionnaire (tobacco), AUDIT (alcohol)
Shochat et al., 2010 [56]./Tzischinsky & Shochat. 2011. [48][c]	449 (50)	Israel	(14, .8)	SSHS (TST, SOL, bedtime); weekday	Electronic media and fatigue questionnaire (TV, VG, internet), SSHS (parent-set BT)
Short et al., 2011. [31]	385 (59)	Australia	13–18 (15.6, .95)	Sleep diary (BT, SOL, TST); weekday	SHSS (parent-set BT, physical activity, extracurricular, homework, work, caffeine, alcohol, tobacco), SAAQ (pre-sleep worry)

Storfer-Isser et al., 2013. [34]	514 (49)	USA	16–19 (17.7, .4)	Sleep log (BT, SOL, TST); weekday	ASHS (sleep hygiene, pre-sleep worry, caffeine, alcohol, tobacco)
Tan et al., 2012. [38]	33 (45)	New Zealand	10–18 (12.9,2.19)	Questionnaire (BT, SOL, TST); weekday	ASHS (sleep hygiene, caffeine, alcohol, tobacco, pre-sleep worry)
Teixeira et al., 2004. [41]	27 (48)	Brazil	14–18 (16.6,1.1)	Actigraphy and activity diary (BT, SOL, TST); weekday	Questionnaire (work, extracurricular, physical activity, tobacco, alcohol)
Yen et al., 2008. [35]	8004	Taiwan	12–18 (14.7,1.7)	Questionnaire (TST); combined	Questionnaire (internet, caffeine, peers, work, family environment)

Note. ASHS = Adolescent sleep hygiene scale; AUDIT = alcohol use disorders identification test; BT = bedtime; EEG = Electroencephalography; PSQI = Pittsburgh sleep quality index; SAAQ = sleep anticipatory anxiety questionnaire, questions 11–15; SOL = sleep onset latency; SSHS = school sleep habits survey; TST = total sleep time; TV = television; VG = video gaming.

[a] Measured sleep onset, not bedtime.

[b] Personal circadian light measurement device.

[c] Same participants, data published in separate articles.

Statistical Analysis

A weighted mean *r* value, sampling error variance and variance of population correlation were determined as per Hunter and Schmidt [36].

The weighted average of *r* was calculated as follows, so that an individual correlation within a study was weighted by the number of persons in the same study:

$$\bar{r} = \frac{\sum[N_i r_i]}{\sum N_i}$$

where r_i = correlation in study *i*, and; N_i = the numbers of participants in study *i*.

The sampling error variance was calculated as shown below:

$$\sigma_{e^2} = \frac{(1 - \bar{r}^2)^2}{\bar{N} - 1}$$

where $\bar{r}^2$= the weighted average of *r*, and; $\bar{N}$ = the average number of people per study.

The estimate of the variance of population correlations was calculated as shown below:

$$\sigma_{\rho^2} = \sigma_{r^2} - \sigma_{e^2} = \sigma_{r^2} - (1 - \bar{r}^2)^2 / (\bar{N} - 1)$$

where σ_{r^2} = the observed variance in correlations.

If the relevant correlation coefficient was not provided in the article, authors were emailed requesting data. For studies which presented data as means and standard deviations only, results were converted to the Pearson product–moment correlation coefficient, using a Microsoft Excel conversion calculator [37].

Both Pearson's *r* and Spearman's rho were considered appropriate correlation coefficients for meta-analysis, as they have the same sampling error variance. Despite point–biserial correlations having larger standard errors than Pearson's *r*, deletion of studies providing point–biserial correlation coefficients was not feasible, due to the low number of studies in the meta-analysis that would result if they were excluded [36]. Furthermore, weighted averages were not transformed to Fisher's *z*, as this transformation weights larger correlations more than smaller correlations, leading to an upward bias [36].

Results from individual studies included in the meta-analysis did not control for other variables (e.g., age, sex), in order to best synthesize results. Where possible weekday data were used, however, combined weekday and weekend data were analysed when necessary. Only the first point of data were included from longitudinal studies [23] and pre-post intervention studies [38].

Cohen's criteria were used as cut-offs for the magnitude of effect sizes [39], where *r* values of .10–.30 were considered small; .30 – .50 medium, and; above .50 considered large [39]. Thus, weighted *r* values greater than .10 (or less than −.10) were considered to be associated with sleep variables, more so than protective and risk factors which fell between −.10 and .10 [39].

Confidence intervals (CIs) for the variance of population correlations were also calculated for each weighted *r* value, reflecting precision after removal of sampling error. As such, CIs suggest unexplained variance, with intervals that span zero indicating no evidence for the relationship between the sleep variable and the protective/risk factor, and large intervals suggesting the potential for moderating or mediating factors.

Results

The sample consisted of 85,561 adolescents in the age range of 10–23 years, with reported mean ages ranging from 12.2 to 17.7 years. All protective and risk factors associated with sleep variables displayed a small to medium correlation (i.e., ± .10 to ± .30).

Risk and Protective Factors Associated with Bedtime

Internet use, exposure to evening light before bed, computer use, mobile phone use, video gaming and negative family environment (based on one study) were positively correlated to bedtimes. Sleep hygiene and physical activity were factors negatively associated with bedtimes. That is, as these factors increased, bedtime became earlier. All other variables had a minimal effect on bedtime. See Table 2.2 for weighted *r*s and variance statistics. Variables are ranked from the largest negative correlation, to the largest positive correlation, indicating the most protective to the least beneficial, respectively. Refer to Figure 2.2 for CIs.

Table 2.2

Mean Weighted r Between Bedtime and Protective/Risk Factors

Variable	Mean weighted *r*	σ_{e^2}	σ_{ρ^2}	*K*
Tobacco [23, 25, 31, 34, 38, 40-46]	-.183	.000	.013	12
Sleep Hygiene [33, 34, 38]	**-.172**	**.004**	**-.004**	**3**
Alcohol [23, 25, 31, 34, 38, 40-45]	-.156	.000	.007	11
Parent set bedtime [31-33, 42, 47, 48]	-.143	.001	.040	6
Physical activity [19, 31, 42, 44-46, 49-51]	**-.137**	**.000**	**.003**	**9**
Longitude [29, 52]	-.097	.000	-.000	2
Extracurricular activity [31, 41, 42]	-.049	.003	-.001	3
Homework [19, 31, 50]	.038	.001	-.000	3
Television [7, 19, 50, 51, 53-56]	.041	.001	.005	8
Work [31, 41, 42, 44, 57]	.066	.002	.006	5
Caffeine [7, 31, 33, 34, 38, 40, 43, 44, 57, 58]	.074	.003	.002	10
Pre-sleep worry [31, 33, 34, 38]	.091	.004	-.001	4
Latitude [52]	.099	.000	-.000	1
Negative family environment [33]	*.103*	*.005*	*-.005*	*1*
Video gaming [7, 19, 54-57]	*.120*	*.001*	*.001*	*6*
Phone use [7, 50, 54]	*.131*	*-.000*	*.000*	*3*
Computer use [53, 54]	*.148*	*.000*	*.003*	*2*
Evening light [28, 30, 50]	*.169*	*.001*	*-.000*	*3*
Internet [7, 50, 55, 56]	*.212*	*.001*	*.003*	*4*
Time spent with peers	-		-	0

Note. σ_{e^2} = sampling error variance; σ_{ρ^2} = variance of population correlations; *K* = number of studies; bold = protective factors (i.e., factors where *r* < -.1 and CI does not overlap 0); italicized = risk factors (i.e., factors where *r* >.1 and CI does not overlap 0).

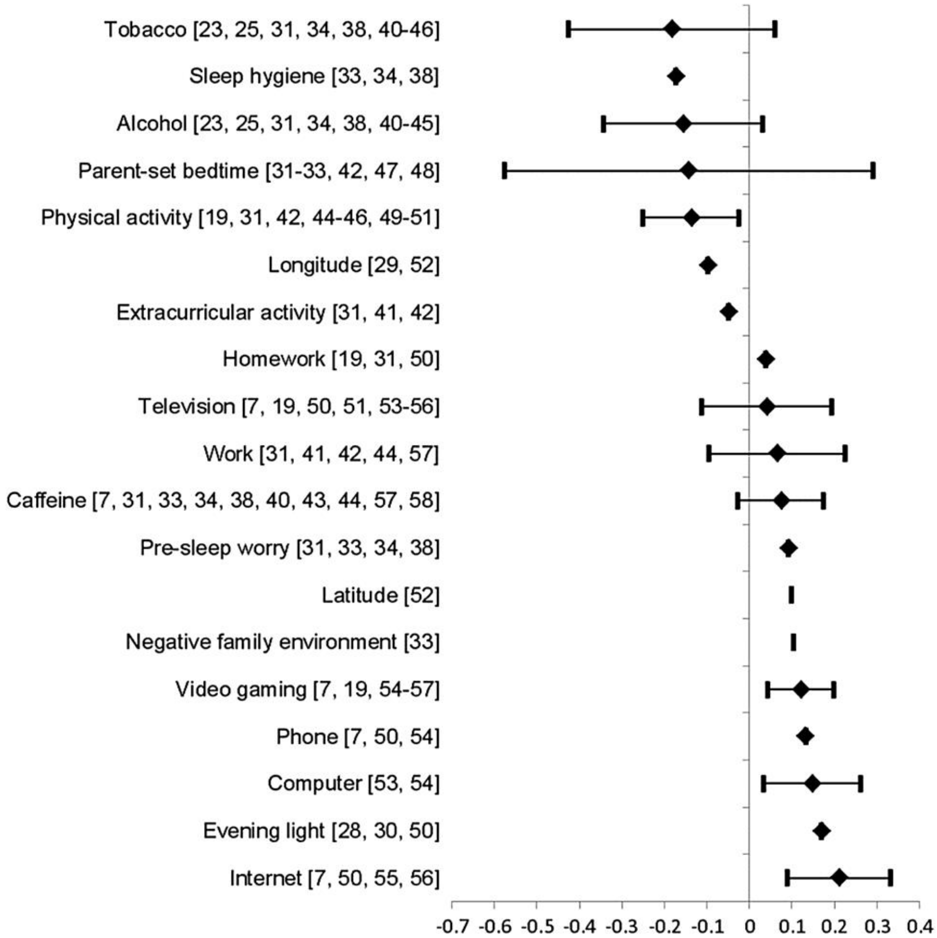

Figure 2.2. Forest plot presenting the mean weighed correlation coefficients and confidence intervals for protective/risk factors and bedtime. Note: dash without a marker represents the data point for variables where N = 1.

Risk and Protective Factors Associated with Sleep Onset Latency

Table 2.3 presents the weighted *r*s and variance statistics for sleep latency, ordered from the most beneficial to the highest risk. Sleep onset latency was positively correlated with a negative family environment. That is, as this factor increased, SOL lengthened. Alternatively, a positive association was seen between SOL and sleep hygiene, with SOL decreasing as sleep hygiene improved. Other variables had weak correlations with SOL. It should be noted that computer use, evening light, longitude and latitude only had one study each, therefore could not be appropriately used in meta-analysis. Refer to Figure 2.3 for CIs.

Table 2.3

Mean Weighted r Between Sleep Onset Latency and Protective/Risk Factors

Variable	Mean weighted *r*	σ_{e^2}	σ_{ρ^2}	*K*
Sleep hygiene [33, 34, 38]	**-.172**	**.004**	**.003**	**3**
Physical activity [19, 31, 42, 44, 46, 49]	-.081	.002	.001	6
Evening light [59]	-0.29	.067	-.067	1
Alcohol [25, 31, 34, 38, 40-44]	-.029	.002	.008	9
Extracurricular activity [31, 41, 42, 60]	-.025	.004	-.002	4
Homework [19, 31]	-.016	.002	.007	2
Tobacco [25, 31, 34, 38, 40-44, 46]	-.015	.002	.011	10
Caffeine [7, 31, 33, 34, 38, 40, 43, 44, 57, 58, 61]	-.015	.003	.003	11
Parent set bedtime [31-33, 42, 47, 48]	-.014	.003	.007	6
Work [31, 35, 41, 44, 57]	.010	.002	.000	5
Television [7, 19, 54-56, 62]	.010	.001	.001	6
Video gaming [7, 19, 54-57, 62, 63]	.031	.001	-.000	8
Phone use [7, 54]	.039	.001	-.001	2
Computer use [54]	.040	.000	-.000	1
Latitude [52]	.072	.000	-.000	1
Internet [7, 55, 56]	.080	.002	.003	3
Longitude [52]	.086	.000	-.000	1
Pre-sleep worry [31, 33, 34, 38]	.137	.002	.010	5
Negative family environment [33, 64]	*.243*	*.006*	*-.001*	*2*
Time spent with peers	-	-		0

Note. σ_{e^2} = sampling error variance; σ_{ρ^2} = variance of population correlations; K = number of studies; bold = protective factors (i.e., factors where $r < -.1$ and CI does not overlap 0); italicized = risk factors (i.e., factors where $r > .1$ and CI does not overlap 0).

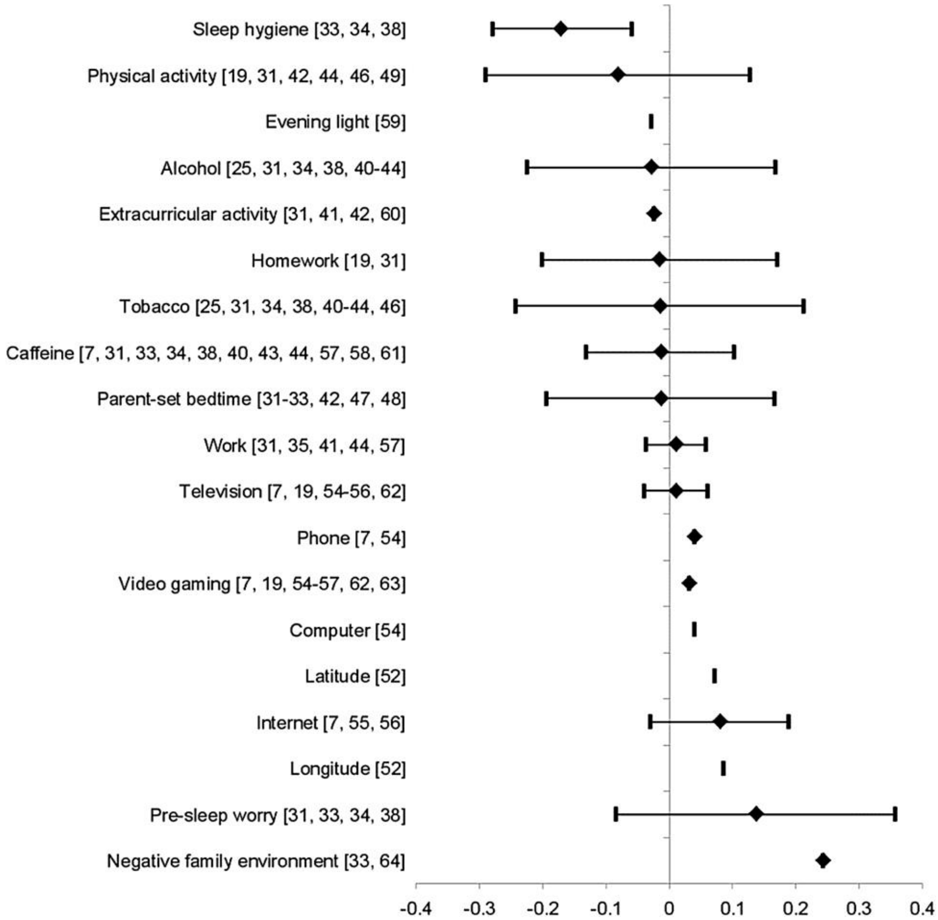

Figure 2.3. Forest plot presenting the mean weighed correlation coefficients and confidence intervals for protective/risk factors and sleep onset latency. Note: dash without a marker represents the data point for variables where $N = 1$.

Risk and Protective Factors Associated with Total Sleep Time

Overall, tobacco use, computer use, evening light, a negative family environment and caffeine consumption had the largest negative associations with TST. Parent-set bedtime had the greatest positive correlation, followed by good sleep hygiene practises. No support was found for the association between all other variables and TST. See Table 2.4 for weighted *r*s and variance statistics. Confidence intervals are displayed in Figure 2.4.

Table 2.4

Mean Weighted r Between Total Sleep Time and Protective/Risk Factors

Variable	Mean weighted *r*	σ_{e^2}	σ_{ρ^2}	*K*
Tobacco [23, 25, 27, 31, 34, 38, 40-44, 46]	*-.183*	*.002*	*.007*	*12*
Computer use [27, 53, 60, 65]	*-.157*	*.001*	*.000*	*4*
Evening light [28, 30, 50]	*-.138*	*.001*	*-.000*	*3*
Negative family environment [33, 35, 64]	*-.133*	*.000*	*.001*	*3*
Alcohol [23, 25, 27, 31, 34, 38, 40-44, 66]#	-.123	.001	.011	15
Caffeine [7, 31, 33-35, 38, 40, 43, 44, 57, 58]	*-.116*	*.001*	*.002*	*11*
Phone use [7, 50, 60, 66]#	-.104	.000	.006	7
Internet use [7, 35, 50, 55, 56]	-.087	.000	.003	5
Homework [19, 31, 50, 65]	-.076	.001	.005	4
Work [31, 35, 41, 42, 44, 57]	-.062	.001	.000	6
Video gaming [7, 19, 55-57, 60, 63, 67]	-.059	.002	-.000	8
Television [7, 19, 50, 51, 53, 55, 56, 60, 65, 67]	-.059	.001	.002	10
Extracurricular activity [31, 41, 42, 60]	-.054	.004	-.002	4
Pre-sleep worry [31, 33, 34, 38]	-.030	.004	.013	4
Latitude [52]	-.019	.000	-.000	1
Time spent with peers [35, 65]	.014	.000	.002	2
Longitude [29, 52]	.070	.000	.001	2
Physical activity [19, 27, 31, 42, 44, 46, 49-51]	.118	.001	.007	9
Sleep hygiene [33, 34, 38]	**.200**	**.004**	**.002**	**3**
Parent set bedtime [31-33, 42, 47, 48]	**.218**	**.001**	**.002**	**6**

Note. σ_{e^2} = sampling error variance; σ_{ρ^2} = variance of population correlations; *K* = number of studies; bold = protective factors (i.e., factors where *r* >.1 and CI does not overlap 0); italicized = risk factors (i.e., factors where *r* < -.1 and CI does not overlap 0); # = Oshima et al. [66] provided data for four separate samples within the same study.

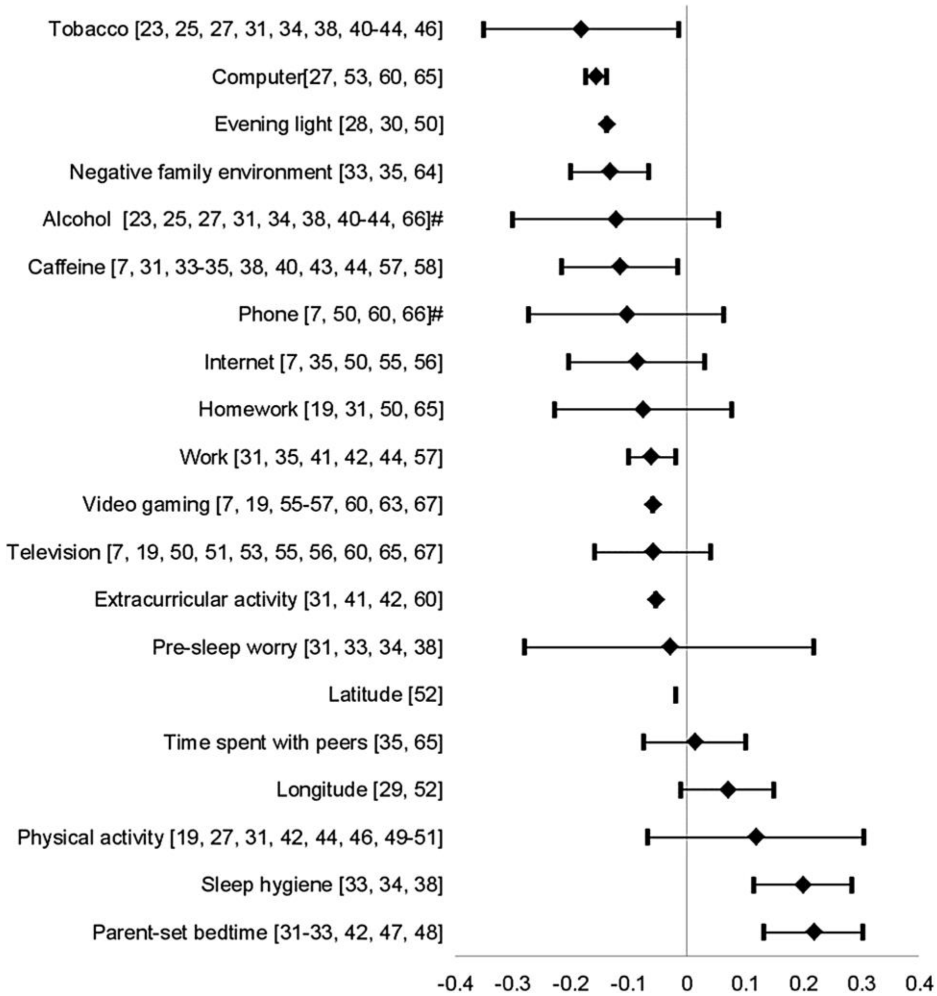

Figure 2.4. Forest plot presenting the mean weighed correlation coefficients and confidence intervals for protective/risk factors and total sleep time. Note: dash without a marker represents the data point for variables where *N* = 1; # = Oshima et al. [66] provided data for four separate samples within the same study.

Caffeine Consumption

Due to differences in measurement between the 11 studies analysed, the consumption of caffeine is presented according to different definitions of the “caffeine” variable, to determine if a particular beverage, or time of consumption, had a stronger relationship with sleep.

No evidence was found for a relationship between caffeine and bedtime (see Table S2.1; Appendix A), or caffeine and SOL (Table S2.2; Appendix A), regardless of the operationalization of caffeine consumption, with the exception of a small, positive effect found between coffee/tea use and bedtime (see Table S2.1; Appendix A). However, slight variations in relationship strength arose when analysed for TST (refer to Table 2.5 for weighted *r*s and variance statistics and Fig. 2.5 for CIs). When all types of consumption were included in the meta-analysis (multiple measures per study were averaged where applicable), a small, negative correlation was found between caffeine use and TST (see Table 2.4). Evening caffeine consumption also had a small, negative effect size. There was no support, however, for the association between drinking caffeinated soda and TST, nor was caffeine consumption defined as “coffee” or “coffee/tea” intake related to TST. Caffeinated energy drink consumption was only assessed individually in one study [58]. Bryant Ludden and Wolfson [58] found no relationship for TST (Table 2.5) or bedtime, however, a small, positive correlation was found between energy drinks and SOL (see Table S2.2; Appendix A).

Table 2.5

Mean Weighted r for Caffeine use Variables and Total Sleep Time

Variable	Mean weighted *r*	σ_{e^2}	σ_{ρ^2}	*K*
Coffee/tea only [31, 40, 44, 58]	-.147	.002	.006	5
Evening use [7, 33-35, 38]	*-.106*	*.001*	*.000*	*5*
Energy drink [58]	-.09	.005	-.005	1
Caffeinated soda [31, 43, 58]	-.004	.005	-.002	3

Note. σ_{e^2} = sampling error variance; σ_{ρ^2} = variance of population correlations; *K* = number of studies; italicized = risk factors (i.e., factors where $r < -.1$ and CI does not overlap 0).

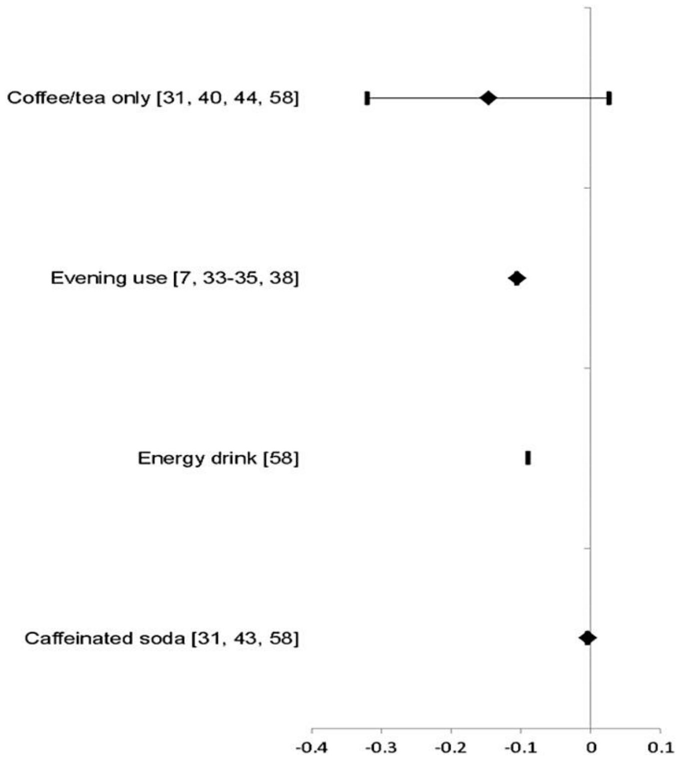

Figure 2.5. Forest plot presenting the mean weighed correlation coefficients and confidence intervals for various types of caffeine use and total sleep time. Note: dash without a marker represents the data point for variables where N = 1.

Discussion

Summary of Findings

Overall, good sleep hygiene and physical activity were associated with earlier bedtimes. On the other hand, internet use, evening light, computer use, phone use, and video gaming were related to later bedtimes. Good sleep hygiene was also correlated with shortened sleep latency. Alternatively, sleep latency lengthened as negative family environment increased. Tobacco use, computer use, evening light, a negative family environment and caffeine use were associated with decreased sleep duration, whereas good sleep hygiene and parent-set bedtimes were related to longer sleep length. Thus of all factors analysed, sleep hygiene was related to all three sleep parameters. Nevertheless, this meta-analysis also observed other factors that possess the potential to affect sleep.

Risk Factors

Family environment.

In terms of factors which may be harmful to adolescent sleep, a negative family environment was associated with longer sleep latencies and short sleep duration. The one study that assessed bedtime also found that a negative home environment was associated with later bedtimes [33]. Findings in the present meta-analysis support previous findings that a negative or disorganised home environment is detrimental to adolescents' sleep [33], [35] and [64]. According to Tynjälä and colleagues [68] a positive home atmosphere, in contrast to a negative home environment, may create a foundation for healthy behaviours, including sufficient sleep [68].

Evening light.

Evening light was related to delayed bedtimes and shorter sleep duration. This may be due to the opportunities that evening light creates [28] and [30]. For example, longer day length may facilitate more participation in outdoor, evening activities [28], hence delaying bedtime and leading to less time sleeping. This hypothesis may also explain why providing electric lighting in adolescents' homes leads to poorer sleep outcomes [30], as the adolescent may be invested in continuing activities made available with indoor lighting.

Alternatively, bright light may alter circadian rhythm timing [69]. Evening light can delay the circadian phase (i.e., the core temperature minimum), making it difficult to fall asleep at a typical bedtime [69]. It can also have an alerting effect, suppressing melatonin levels which would otherwise typically increase as the body prepares for sleep [70]. As light suppresses melatonin and increases alertness, outdoor, indoor and/or screen light may be capable of decreasing subjective sleepiness, delaying bedtimes, and leading to shorter sleep length.

We should caution here that although bright light before bed was not associated with prolonged sleep latency, these results were only based on one study [59], which assessed 1 hr of pre-bed bright screen light on sleep. Among adult samples, longer durations of bright, evening screen light has decreased subjective sleepiness [70], and impacted sleep latency [71]. Due to continued mixed results concerning the effect of screen light exposure on sleep, further investigation is necessary to establish the duration of bright light, the threshold of luminance needed for an effect, and the timing of exposure, before conclusions can be made about the extent to which bright light affects adolescents' sleep latency [59].

Technology use.

Despite many online media claims branding technology as a culprit for causing devastating effects on teenage sleep (e.g., [18] and [72]), the correlations between technology use and sleep were small. One of the five technological devices measured (computers) was related to less total sleep. Internet, computer and phone use, and video gaming, were all associated with later bedtimes, albeit showing small effects. These technologies may engage the user so that they become distracted or apathetic towards the time, thus displacing bedtime [13] and [73].

The physical, emotional or psychological arousal which may take place when using these devices could lead adolescents to feel less sleepy, once again causing later bedtimes [13] and [73]. Sleep may then be restricted when needing to wake up for school the following morning.

Many teenagers use their phone *after* sleep onset [74], disrupting sleep and leading to less total sleep time. With the internet now accessible on portable devices, such as cell phones [75], future studies may need to consider whether internet use (such as connections to social media) is disrupting adolescent sleep in a similar way to text messaging.

As the present meta-analysis was correlational in nature, it is possible that adolescents entertained themselves through the use of technology whilst waiting for sleep [76]. While this explanation is plausible, Pieters and colleagues [54] found adolescents whose parents set rules regarding the duration and timing of television viewing, computer use and video gaming had earlier weekday bedtimes than those without parental restriction [54]. Though it may be that adolescents who feel less tired in the evening fill the void with technology use rather than sleep [76], the observation that adolescents with technology restrictions have earlier bedtimes [54] suggests the contrary: that technology use leads to later bedtimes. These meta-analytic results demonstrate the contribution technology use has in delaying adolescents' bedtimes. Although not all devices were associated with less total sleep time, caution needs to be taken by adolescents using technology, to minimize its impact on sleep.

Substance use.

Caffeine.

Caffeine use was only found to be associated with shorter sleep duration. This may indicate two things. First; the use of caffeine makes adolescents more alert and unable to sleep [24], or, alternatively; adolescents who obtain less sleep are more tired, thus drink caffeinated beverages in an attempt to fight fatigue [58]. Some adolescents may use caffeine to increase alertness yet for others, alertness may be a by-product of ulterior motives, such as “*to experiment*” and “*to have fun*” [58], with one consequence being less sleep duration. Bryant Ludden and Wolfson [58] found that consumers of multiple types of caffeinated beverages (such as those in the current meta-analysis) were more likely to use caffeine for the purpose of “*getting through the day*”, and had earlier school day rise times, than low caffeine users or adolescents who consumed high amounts of soda [58], supporting the idea that adolescents who sleep less are more likely to use caffeine. Importantly, according to the current meta-analysis, caffeine use, including combined beverage use and use in the evening, has a small impact on sleep duration. Thus, it is important for adolescents using caffeine for reasons such as “*to appear interesting*” or “*have fun*” to comprehend that less sleep may result from their behaviour. For adolescents who primarily consume caffeine as a means of increasing alertness, intervention would need to educate that increased caffeine consumption may later inhibit ability to obtain adequate sleep, as well as tackling other causes for why insufficient sleep is obtained.

Tobacco.

Tobacco was related to less total sleep time. Cigarette smokers are more likely to have trouble staying asleep than those who do not smoke [77]. These disruptions in sleep, would, in turn, lead to less sleep quantity. Future research may wish to look at the sleep of adolescent smokers verse non-smokers. For example, a pre-post design could be employed, whereby current adolescent smokers' sleep is measured before and after a period of abstinence (after withdrawal effects have diminished), in order ascertain whether sleep improves.

Factors Which are Neither Risky nor Protective

Technology use.

In terms of technology use, television was not related to bedtime, and none of the technology variables (i.e., video gaming, phone, computer and internet use and television) were related to sleep latency. Furthermore, phone use, internet use, video gaming and television were not related to sleep duration. What can be made of these mixed results? Calamaro and colleagues [24] found that night time media use of a variety of individual devices did not impact sleep duration. However, technological multi-tasking, that is, using more than one technological device at a time, was associated with less sleep [24]. Possible mechanisms for technology affecting sleep, such as displaced bedtime, increase in arousal and exposure to bright light which may delay the circadian rhythm [13] and [73] all have increased opportunity to affect sleep when adolescents are interacting with multiple devices. Unfortunately, multi-tasking could not be measured in this meta-analysis due to a lack of literature and required statistics [24].

Device content should also be considered. Interactive forms of technology, such as computers, cell phones, and video gaming have been found to affect sleep above those which were passive, such as television [7]. The current meta-analysis supported these findings to some extent, as watching television was not related to sleep variables. However, devices which were interactive (video gaming), or had the potential to be interactive (e.g., computer use and internet use) were not always related to poor sleep. This may be in part that the *content* of computer and internet use were not ascertained in the present meta-analysis, therefore, hypothetically, adolescents could have been using these media for passive activities, such as watching movies, with subsequently less impact on their sleep.

As with bright light, the timing and duration of technology use may need to be more specifically studied, using experimental designs, before the true effects can be disentangled.

For example, one experiment of males, aged 15 to 17 y, demonstrated that 50 min of pre-bed video gaming did not impact objective sleep duration or subjective SOL, whereas 150 min decreased sleep duration and increased SOL [63]. This implies that the association between technology use and sleep is not straight forward. The number of devices used [24], the content of the device [7] and the duration of use [63] may all contribute to how technology influences adolescents' sleep.

Substance use.

Caffeine.

Despite caffeine use being associated with lower total sleep time, it was generally not associated with sleep latency or bedtime, although coffee/tea consumption was marginally related to later bedtimes. Calamaro and colleagues [24] found that caffeine consumption was 76% higher among teenagers who fell asleep at school than those who did not, demonstrating that caffeine may be used to combat fatigue, however, it may not fully overcome sleep pressure [24]. It is plausible that adolescents who sleep less are more likely to consume caffeine, yet also have higher sleep pressure, which counteracts caffeine's alerting effects. This could explain the findings of the present meta-analysis, as despite caffeine and sleep duration being negatively correlated, if adolescents who are more tired (and have less sleep) are higher consumers of caffeine, their sleep pressure and caffeine use may cancel each other out, resulting in similar bedtimes and sleep latencies for both high and low consumers of caffeine. Nevertheless, experiments, as opposed to correlational studies, are needed to determine the effects of caffeine, and the timing of its consumption, on adolescent sleep.

Alcohol and tobacco.

Alcohol was not related to any sleep variables and tobacco use showed no relationship between bedtime or sleep onset latency. Links have been found between longer sleep latency and adult smokers [78], yet there is a lack of published literature concerning the same link in adolescents. Most of the data collected for the current meta-analysis were due to the generous contribution of authors replying to emails sent by KB requesting results. As such, it is difficult to ascertain reasons why similar results were not found between adolescent sleep onset and tobacco use as those found in adult samples.

Results from the current meta-analysis support experimental data from young adults, aged 18–21 y, which demonstrated that alcohol consumption did not affect sleep onset [79]. Of note, the same study also found that alcohol consumption did lead to more awakenings after sleep initiation [79], indicating that although alcohol may not impede sleep initiation, it may disturb sleep quality.

Neither alcohol nor tobacco use were found to be related to earlier bedtimes. One explanation for such findings is that drinking and/or smoking cigarettes may be more conducive to a party lifestyle [80]. These adolescents may sleep significantly less on weekends than their non-partying peers, hence may be sleep deprived during the week. Consequently, excess sleep pressure may lead to similar weekday bedtimes, despite possible weekend delays.

Despite no evidence for the relationships between alcohol or tobacco and bedtime, and alcohol and TST, small effect sizes were present, with large confidence intervals suggesting the potential for moderating factors. For example, Gutman and colleagues [81] found negative family interactions were associated with increased alcohol consumption and smoking. Given that the present meta-analysis found a link between a negative family environment and sleep variables, it may be that this factor was a confound for the relationship between alcohol and/or tobacco use and sleep, hence a consistent relationship between these substances and sleep could not be found in the present meta-analysis.

Physical activity.

Physical activity was beneficial for bedtime, yet it was not associated with sleep latency or total sleep time. Possibly, sports participation only impacts sleep latency in more extreme instances. Of the six studies included in the meta-analysis, only one found an effect of exercise on sleep latency, with athletes falling asleep faster than controls [49]. Looking at individual studies, one interpretation of these findings is that a range may exist, within which the number of hours of exercise does not impact sleep latency, however, in more extreme cases, as in the case of athletes, it helps adolescents fall asleep faster.

A small effect size was present between sleep duration and physical activity, yet no relationship could be determined, due to large CIs. As this suggests the possibility of mediating or moderating factors, this relationship will be discussed in ‘Protective Factors’.

Activities outside of school.

Participation in activities outside of school hours, such as extracurricular involvement, work, homework and time spent with peers, had no relationship with sleep variables. Once again, there may be a range within which adolescents are able to engage in activities outside of school, wherein their sleep is not greatly affected.

Contrary to the overall meta-analysis results, Dorofaeff and Denny [82] found the hours an adolescent worked in paid employment each week strongly related to less sleep, particularly for students who worked over 3 hr per week. The specific duration of work, or other activities outside of school, was not measured in the present meta-analysis, so the possibility that there is a cut-off, after which sleep is affected more dramatically, could not be assessed.

Moreover, Fuligni and colleagues [65] analysed individuals' sleep length after measuring activity duration over individual days. Less sleep was obtained following days where adolescents had studied more outside of school. However, sleep duration remained unaffected regardless of whether more or less time had been spent with peers [65]. Furthermore, variability existed for individuals between the amount of time they spent on an activity, per day, and the subsequent night's sleep duration. Daily studying and socializing both had significant individual variance, indicating that adolescents' sleep patterns may not always respond in a systematic manner to daily activities [65]. Consequently, it may be difficult in a therapeutic or educational setting to demonstrate to adolescents how much time can be spent participating in activities outside of school before their sleep is affected. For example, on some nights excessive studying outside of school may lead to less sleep, yet on other nights sleep duration will remain unaffected, regardless of study duration.

Perceived demands from family, school and friends were also related to less sleep, indicating that whether adolescents find these outside of school activities enjoyable or stressful may mediate the effect on sleep duration [65]. For example, lower weekend sleep duration has been found among adolescents who have higher psychological demands at work [83].

In summary, although the present meta-analysis did not find any association between sleep variables and extracurricular involvement, work, homework or time spent with peers, it may be that a “safe” amount of activity involvement exists; that the enjoyment or stress of these activities has an effect on sleep, rather than the activity itself, and; that large individual variability exists in response to the duration of activity participation.

Latitude and longitude.

Neither latitude nor longitude were related to any of the sleep variables. The analysis of these variables was limited in that only one or two studies provided results appropriate for analysis. Bedtime was approaching a meaningful negative relationship with longitude, and a positive relationship with latitude.

Borisenkov and colleagues [52] found a 68 min delay in the timing of sleep with a 27° shift westward in longitude. Similarly, a 16 min delay was observed in adolescents who lived as little as 8° further North [52]. As these effects were found between relatively small shifts West and North, further investigation into the effects of longitude and latitude on adolescent sleep is warranted.

Pre-sleep worry.

An emerging trend was found for later bedtimes as pre-sleep worries increased, however, overall sleep duration and sleep onset latency remained unrelated. Storfer-Isser and colleagues [34] found that cognitive and emotional arousal before initiating sleep was not related to awakenings after sleep onset, nor was it associated with sleep efficiency (i.e., the percentage of time in bed spent asleep). Thus, despite potential frustration in initiating sleep, if sleep efficiency remains unaltered by cognitive and emotional arousal prior to falling asleep, sleep duration may not be harmed by pre-sleep worry.

Worry just before sleep was not associated with increased sleep latency, due to the large variability in population variance (i.e., the 95%CI crossed zero; Fig. 3), yet it did present a small effect. Specifically, cognitive and/or emotional arousal when going to bed [33], [34] and [38] or while trying to get to sleep [31] and [61] were included in the meta-analysis. Adolescents with sleep difficulties often catastrophize their anxieties about events during the day and plans for the next day while attempting to initiate sleep [61]. Although cause and effect could not be established in the present meta-analysis, it seems plausible that ruminating on the day's events, worrying about home or school, and thinking about tasks which need to be completed [34] may impede sleep initiation, especially if catastrophic thinking intensifies these thoughts [61]. However, as indicated in the present meta-analysis, it appears that in terms of sleep latency, a large fluctuation surrounds who is affected by worrying thoughts before bedtime.

Furthermore, as adolescents worried more, a trend to go to bed later emerged, although it did not meet Cohen's criteria for a small effect [39]. It may be that adolescents who are more cognitively and emotionally aroused before bed tend to delay bedtime [34] and [38].

Protective Factors

Sleep hygiene.

Implementing good sleep hygiene practises was found to be beneficial for bedtimes, sleep latency and sleep duration, having similar effect sizes on all of these sleep dimensions. Sleep hygiene encompasses multiple facets, such as behavioural, physiological and emotional arousal before bed, sleep environment and sleep stability [34]. Hence, in order for an adolescent to have good overall sleep hygiene, many components need to be satisfied. Therefore, if an adolescent has low arousal before bed, has consistent sleep patterns and a good sleep environment, sleep should necessarily benefit, with the more of these components adhered to, the better the sleep. Parents may play a role in the consistency of adolescents' sleeping patterns.

Parent-set bedtime.

Parent-set bedtimes were related to longer sleep quantity, but not sleep latency. Moreover, despite relation to earlier bedtimes, to a small extent, there was large variability between populations. This demonstrates that even though some parents send their teenagers to bed earlier than adolescent would choose, this does not necessarily predispose them to lying awake for longer. It appears that adolescents who go to bed at a time elected by their parents fall asleep within the same time frame as their peers who chose their own bedtime, thus may have (and seize) the opportunity to sleep longer before waking up for school. As such, parent-set bedtime may be a protective factor.

Physical activity.

Exercise was found to be a protective factor in regards to adolescents' bedtimes, with more exercise linked to an earlier bedtime. Although no relationship was identified between sleep duration and physical activity, large variance across samples suggests the possibility of moderating or mediating factors. Accordingly, the question remains as to when the benefits of exercise on sleep are most likely to arise.

The timing of exercise may impact sleep. In an adult population, performing moderate or vigorous exercise in the morning, as opposed to abstaining from morning exercise, was associated with better sleep quality [84]. Furthermore, those who performed light exercise within 4 hr of bed reported sleeping longer than those who did not exercise in this time frame [84]. Although exercising within the hour before bed is not conducive to good sleep hygiene [34], exercising 4 hr beforehand, or in the morning, may be beneficial to sleep duration.

Exercise duration and intensity may influence the effects of exercise on sleep [85]. Adolescents from North America who exercised for over 60 min/day, for four or more days/week, had better odds of obtaining sufficient sleep than adolescents who did not exercise for this duration on any day [85]. Moreover, adolescents who completed a minimum of 20 min of *vigorous* exercise on at least 5 days/week also had better odds of achieving sufficient sleep than adolescents who did not partake in this exercise [85]. From an opposing point of view, it is possible that adolescents who sleep less feel more tired. This lack of energy may present a barrier to exercising [86].

It would be beneficial to conduct experiments to determine which factors, such as exercise timing, intensity and duration, are the most influential on adolescent sleep.

School Start Times

Given that school start times often determine the wake-up schedules of teenagers, and that delaying school start times can improve adolescents' sleep [11] it is worth considering that a delay in school start times may also be a protective factor. Although adolescents do not have control over the time at which they are required to attend school, school bodies may benefit from considering a delay in start times.

Strengths, Limitations and Considerations

This is the first meta-analysis to assess a large range of factors which may be associated with adolescent sleep. Insight was provided into what helps adolescents' sleep, rather than merely focussing on what adolescents' should avoid.

Although not included, cultural factors may also impact sleep. Given that culture may change even within the same county we felt it was beyond the scope of this paper to include. Nonetheless, cultural influences should be considered when interpreting and applying these results. For example, in Asian cultures, bedtimes are usually later, and sleep time shorter, than Northern American and European cultures [5].

It is possible that younger and older adolescents' sleep may have offered different relationships with protective and risk factors. For majority of the variables there were not enough studies to divide into a ‘younger’ and ‘older’ age group. Future research, however, may wish to investigate this possibility further.

Technology use is increasing among adolescents [11]. This meta-analysis did not take into account the year of publication, to determine if heavier technology use occurred in more recent publications, and whether this impacted sleep. It is hoped that by only including data from 2003 onwards that this problem was minimised.

Importantly, due to the correlational nature, no cause or effect could be determined, and future experiments will need to ascertain the direction of effect. The present meta-analysis focused on relationships between variables without controlling for other factors, in an attempt to equally summarize variables across studies. There is potential, however, for confounding factors within the relationships explored. For example, age, gender, culture and parent-teenager relationship may all impact the associations between protective and risk factors, and sleep. Furthermore, adolescents who have more structured home environments and parent-set bedtimes may be more likely to have good sleep hygiene, although this could not be determined from this study.

To complicate the understanding of which factors advance or delay bedtime, or prolong or shorten SOL or sleep length, some studies divide the week into weekdays (where parameters are set in place by schools) and weekends (which allow less restricted sleep), while other studies analyse both weekday and weekend data together. Furthermore, the operationalization of both sleep and risk/protective variables frequently vary between studies, making it difficult for the reader to compare results. As an example, caffeine use has been measured by asking adolescents how often they consume coffee, with response options ranging from 0 '*never*' to 4 '*often*' [44], yet in another study, adolescents were asked whether they drank coffee at night to reinvigorate themselves [35]. Yet again, each study in the present meta-analysis which assessed home environment used a different questionnaire, leading to variability between measurement tools. Due to these limitations, understanding the relationships between variables can be confounded, as multiple dimensions must be taken into consideration for proper interpretation.

One solution is to implement standardization of measurement tools when measuring similar constructs. For example the School Sleep Habits Survey is a widely used instrument which assesses various components of adolescent sleep [87]. It measures weekday and weekend sleep variables separately, as well as many protective and risk factors. The survey sleep time measures are correlated with both actigraphy and sleep diary data [87]. Additionally, the Adolescent Sleep Hygiene Scale is also commonly used, assessing many practices before bed [34]. The revised version has an internal validity of $\alpha = .084$ [34]. Where possible, weekday (i.e., Sunday-Thursday night) and weekend (i.e., Friday-Saturday night) sleep variables should be measured separately [87], with clear indication concerning which sleep variables were measured and reported.

Similarly, the reporting of sleep variables and their relationships with variables of interest should be standardized, where appropriate. This would ease comparison of results. For example, correlation coefficients, or means and standard deviations, should be presented either within an article, or in supplementary data files, in order for simple relationships to be determined by readers, and compared to other studies where necessary/appropriate.

Finally, the robustness of meta-analysed findings are dependent on the number of independent studies examining them. In order for the field to gain more insight into protective and risk factors for adolescent sleep, future replication of studies are needed, followed by an updated meta-analysis of new and older data. The present study has included the meta file as a supplementary file should any researchers wish to further analyse, or extend, these findings.

Conclusions

Good sleep hygiene appears to be a protective factor, whereas a negative home environment and evening light appear to be risk factors. Cautious use of technology (other than television), caffeine, tobacco and alcohol should be considered, as these factors are likely to have some negative impact on sleep, as is the case with pre-sleep worry. Further investigation into the effects of parent-set bedtime and physical activity is warranted to determine whether these are protective factors. Experiments are necessary to understand the direction of effect, as well as when and how sleep is most affected by protective and risk factors. Regardless of study design, future research needs standardization of measurement tools and better access to descriptive statistics, through reporting within the article, or supplementary data.

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CHAPTER 3. The Short and Long of Adolescent Sleep: The Unique Impact of Day Length

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Abstract

Variation in day length is proposed to impact sleep, yet it is unknown whether this is above the influence of behavioural factors. Day length, sleep hygiene and parent-set bedtime were simultaneously explored, to investigate the relative importance of each on adolescents' sleep. An online survey was distributed in 4 countries at varying latitudes/longitudes (Australia, The Netherlands, Canada, Norway). Overall, 711 (242 male; age M=15.7±1.6, range=12-19 years) adolescents contributed data. Hierarchical regression analyses showed good sleep hygiene was associated with earlier bedtime, shorter sleep latency and longer sleep (ß=-.34;-.30;.32, p<.05, respectively). Shorter day length predicted later bedtime (ß=.11, p=.009), decreased sleep latency (ß=-.21, p<.001), and total sleep (ß=-.14, p=.001). Longer day length predicted earlier bedtimes (ß=-.11, p=.004) and longer sleep (ß=.10, p=.011). Sleep hygiene had the most clinical relevance for improving sleep, thus should be considered when implementing adolescent sleep interventions, particularly as small negative effects of shorter day length may be minimised through sleep hygiene techniques.

The Short and Long of Adolescent Sleep: The Unique Impact of Day Length

Adolescence is a time marked by relatively rapid physiological, biological and hormonal changes, all of which contribute to changing sleep patterns (Carskadon, 2011; Jenni & Carskadon, 2004; Roenneberg et al., 2004). As adolescents become older, their ability to postpone sleep onset increases, through a reduction in the escalation of sleep pressure, and a natural delay in their sleep timing (via a delayed 24-hr circadian rhythm timing; Carskadon, 2011). This, in conjunction with constraints imposed on sleep through starting school can lead to restricted sleep, especially on weekdays (Gradisar, Gardner, & Dohnt, 2011; Perkinson-Gloor, Lemola, & Grob, 2013). Healthy sleep is vital for adolescents' wellbeing (Roberts, Roberts, & Duong, 2009), affecting their mental health, interpersonal problems (Roberts et al., 2009) and school performance (Kronholm et al., 2015). It is thus important to consider the extent to which contributing factors beyond adolescents' behavioural control (i.e., age, gender, day length) influence their sleep, before examining factors within their control (i.e., sleep hygiene, parent-set bedtime, alcohol, tobacco) in order to empower adolescents, and their caregivers, with the knowledge and tools to achieve optimal sleep health.

In terms of demographics, younger *age* is predictive of longer sleep in adolescents, yet effects of *gender* decrease by mid-adolescents (Fredriksen, Rhodes, Reddy, & Way, 2004). *Sleep hygiene* is a factor under behavioural control, and comprises multiple facets that may benefit the sleep of adolescents, including consistent bedtime routines, avoidance of pre-bedtime stimulating substances (e.g., caffeine) and activities (e.g., technology use), or a comfortable sleep environment (e.g., quiet and dark bedroom; Bartel, Gradisar, & Williamson, 2015; Storfer-Isser, Lebourgeois, Harsh, Tompsett, & Redline, 2013). *Parent-set bedtimes* have recently been shown to be an important determinant of adolescents' sleep, being consistently linked with longer sleep durations (yet not sleep latency; Bartel et al., 2015), which in turn improve adolescents' daytime alertness and decreasing their fatigue (Short et al., 2011), depression and suicidal ideation (Gangwisch et al., 2010). However, the benefits of weekday parent-set bedtime on bedtime and total sleep do not occur when parents' limitations are temporarily removed (i.e., weekends (Short et al., 2011).

However, one understudied area are geographic factors, which may influence when adolescents retire for bed, how long it takes them to fall asleep, and how much sleep they obtain. Interestingly, small shifts in *longitude and latitude* are suggested to impact bedtime (Borisenkov, Perminova, & Kosova, 2010), with a trend towards a negative relationship with longitude (i.e., further East longitude and earlier bedtime), yet a positive relationship with latitude (i.e., further North latitude and later bedtime; Bartel et al., 2015). Trends in the association between longitude/latitude and adolescent sleep duration have not appeared (Masal et al., 2015), however, there is potential for broader ranges in longitude and latitude to allow for differences in sleep duration to be observed (i.e., Masal et al., 2015) measured adolescents at differences of 6^0E and 19^0N). Nevertheless, the number of studies into the associations between longitude and latitude with adolescents' sleep is extremely small (i.e., 4 studies to the authors' knowledge; Borisenkov et al., 2010; Masal et al., 2015; Randler, 2008a; Randler, 2008b), especially when compared to the plethora of studies investigating topical factors (e.g., technology use; 67 studies with 5-17 year old participants; Hale, & Guan, 2015). A recent meta-analysis showed the possibility of small relationships between latitude and longitude with adolescents' bedtimes, sleep latency, and total sleep time, yet unfortunately, these were based on only 2 studies, each with relatively small shifts in longitude and latitude (Bartel et al., 2015). Of note, changes in longitude and latitude result in variations in sunrise and sunset times, and hence day length. To increase our confidence that there does indeed exist a meaningful association between longitude and latitude (and therefore day length) with adolescents' sleep, more studies are needed. The aim of the present study was to assess the unique impact of day length on adolescents' bedtimes, sleep latency and total sleep time by sampling across multiple countries with large variations in latitudes (Australia, The Netherlands, Canada, Norway), whilst simultaneously controlling for important factors under behavioural control (i.e., sleep hygiene, parent-set bedtimes, demographics).

Method

Participants

A total of 1,554 adolescents commenced the survey from all 4 countries. Of these, 711 (242m) contributed data (see Table 3.1). Participants were aged 12-19 yrs (M = 15.7, SD = 1.6). This age range was chosen as sleep patterns start delaying in early teenage years, until the age of 20, and are suggested as the beginning and end of adolescent sleep patterns, respectively (Roenneberg et al., 2004). Age and gender demographics were similar for those who provided data compared to all adolescents who started the survey.

Table 3.1

Impact of Day Length on Sleep: Descriptive Statistics and Frequencies

Variable	*N*	*M*	*SD*	*Range*
Australia	294	-	-	-
The Netherlands	138	-	-	-
Canada	146	-	-	-
Norway	133	-	-	-
Age (years)	711	15.71	1.61	12-19
Weekday bedtime (decimal)	708	22.87	1.16	19.98-26.52
Weekday sleep onset latency (min)[b]	699	40.87	38.37	0.00-270.00
Weekday total sleep time (min)	685	442.19	76.67	197-690
ASHS-R	711	4.33	0.60	2.36-5.66
Short day length (hours, decimal)	133	0.50	0.0[a]	0.50
Mid length (hours, decimal)	290	9.93	1.47	7.58-13.00
Long day length (hours, decimal)	288	13.75	0.66	13.03-16.02
	N	*Yes*	*No*	
Parent-set bedtime	711	293	418	
Tobacco (after 6pm)	711	73	638	
Alcohol (after 6pm)	711	184	527	

Note. ASHS-r = Adolescent Sleep Hygiene Scale – Revised, M = mean, SD = standard deviation, [a] All participants in the short day length group were from Norway, and completed the questionnaire in the same time period, hence 0 variation in day length, [b] results for untransformed SOL variable.

Materials

Survey completion date, and residence/postcode were used to determine sunrise and sunset times for individuals (online sunrise/ sunset calculator; http://www.sunrise-and-sunset.com/en/sun). Sunset and sunrise times were highly correlated (r= -.96, N = 711, p<.001), thus, to minimise collinearity, day length was calculated as follows: day length = sunset time in 24hr decimal clock time– sunrise time in decimal clock time.

Participants were asked to retrospectively report their typical weekday bedtime, sleep onset latency and total sleep time over the previous 2 weeks (e.g., *At what time do you usually go to bed to sleep at night?).* Norwegian sleep onset latency and total sleep time data were an exception, with weekday averages calculated from a 1-week sleep diary completed throughout the week. A high correlation between weekday sleep measured via sleep diaries and questionnaires have been previously reported (Arora, Broglia, Pushpakumar, Lodhi, & Taheri, 2013; Wolfson et al., 2003), therefore, although data collected in Norway was via a different method, Norwegian data remains comparable for analysis to that collected in the other 3 countries.

Sleep hygiene over the previous 2 weeks was measured via The Adolescent Sleep Hygiene Scale – Revised (ASHS-R; Storfer-Isser et al., 2013), which is a 24-item scale (6-point scale, *1* [*never*, *0%*] *–6* [*always*, *100%*]). Scores were reversed so that higher scores indicated better sleep hygiene. The ASHS-R has six subscales: physiological (5 items), behavioural arousal (3 items), cognitive/emotional (6 items), sleep environment (5 items), sleep stability (3 items) and daytime sleep (2 items). Each subscale score is the average of the items of which it comprises. The mean of each subscale score is summed (Storfer-Isser et al., 2013), and then divided by the number of subscales (i.e., 6) to obtain the total score. Thus, the total score is an average of the subscale ratings, ranging from 1-6, with higher scoring indicating better sleep hygiene. For the total sample, internal consistency for the 24 items was good (Cronbach's α = .83, *N* = 711). Internal consistency for the 24 items was also acceptable for each country (Cronbach's α = .83, *N* = 294, for Australian adolescents; Cronbach's α = .77, *N* = 138, for Dutch adolescents; Cronbach's α = .86, *N* = 146, for Canadian adolescents; Cronbach's α = .81, *N* = 133, for Norwegian adolescents). Respondents were asked whether they "*Smoked/chewed tobacco after 6pm"*, or "*drank alcohol after 6pm"*, using the same response scale.

Australian, Dutch and Canadian adolescents were asked "*My parents set my bedtime"* for weekdays (7-point response scale, *never –always*; recoded: *never/almost never* = 0, *sometimes-always* = 1). These data were recoded to match Norwegian data, where adolescents were asked whether their parents set their bedtimes on weekdays (*no/yes*). Finally, age and gender (*male*= 0, *female* = 1) were also collected.

Procedure

A 30-min, online survey, approved by the Social and Behavioural Research Ethics Committee, Flinders University, was conducted using Qualtrics (Qualtrics.com; Provo, Utah)[1]. A preliminary survey question asked for adolescents' consent to participate in the survey. Data collection in South Australia occurred from October 2013 to May 2014, with the exception of school holidays which may alter adolescents sleep patterns (13/12/2013-9/02/2014; Bei et al., 2013; Warner, Murray, & Meyer, 2007). Upon completion, participants selected a charity, to donate AUD$1. Data were collected from the Netherlands (07/11/2013–21/05/2014; Faculty Ethics Review Board of the Faculty of Social and Behavioural Sciences, University of Amsterdam); Tromsø, Norway (13/01-19/01/2014; The Regional Committee of

[1] Extra questionnaire data were collected for Australia, Canada and the Netherlands, and are accepted for publication elsewhere (Bartel, K., Williamson, P., van Maanen, A., Cassoff, J., Meijer, A. M., Oort, F., ... & Gradisar, M. (2016). Protective and risk Factors associated with adolescent sleep: Findings from Australia, Canada and The Netherlands. *Sleep Medicine,* 26, 97-103), yet the current paper focuses on day length, with higher variability in day length enabled due to collection of data among Norwegian adolescents for the data described in the current paper.

Medical and Health Research Ethics – Region North) and Canada (17/01-27/02/2014; 16/09/2014–23/02/2015; McGill University Research Ethics Board). Canadian participants were entered into a draw to win an iPad.

Statistical analysis

Outliers were identified as data with *z* scores outside $\pm$3.29 (Tabachnick & Fidell, 2007). Seven outliers were identified for bedtime, 2 for total sleep time and 1 for ASHS-R scores. Outliers were changed to one unit lower (for *z* scores below -3.29) or higher (for *z* scores above 3.29) than the next data point with an appropriate *z* score (Tabachnick & Fidell, 2007). Sleep onset latency was positively skewed; therefore corrected via logarithmic transformation (Tabachnick & Fidell, 2007). Other variables had normal or near normal distribution. Tobacco and alcohol use were both unevenly split, thus recoded (ASHS-R answers of *never*=0, responses 2-6=1).

Day length was non-normally distributed, thus dummy coded into three groups (short [range =0.5hr], mid [reference group; range = 7.58-13.00hr], long [range = 13.03-16.02hr]). It should be noted that due to all data collection taking place within the week following polar night (a time of 24hr darkness) in Norway, all adolescents in the short day length reference group were from Norway. The mid length group comprised 14.5% Australian, 50.3% Canadian and 35.2% Dutch adolescents. The long length group comprised 87.5% Australian and 12.5% Dutch adolescents.

Multiple hierarchical regression analyses assessed the contribution of the covariates on the dependent variables of bedtime, sleep onset latency and total sleep time. Only participants with complete data for individual sleep variables were used. Age and ASHS-R scores were centred for ease of interpretation. Age and gender were entered in step 1. Behavioural factors:

sleep hygiene, parent-set bedtime, tobacco and alcohol, were entered at step 2, and day length was entered at step 3.

Results

Bedtime

Variables at step 1 predicted 9.9% of the variance in bedtime, R^2=.099, F(2,705)=44.44, p<.001. Step 2 explained an additional 15.9% of variance, R^2*change* =.159, *Fchange* (4,701)=37.59, p<.001. Day length explained an additional 2.7% of variance in step 3, R^2*change* =.027, *Fchange* (2,699)=6.45, p<.001. Together, all variables explained 28.6% of variance of bedtime with good sleep hygiene habits having the largest association with earlier bedtimes. See Table 3.2 for regression coefficients.

Table 3.2

Multiple hierarchical regression analysis for variables predicting weekday bedtime (N=708), sleep onset latency (N = 699) and total sleep time (N = 685)

		Bedtime			Sleep Onset Latency			Total Sleep Time		
Model	Factors	b	SE	Beta(p)	b[b]	SE	Beta(p)	b	SE	Beta(p)
1	(Constant)	22.86	<.001	(<.001)	1.403	.025	(<.001)	451.515	4.757	(<.001)
	Age*	.223	<.001	.315(<.001)	-.041	.009	-.170 (<.001)	-13.326	1.697	-0.296(<.001)
	Gender[a]	.009	<.001	.004(.919)	.077	.031	.094 (.012)	-14.658	5.875	-0.079 (.013)
2	(Constant)	23.044	.080	(<.001)	1.435	.030	(<.001)	433.580	5.678	(<.001)
	Age*	.167	.027	.236(<.001)	-.021	.010	-.088 (.032)	-12.667	1.881	-.268(<.001)
	Gender[a]	-.144	.080	-.060(.071)	.027	.030	.033 (.355)	-3.878	5.683	-.024(.495)
	Sleep Hygiene*	.567	.064	-.300(<.001)	-.215	.024	-.331(<.001)	35.281	4.526	.279(<.001)
	Parent-set bedtime	-.392	.083	.083(<.001)	.060	.031	.076(.052)	19.419	5.920	.126(.001)
	Tobacco	.590	.130	.157(<.001)	-.040	.049	-.031(.410)	-22.868	9.371	-.090(.015)
	Alcohol	.071	.093	.027(.443)	-.055	.034	-.061(.111)	19.317	6.597	.110(.004)

3	(Constant)	23.129	.098	(<.001)	1.467	.036	(<.001)	429.422	6.932	(<.001)
	Age	.166	.027	.235(<.001)	-.012	.010	-.051 (.217)	-12.262	1.922	-.259(<.001)
	Gender[a]	-.213	.080	-.089(.008)	.038	.030	.046(.202)	0.906	5.714	.006(.874)
	Sleep Hygiene*	-.633	.064	-.335(<.001)	-.191	.024	-.295(<.001)	40.652	4.541	.321(<.001)
	Parent-set bedtime	-.334	.083	-.145(<.001)	.032	.031	.040(.307)	14.804	5.885	.096(.012)
	Tobacco	.450	.134	.120(.001)	.035	.050	.027(.482)	-10.929	9.579	-.043(.254)
	Alcohol	.042	.091	.016(.644)	-.047	.034	-.052(.166)	20.802	6.471	.119(.001)
	Day length (short)*	.307	.117	.106(.009)	-.212	.044	- .209(<.001)	-28.587	8.475	-.142(.001)
	Day length (long)	-.247	.085	-.107(.004)	-.005	.032	.006(.879)	15.392	6.017	.099(.011)

Note. b = unstandardized regression coefficients, SE = standard error, [a]male= 0, female = 1, [b] = sleep onset latency was transformed, therefore unstandarsied regression coefficients do not represent an interpretable minute value, *indicates significance for all sleep variables at p<.05.

Sleep onset latency

Variables at step 1 predicted 3.7% of the variance of sleep latency, R^2=.037, F(2,696)=13.52, p<.001. Variables in step 2 explained an additional 10.5% of variance, R^2*change* =.105, *Fchange* (4,692)=21.21, p<.001. Day length explained an additional 3.5% of variance, R^2*change* =.035, *Fchange* (2,690)=14.61, p<.001. Together, the variables predicted 17.7% of variance of sleep latency, with good sleep hygiene having the highest value association on shorter sleep onset latency (see Table 3.2 for regression coefficients).

Total sleep time

Variables at step 1 predicted 8.8% of the variance of total sleep time, R^2=.088, F(2,682)=32.93, p<.001. Variables in step 2 explained an additional 10.5% of variance, R^2*change*=.105, *Fchange* (4,678)=21.96, p<.001. Day length explained an additional 3.5% of variance, R^2*change*=.035, *F change* (2,676)=15.12, p<.001. Together, variables predicted 22.7% of variance of total sleep time. Good sleep hygiene predicted the most variance in total sleep time (see Table 3.2 for regression coefficients).

Discussion

A shorter day length uniquely predicted later bedtimes, a shorter sleep onset latency and shorter total sleep time, whereas a longer day length predicted earlier bedtimes and longer sleep duration, in a significant, but small manner. Adolescents in Norway went to bed 18 min later and slept for 29 min less than adolescents in the mid-day length group. Furthermore, adolescents in the longer day length went to bed 15 min earlier and obtained 15 min more sleep than adolescents in the mid length group. This finding concurs with other studies, where shorter days for young adults have been associated with later sleep timing than longer days (Borisenkov, 2010; Friborg, Rosenvinge, Wynn, & Gradisar, 2014). We note though that adolescents in the present study may have been subjected to indoor- and screen-light, potentially delaying bedtimes and restricting sleep[2]. Adolescents living in areas with a shorter day length may be particularly vulnerable to the effects of evening light, as sensitivity to evening light has also been shown to increase for people who receive less light during the day (Chang, Scheer, & Czeisler, 2011; Wright et al., 2013; Zeitzer, Friedman, & Yesavage, 2011) and the period of adolescence maybe a time for increased sensitivity to evening light (Hagenauer, Perryman, Lee, & Carskadon, 2009). For instance, previous experiments freeing young adults of electronic media exposure (i.e., camping) have demonstrated earlier bedtimes and thus earlier sleep and circadian timing (Wright et al., 2013). Furthermore, a sample of Tromsø residents (including <10% of adolescents) studied over half a century ago (i.e., decades prior to the invention of technological devices yet with access to electrical lighting) went to bed earlier during shorter days compared to longer days (Kleitman & Kleitman, 1953). Therefore, it is possible that although adolescents in the short day length group experienced an earlier sunset time associated with shorter day length, that this lack of daylight exposure actually *increased* their sensitivity to evening artificial light, thus leading to later bedtimes. This hypothesis is further strengthened, as people who spend up to 2 hours outside each day are more likely to go to bed and rise earlier (Roenneburg & Merrow, 2007).Thus, future studies into day length would benefit from simultaneously measuring daylight, electrical lighting and screen-light.

In terms of demographic influences on sleep, gender had minimal impact, with females going to bed slightly later than males, after taking into consideration all other variables. For each year of increased age, adolescents' bedtimes delayed 10 min, and total sleep decreased 12 min, with previous research finding similar trends across cultures (Gradisar et al., 2011; Olds, Blunden, Petkov, & Forchino, 2010). Effects of age on sleep onset latency were no

[2] Of note, rerunning the sleep onset latency regression to control for bedtime and total sleep time in step 2 (results not presented) did not meaningfully alter the association with day length.

longer present after accounting for other factors. Behavioural factors accounted for more variance than demographic factors, giving rise to the potential for effective behavioural interventions.

Good sleep hygiene had the largest, positive influence on sleep. For each 1-point increase on the sleep hygiene scale, bedtimes became 40 min earlier, and sleep was extended 41 min. Considering that an increase in total sleep by 20 min can improve performance on some cognitive tasks (Dewald-Kaufmann, Oort, & Meijer, 2013), this suggests our findings have clinical and academic relevance. Given sleep hygiene practises are under behavioural control, these should be encouraged among adolescents, including offering ways to relax before bedtime (e.g., mindfulness), and avoiding evening stimulation, such as caffeine (Bartel et al., 2015). Programs promoting sleep hygiene awareness and practice are promising (de Sousa, Araujo, de Azevedo, 2007) and may be a more effective method of improving adolescents' sleep en masse. Moreover, considering adolescents who had parent-set bedtimes went to bed 20 min earlier, and obtained 15 min more sleep, educating parents to consistently regulate adolescents' bedtimes may be a feasible approach (Gangwisch et al., 2010; Short et al., 2011) to improving adolescents' sleep. Thus, a consistent approach between schools, adolescents and their parents has the potential to enhance adolescent sleep health beyond the effects of day length.

Limitations

We note that reports on sleep were subjective, thus introducing some degree of recall bias. However, use of objective measures of sleep (i.e., wrist actigraphy; Wolfson et al., 2003) were not feasible on this scale. Increasing the number of participating countries of differing latitudes/longitudes may increase the sensitivity of the day length variable, as well as allowing for more sensitive assessment of the role of cultural influences, a potential confound in the present study. For example, the timing of photoperiod can impact social rhythms (Jankowski, Vollmer, Linke, & Randler, 2014), therefore it is possible that day length may impact the timing of meals, and other social activities, on a population level in Norway differently from other countries, which in turn may influence adolescents' bedtime, sleep latency and sleep duration. Previous research, however, has demonstrated that the daylight is stronger regulator of the circadian rhythm than the social clock (Borisenkov et al., 2016; Roenneburg & Merrow, 2007). Furthermore, in a study conducted during Winter, among Russians living in northern latitudes (thus short daylight hours), increases in latitude were related to later bedtimes (Borisenkov, 2010). Thus, these studies (Borisenkov, 2010; Borisenkov et al., 2016; Roenneburg & Merrow, 2007) decrease the chance that our results could be explained by culture alone. Yet, our study adds to previous findings, as it expands the results of later bedtimes at shorter daylight hours to multiple continents. School start time can also influence sleep (Owens, Belon, & Moss, 2010). Norwegian adolescents commenced school at 8.30am, and majority of adolescents across Australian, Canadian and Dutch samples in the present study reported starting school between 8-9am. Thus although not analysed, confidence in the results relating to day length, and not school timing, is increased.

There are further potential cultural differences between countries which were not measured, and should be considered. For example, a higher percentage of adolescents have been reported to spend 4 or more nights per week with peers in The Netherlands, Canada and Norway, respectively (World Health Organization [WHO], 2012). Despite this difference in patterns of socialising, time spent with peers has not been found to be associated with adolescent sleep (Bartel et al., 2015). As another example, higher levels of stress, including those felt at school, relate to more sleep problems (Wiklund, Malmgren-Olsson, Öhman, Bergström, & Fjellman-Wiklund, 2012). The prevalence of adolescents experiencing schoolwork pressure is higher in Canadian and Norwegian adolescents than among Dutch adolescents (Currie et al., 2012). Considering 50 percent of the mid length group comprised Canadian adolescents, this cultural factor fails to explain why Norwegian adolescents (short day length group), who share a similar prevalence of perceived schoolwork pressure to Canadian adolescents, would have later bedtimes, shorter sleep latency, and less sleep compared to the mid length group. Furthermore, although variation in patterns between countries of alcohol consumption depend on age and gender (Currie et al., 2012), age, gender and alcohol consumption were controlled in the present study, as was tobacco use.

Although these cultural differences should be considered when assessing the impact of day length on sleep parameters, there is insufficient evidence to suggest they outweigh the impact of day length on adolescent sleep. This is particularly true as parent-set bedtimes and good sleep hygiene, which were measured in the present study, should theoretically mediate any associations between evenings spent with peers and adolescent sleep, and the fact that alcohol and tobacco use were accounted for in the present study. Increasing participating countries would also allow for investigation of the influence of individual or other differences in sleep (van Dongen, Rogers, & Dinges, 2003).

Conclusion

Despite these caveats, our data suggest that adolescents living during times of reduced day length are not overly disadvantaged, despite shorter day length predicting later weekday bedtimes and less sleep. Compensation for any detrimental effects of shorter day length on adolescent sleep may occur, especially if parents employ weekday bedtimes, and adolescents can practice healthy sleep habits themselves, or as part of a school-based sleep program (Bei et al., 2013; Bonnar et al., 2015; Cassoff, Knäuper, Michaelsen, & Gruber, 2013).

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CHAPTER 4. Protective and Risk Factors Associated with Adolescent Sleep: Findings from Australia, Canada and The Netherlands

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Abstract

Sleep is vital for adolescent functioning. This study explored the influence of numerous protective and risk factors on adolescent's school night sleep (bedtime, sleep latency, total sleep time) simultaneously to assess the importance of each one and compare within three countries. Online survey data were collected from Australia, Canada and The Netherlands. Overall, 325 (137 male), 193 (28 male) and 150 (55 male) contributed to data from Australia, Canada and The Netherlands, respectively (age range 12-19 years). Results from regression analyses were mixed, when comparing protective and risk factors for sleep parameters within different countries, with combined behavioural factors contributing to small to large shared portions of variance in each regression (9-50%). One consistent finding between countries was found, with increased pre-sleep cognitive emotional sleep hygiene related to decreased sleep latency (*beta* = -.25 to -.33, $p < .05$). Technology use (mobile phone/internet stop time) was associated with later bedtime, or less total sleep, with the strength of association varying between device and country. Results indicate that when designing interventions for adolescent sleep, multiple lifestyle factors need to be considered, whereas country of residence may play a lesser role.

Protective and Risk Factors Associated with Adolescent Sleep: Findings from Australia, Canada and The Netherlands

Sleep is critical for adolescents' daily functioning (Roberts, Roberts & Duong, 2009; Shochat, Cohen-Zion & Tzischinsky, 2014). With longer sleep duration, adolescents have improved capabilities to learn, remember and perform well academically (Curcio, Ferrara, & De Gennaro, 2006; Dewald et al., 2010), and decreased rates of motor vehicle accidents (Martiniuket al., 2013), whereas less than 7 hr of sleep per night is associated with higher rates of delinquency and crime (Backmanet al., 2015). Poorer mental health is associated with adolescents who obtain less than 7 hr sleep per night, compared to adolescents who sleep 7-9 hr per night (Kaneita et al., 2007). Earlier bedtimes, shorter sleep latencies (i.e., the time it takes to fall asleep) and longer sleep length are also related to lower anxiety, depressed mood, suicidal ideation and fatigue scores (Gangwisch et al., 2010; Short, Gradisar, Lack, Wright & Dohnt, 2013).

The transition from middle childhood to adolescence is marked, for some, by an increase in the time it takes for sleep pressure to accumulate, and a delay in the circadian rhythm (Carskadon, 2011). Consequently, adolescents may struggle to fall asleep at a time which allows for an adequate sleep opportunity during the school week, when sleep may be constrained by school start times (Carskadon, 2011). In addition to biological factors, extrinsic factors also play a part in delaying bedtimes, increasing sleep latency and decreasing sleep time, particularly on school days. As adolescents' sleep can be affected by a plethora of environmental factors, it is important to understand the relative influence of such factors so that appropriate interventions may minimise their impact. Whilst we review many influential factors here, it is important to note that most research studies investigate one-to-a-few factors without consideration of the majority of risk and protective factors (Bartel, Gradisar, & Williamson, 2015). Thus, the primary aim of the present study will be to analyse the relative importance of multiple risk and protective factors associated with adolescents' sleep, such as *technology use, substance use, pre-sleep cognitive and emotional arousal, home environment* and *after school sport*, and to ascertain whether these factors pertain to adolescent sleep in a similar manner for different countries.

Age is a potential risk factor, with older adolescents sleeping less than younger adolescents - a phenomenon found across Australia, Europe, North America, and Asia (Gradisar, Gardner, & Dohnt, 2011; Olds, Blunden, Petkov, & Forchino, 2010). Gender is also influential on sleep, with girls sleeping more than boys (Olds et al., 2010), yet girls' time in bed decreasing at a larger rate than boys for each increasing year of age (Olds et al., 2010).

Concerning adolescents' "screen consumption", multiple studies, particularly surveys, have found links between *technology use* and later bedtimes (e.g., Gamble et al., 2014) and short sleep duration and longer sleep latency (e.g., Hysing et al., 2015). However, some controlled laboratory experiments (e.g., Heath et al., 2014; van der Lely et al., 2015; Weaver, Gradisar, Dohnt, Lovato & Douglas, 2010) have found little-to-no negative causal effects of pre-bed technology use on sleep. Indeed, a meta-analysis found, if anything, that technological devices are predominantly related to adolescents' later bedtimes (Bartel at al., 2015).

The link between substance use and adolescent sleep remains unclear (Bartel et al., 2015). Although there seems to be no association between sleep latency and *alcohol* or *tobacco use*, links between these substances and sleep duration and bedtime are less distinct, with the potential for moderating or mediating factors, such as negative family interactions (Bartel et al., 2015). In terms of *caffeine*, its use is associated with less total sleep, especially when consumed in the evening (Bartel et al., 2015; Bonnar & Gradisar, 2015). However, links between caffeine use and sleep latency and bedtime are varied (Bonnar & Gradisar, 2015).

Sleep hygiene comprises multiple factors, such as *pre-sleep cognitive and emotional arousal*, physiological arousal, sleep environment, sleep stability, behavioural arousal and daytime sleep (i.e., napping; Storfer-Isser, Lebourgeois, Harsh, Tompsett & Redline, 2013). Good sleep hygiene has typically benefitted adolescent sleep parameters (e.g., Bartel et al., 2015; Storfer-Isser et al., 2013). Less pre-sleep worry in adolescents has shown to be related to decreased sleep latency (Bartel et al., 2015), and less *cognitive and emotional arousal* prior to bed has been shown to relate to earlier bedtimes, a shorter sleep latency, and longer sleep time (Storfer-Isser et al., 2013).

Adolescents' sleep has consistently shown to be enhanced when their *home environment* is positive (Bajoghli, Alipouri, Holsboer-Trachsler & Brand, 2013; Bartel et al., 2015; Billows et al., 2009; Kalak et al., 2012; Yen, Ko, Yen & Cheng , 2008). A home environment encompasses many components, such as stress of demands (Fuligni & Hardway, 2006), conflict (Yen et al., 2008) and disorganisation (Billows et al., 2009). Sufficient sleep may be supported in a positive home environment, where a foundation is laid for health promoting behaviours (Tynjälä, Kannas, Levälahti & Välimaa, 1999), and less chaos is present (Billows et al., 2009). Similarly, *parent-set bedtimes* are consistently linked with longer sleep durations, but not sleep latency (Bartel et al., 2015), above the effects of age (Randler, Bilger, & Díaz-Morales, 2009), thus improving adolescents' daytime wakefulness and decreasing their fatigue (Short et al., 2011).

Activities outside of school (i.e., extracurricular, work, study, sport) have been proposed to shorten sleep (Short, Gradisar, Lack, Wright, Dewald et al., 2013; Teixeira, Fischer, de Andrade, Louzada, & Nagai, 2004). Although a meta-analysis found a beneficial relationship between *physical activity* and bedtime, the association between other activities on bedtime, sleep latency or total sleep time was not found (Bartel at al., 2015). Moreover, access to *indoor room lighting* may also decrease adolescents' sleep, even at low lux (Peixoto, da Silva, Carskadon, & Louzada, 2009).

Despite the multiple factors which have been proposed to positively or negatively affect adolescents' sleep, these variables have not been studied simultaneously or in multiple countries, to determine the strength of their influence, when accounting for the presence of each other. Considering sleep broadly impacts daily functioning (Curcio et al., 2006; Martiniuk et al., 2013; Roberts et al., 2009; Shochat et al., 2014; Short et al., 2013), it is within the best interests of the scientific community to determine which extrinsic factors provide the largest contribution in assisting, and hindering, the chances of a teenager getting to bed early, falling asleep quickly and sleeping for longer. Such knowledge can direct healthcare professionals, parents and adolescents themselves in achieving these sleep goals. In line with this, we created an online survey to collect data on adolescents' technology use, substance use, home environment, parent-set bedtime and physical activity, at a single time point. In doing so, all factors could be analysed together, thus assessing which variables were more highly associated with adolescent bedtime, sleep latency and total sleep than others. The added benefit of sampling across multiple countries was to assess the generalisability of findings to various adolescent populations across the globe.

Method

Participants

A total of 460, 588 and 354 adolescents commenced the survey from Australia, Canada and the Netherlands, respectively. Of those, 325 (137 male), 193 (28 male) and 150 (55 male) contributed to data from the 178-item questionnaire battery, respectively. See Table 4.1 for descriptive statistics and frequencies for each sample.

Table 4.1

Descriptive statistics and Frequencies: Australia, Canada, the Netherlands M±SD (N)/Percentage Yes (N)

Variable (scale range)	Australia	Canada	Netherlands
Age (12-19 years)	15.85±1.34 (323)	15.90±1.60 (193)	16.38±1.86 (149)
Weekday BT (decimal)	22.71±1.16 (322)	23.06±1.22 (192)	22.53±0.91 (150)
Weekday SOL (min)	44.57±41.27 (322)	48.34±41.18 (192)	36.59±28.53 (148)
Weekday TST (min)	451.36±74.05 (317)	429.65±78.90 (189)	472.12±65.33 (149)
Mobile stop time (weekday, decimal)	22.07±2.04 (123)	22.04±2.01 (93)	22.43± 1.63(99)
Internet stop time (weekday, decimal)	21.97±1.82 (174)	22.32±1.73 (125)	22.19±1.63 (100)
Cognitive emotional arousal (ASHS-R cognitive emotional scale;1-6)	3.77±1.07 (323)	3.59±1.14 (192)	4.44±0.92 (148)
Caffeine after 6pm (1-6)	2.34±1.54 (324)	3.13±1.26 (193)	3.02±1.61 (150)
Home environment (CHAOS; 1-5)	2.53±0.89 (295)	2.79±1.02 (169)	2.07±0.72 (141)
Sports after school/week (min)	102.16±138.79 (274)	116.24±172.12 (165)	151.62±122.38 (139)
Daytime functioning (SRSQ; 9-27)	17.6±4.16 (245)	19.06±3.95 (172)	16.18±3.65 (141)
Tobacco (after 6pm)	4.94% (324)	6.74% (193)	8.00% (150)
Alcohol (after 6pm)	16.05% (324)	17.1% (193)	18.67% (150)
Parent-set BT	38.33% (300)	40.23% (174)	72.70% (143)

Note. ASHS-R = Adolescent Sleep Hygiene Scale – Revised, BT = bedtime, CHAOS = Confusion Hubbub and Order Scale, SOL = weekday sleep onset latency, SRSQ = Sleep Reduction Screening Questionnaire, TST = weekday total sleep time.

Materials

All variables, other than caffeine, alcohol and tobacco use, pre-sleep cognitive-emotional arousal, and sleep reduction, asked adolescents about their school day and weekend habits separately. Only school day data were reported, as restriction of sleep, imposed by school start times, offers a larger threat for daytime consequences (Short et al., 2011), as well as altered weekend behaviour patterns (e.g., decreased prevalence of parent-set bedtimes on weekend nights; Randler et al., 2009; Short et al., 2011). Demographic information on age, gender and school were collected.

Sleep.

Participants were asked about their bedtime (*At what time do you usually go to bed to sleep at night?),* sleep onset latency (*How long does it usually take you to fall asleep?*), awakenings after sleep onset, wake-up time, time out of bed and total sleep time (*How many hours do you usually sleep?),* over the previous 2 weeks. Answers reported for bedtime, sleep latency, and total sleep were used for analyses. Adolescents were also asked if they had any health conditions affecting their sleep, using a free text response. As this survey was aimed at looking at the general population of adolescents in secondary schools, all data were analysed together, regardless of any sleep problem.

Technology use.

Adolescents were asked how many hours and minutes they spent on media, after 6pm. The categories were as follows; *television; mobile phone (NOT including internet on mobile phone, includes checking text messages for short periods of time; computer (other than internet use); internet (including internet use on desktop, laptop, tablet and mobile phone); video gaming*, and; *Wii/other electronic games involving movement*. They were also asked what time they start and stop using each device, after 6pm. To limit the impact of collinearity (Myers, 1990) if including all technological devices, only internet and phone use were used in analyses, as these devices have consistently been linked with sleep (Bartel et al., 2015) and are used increasingly during adolescence (Bruni et al., 2014).

Sleep hygiene and substance use.

The Adolescent Sleep Hygiene Scale – revised (ASHS-R; Storfer-Isser et al., 2013) is a 24-item scale, used to measure sleep hygiene. Participants from all countries were asked to respond in regards to the previous 2 weeks, using a 6-point scale, ranging from *1* (*never, 0%*) to *6* (*always, 100%*). Scores were reversed so that higher scores indicated better sleep hygiene. The ASHS-R has six subscales: physiological (five items), behavioural arousal (three items), cognitive/emotional (six items), sleep environment (five items), sleep stability (three items) and daytime sleep (two items). Each subscale score is the average of the items of which it comprises, with the mean of the subscale scores used to calculate the total sleep hygiene score. Internal consistency for the 24 items was good (Cronbach's $\alpha = .83$, $N = 324$, for the Australian data; Cronbach's $\alpha = .87$, $N=193$, for the Canadian data, and; Cronbach's $\alpha = .77$, $N = 150$, for the Dutch data). Only one factor (cognitive/emotional scale) was chosen to enter into the regressions, as effects of pre-sleep cognitive and emotional arousal have been demonstrated previously (e.g., Storfer-Isser et al., 2013), and other aspects of sleep hygiene (e.g., caffeine use, consistent bedtime) were measured as independent variables. Respondents were also asked whether they "*Smoked/chewed tobacco after 6pm*, or *drank alcohol after 6pm'*, using the same response scale.

Home environment and parent-set bedtime.

Home environment was measured using five items from the Confusion, Hubbub and Order Scale (CHAOS; Matheny, Washs, Ludwig & Philips, 1995). Responses were on a 5-point scale, ranging from 1 (*always)* to 5 (*never)*. Participants were asked to indicate how they felt at home, during the last 2 weeks, concerning the following items; "O*ur home is a good place to relax"; "There is very little commotion in our home"; "I often get drawn into other* *people's arguments at home"; "There is often a fuss going on at our home";* and, *"The atmosphere in our home is calm".* The third and fourth items were reverse coded. Higher scores indicated more chaos. Internal consistency for the five items was good (Cronbach's α = .86, *N* = 298, for the Australian data; Cronbach's α = .90, *N* = 169, for the Canadian data; Cronbach's α = .80, *N* = 141, for the Dutch data).

Adolescents were asked whether their parents set their bedtimes on weekdays, with response options measured on a 7-point scale (*never-always*). For the purpose of analysis, this question was recoded as 1 =*never/almost never*, 2 = *sometimes-always*.

Activities outside of school.

Activities undertaken outside of school hours were assessed using modified questions from the School Sleep Habits Survey (SSHS; Wolfson & Carskadon, 1998). Participants were asked about "*Working...at a job for pay; ...organized sports or a regularly scheduled physical activity; ...organised extracurricular activities;* and…*study/...homework outside of school hours"* during the past 2 weeks. They were asked the number of hours/minutes spent doing each activity separately, before school and after school.

Room lighting.

Room lighting was measured by asking, "*Think about the room you spent the most time in after 6PM, over the last two weeks…".* Participants were also asked which type of light they used (dim overhead, dim lamp, bright overhead, bright lamp), with adolescents able to respond to multiple options, and the start and stop time of these lights.

Daytime consequences.

The Sleep Reduction Screening Questionnaire (SRSQ; van Maanen et al., 2014) is a 9-item scale, used to assess the daytime consequences of chronic sleep reduction. It has been validated against actigraphy, with moderate-to-strong correlations found between SRSQ scores and objective sleep measures (van Maanen et al., 2014). Items are scored on a 3-point ordinal scale, and adolescents were asked to consider the previous 2 weeks when answering questions. Higher scores indicated more chronic sleep reduction. Internal validity was good for all data (Cronbach's α =.83, N = 246, for the Australian data; Cronbach's α = .82, N = 172, for the Canadian data; Cronbach's α =.78, N = 141, for the Dutch data).

Procedure

An online survey, approved by the Social and Behavioural Research Ethics Committee at Flinders University, was conducted using the survey website Qualtrics. Data collection in South Australia occurred from October 2013 to May 2014, with the exception of the holiday period which may impact sleeping patterns (Bei et al., 2014; Warner, Murray, & Meyer, 2008). As such, no data were collected between 13 December 2013 and 9 February 2014. The survey took approximately 30 min to complete, and upon completion participants could select one of four charities, of which AUD$1 would be donated.

Data from Canada were collected between 17 January to 27 February 2014 and 16 September 2014 to 23 February 2015. Ethics approval was received from the McGill University Research Ethics Board. Canadian adolescents were entered into a draw to win an iPad. Data from the Netherlands were collected between 7 November 2013 and 21 May, 2014. Ethics approval was received from the Faculty Ethics Review Board of the Faculty of Social and Behavioural Sciences, University of Amsterdam. No reimbursements were offered to participants.

Statistical analysis

Data were visually inspected, with any outliers deleted (Tabachnick & Fidell, 2007). Among the Australian data, bedtime (BT), sleep onset latency (SOL), mobile stop time, ASHS cognitive-emotional scale, sport after school and caffeine use were found to be skewed;

among the Canadian data, SOL, caffeine use, sport after school and mobile phone stop time were skewed; and among the Dutch data SOL was skewed. These were corrected via appropriate transformations (Tabachnick & Fidell, 2007). In terms of weekday parent-set bedtime, answers '*never/almost never'* were re-coded as 1, and responses '*sometimes to always'* were re-coded as 2, as these responses had less than 12% of participants in each response category in both the Australian and Canadian data. In terms of gender, '*male'* was coded as 1, and '*female'* coded as 2. Tobacco and alcohol use were both unevenly distributed, therefore they were recoded, such that answers of '*never'* were re-coded as 1, and responses 2-6 from the ASHS-r were re-coded as 2 (see Table 4.1 for frequencies). Due to the highly uneven split (i.e., a 90/10 split; Rummel, 1970) of tobacco, all relevant regressions were performed with and without inclusion of the tobacco variable, with minimal difference to outcomes. As such, tobacco was included in analyses in order to observe any effects. Collinearity was found to be within acceptable limits (i.e., variance inflation factor <10; Myers, 1990). Room lighting could not be included in analyses, due to low response rates, particularly among Australian adolescents (i.e., <45%).

Multiple hierarchical regression analyses were performed using IBM SPSS Statistics 22 (IBM Corporation, United States of America) to assess the impact of protective and risk factors on BT, SOL and total sleep time (TST). A correlation matrix between analysed factors is provided as supplementary data for each country (Tables S4.1, S4.2, S4.3; Appendix C). Age and gender were entered in step 1 for all regressions. Factors under behavioural control were entered at step 2, to ensure that any effects found in step 2 were above those found due to factors outside the participant's behavioural control. Unstandardised coefficients are not reported, due to data transformations making the units uninterpretable to the reader.

Results

Behavioural Protective and Risk Factors

Hierarchical regression analyses were performed to assess the impact of protective and risk factors on BT, SOL and TST. Different predictive factors for each sleep variable were chosen based on the results from a previous meta-analysis on the protective and risk factors on adolescents' sleep (Bartel et al., 2015), such that factors previously found to have no relationship with a specific sleep variable were not included in regression models for that sleep variable.

Bedtime.

For Australian adolescents, variables at step 1 predicted 9.6% of the variance of bedtime, R^2 = .096, $F(2,114) = 6.02$, $p = .003$. Additional variables added to step 2 were: mobile phone stop time, internet stop time, tobacco, alcohol, pre-bed cognitive and emotional arousal, home environment (i.e., CHAOS scores), parent set BT and sport (after school). Of these, after school sport was associated with earlier bedtimes, whereas mobile phone and internet stop times contributed significantly to delaying bedtimes (see Table 4.2). Variables in step 2 explained an additional 49.8% of variance, R^2 *change*= .498, *F change* (8,106) = 16.22, $p<.001$.

For Canadian adolescents, variables at step 1 did not significantly predict any of the variance of bedtime, $R^2 = .028$, $F(2,84) = 1.22$, $p = .301$. Of step 2 variables, good cognitive and emotional sleep hygiene was related to earlier bedtimes, whereas internet stop times contributed significantly to delaying bedtimes (see Table 4.2). Variables in step 2 explained an additional 43.6% of variance, R^2 *change*= .436, *F change* (8,76) = 7.73, $p<.001$.

Among Dutch adolescents, variables at step 1 predicted 36.1% of the variance of bedtime, $R^2 = .361$, $F(2,89) = 25.09$, $p < .001$. In step 2 age and mobile phone stop time contributed significantly to delaying bedtimes (see Table 4.2). Variables in step 2 explained an additional 16.5% of variance, R^2 *change*= .165, *F change* (8,81) = 3.53, *p* = .001

Table 4.2

Hierarchical Regression Analysis for Variables Predicting Weekday BT in Australian (N=117), Canadian (N = 87) and Dutch (N = 92) Adolescents

		Australia		Canada		Netherlands	
Model	Factors	*Beta*	*p*	*Beta*	*p*	*Beta*	*p*
1	(Constant)		<.001		<.001		<.001
	Age	.311	.001	-.044	.682	.611	<.001
	Gender	.021	.812	.165	.129	-.164[a]	.061
2	(Constant)		<.001		<.001		<.001
	Age	.043	.553	.037	.705	.387	<.001
	Gender	.030	.666	-.058[a]	.540	-.071[a]	.399
	Mobile phone stop time (weekday)	.202	.005	-.155	.106	.287	.005
	Internet stop time (weekday)	.536	<.001	.494	<.001	.183	.061
	Tobacco	.060	.366	.007	.941	-.003	.970
	Alcohol	.018	.792	.027	.777	.062	.500
	ASHS-R cognitive emotional	-.129	.080	-.261	.007	.074	.411
	Home environment (CHAOS)	-.126	.084	.011	.906	.016	.852
	Parent-set BT	-.043	.534	-.169	.081	-.080	.371
	Sport (after school)	-.240	<.001	.063	.487	.031	.711

Note. ASHS-R = Adolescent sleep hygiene scale – revised, BT=bedtime, CHAOS = Confusion Hubbub and Order Scale. [a] Negative beta value indicates non-significant trend of later BT for males than females.

Sleep onset latency.

For Australian adolescents, variables in step 1 did not account for a significant amount of SOL variance, R^2 = .011, *F*(2,289) = 1.60, *p* = .20. In step 2, the variables explained an additional 13.1% of variance, R^2 *change*= .131, *F change* (2,287) = 21.91, *p*<.001. Higher CHAOS scores (i.e., home environment) increased SOL, whereas increased cognitive and emotional sleep hygiene scores decreased SOL (see Table 4.3).

For Canadian adolescents, variables in step 1 accounted for 4.6% of variance in SOL, R^2 = .046, *F*(2,164) = 3.94, *p* = .02. In step 2, the variables explained an additional 12.3% of variance, R^2 *change* = .123, *F change* (2,162) = 9.27, *p*<.001. Better cognitive and emotional sleep hygiene scores and younger age predicted decreased SOL (see Table 4.3).

Among Dutch adolescents, variables in step 1 did not account for a significant amount of SOL variance, R^2 = .004, *F*(2,133) = .275, *p* = .760. In step 2, the variables explained an additional 9.1% of variance, R^2 *change* = .091, *F change* (2,131) = 6.55, *p* = .002. Increased cognitive and emotional sleep hygiene scores decreased SOL (see Table 4.3).

Table 4.3

Hierarchical Regression Analysis for Variables Predicting Weekday SOL in Australian (N=292), Canadian (N = 167) and Dutch (N = 136) Adolescents

		Australia		Canada		Netherlands	
Model	Factors	*Beta*	*p*	*Beta*	*p*	*Beta*	*p*
1	(Constant)		<.001		<.001		<.001
	Age	-.071	.226	-.179	.021	-.062	.473
	Gender	.075	.199	.145	.061	-.011	.901
2	(Constant)		<.001		<.001		<.001
	Age	-.082	.134	-.160	.031	-.070	.405
	Gender	-.044	.446	.049	.524	-.082	.340
	ASHS-R cognitive emotional*	-.316	<.001	-.334	<.001	-.249	.006
	Home environment (CHOAS)	.120	.047	-.023	.761	.121	.172

Note. ASHS-R = Adolescent Sleep Hygiene Scale – revised, CHAOS = Confusion Hubbub and Order Scale, * indicates p <.05 for all three countries.

Total sleep time.

For Australian adolescents, variables at step 1 predicted 7.4% of the variance of TST, R^2 = .045, F(2,112) = 4.51, p = .013. Additional variables added to step 2 were: mobile phone stop time, internet stop time, tobacco, alcohol, caffeine use after 6pm, pre-sleep cognitive and emotional arousal, home environment, parent-set BT and sport (weekday, after school). Of these, internet stop time was found to significantly predict a decrease in TST, and good cognitive emotional sleep hygiene, having a parent-set BT and consuming alcohol one or more times per week were found to significantly increase TST. Variables in step 2 explained an additional 34.4% of variance, R^2*change*= .344, F *change*(9,103) = 6.19, p<.001 (see Table 4.4).

For Canadian adolescents, variables at step 1 did not predict a significant amount of variance in TST, R^2 = .035, $F(2,83) = 1.49$, p = .231. From variables added in step 2, internet stop time was found to significantly predict a decrease in TST, and good cognitive emotional sleep hygiene was found to increase TST. Variables in step 2 explained an additional 25.1% of variance, R^2*change*= .251, *F change*(9,74) = 2.89, p = .006 (see Table 4.4).

Among Dutch adolescents, variables at step 1 predicted 19.6% of the variance of TST, R^2 = .196, $F(2,88) = 10.72$, p <.001. Variables at step 2 did not explain additional variance in TST, R^2*change*= .142, *F change*(9,79) = 1.89, p = .066, although older age and later mobile phone stop time still significantly predicted less TST (see Table 4.4).

Table 4.4

Hierarchical Regression Analysis for Variables Predicting Weekday TST in Australian (N=115), Canadian (N = 86) and Dutch (N = 91) Adolescents

		Australia		*Canada*		*Netherlands*	
Model	Factors	Beta	*p*	*Beta*	*p*	*Beta*	*p*
1	(Constant)		<.001		<.001		<.001
	Age	-.276	.003	.012	.912	-.449	<.001
	Gender	-.042[a]	.646	-.187[a]	.088	.041	.677
2	(Constant)		<.001		.002		<.001
	Age	-.065	.458	-.149	.205	-.423	<.001
	Gender	.025	.758	.024	.833	-.019[a]	.848
	Mobile phone stop time (weekday)	-.124	.151	.087	.436	-.358	.005
	Internet stop time (weekday)	-.365	<.001	-.255	.028	-.025	.837
	Tobacco	-.059	.468	.035	.756	.184	.087
	Alcohol	.191	.029	.176	.124	.070	.530
	Caffeine	-.062	.434	.085	.488	-.045	.659
	ASHS-R cognitive emotional	.227	.012	.428	<.001	.028	.848
	Home environment (CHAOS)	.045	.611	-.041	.706	.060	.576
	Parent-set BT	.201	.018	.032	.784	-.187	.080
	Sport (after school)	.152	.058	.094	.376	.072	.475

Note. ASHS-R = Adolescent sleep hygiene scale – Revised, BT=bedtime, CHAOS = Confusion Hubbub and Order Scale. [a] Negative beta value indicates non-significant trend of longer TST for males than females.

Daytime consequences.

Relationships between sleep parameters and daytime functioning were analysed, to ascertain whether variations in adolescents' sleep are associated with daytime functioning. Significant, positive correlations were found between the SRSQ and BT (r = .41, N = 244, p<.001) and SOL (r = .29, N = 244, p<.001), whereas a negative correlation was found between SRSQ and TST (r = -.42, N = 241, p<.001) for Australian adolescents. Similar trends were observed among SRSQ scores and sleep variables as follows for the Canadian data; BT (r = .35, N = 171, p < .001); SOL (r = .30, N = 171, p<.001), and; TST (r = -.44, N = 169, p <.001); and the Dutch data; BT (r = .29, N = 141, p = .001); SOL (r = .19, N = 139, p = .032), and; TST (r = -.31, N = 140, p < .001). This indicates that as adolescents go to bed later, and take longer to fall asleep, they experience more symptoms of chronic sleep reduction during the day, yet those who sleep more experience less chronic sleep reduction symptoms.

Discussion

Overall, although the magnitude of effect varied slightly between countries, many similarities also arose, with a large portion of variance attributed to extrinsic factors. For each country the time adolescents stopped using their mobile phone and/or the internet, was associated with sleep, with later stop times related to later bedtimes and shorter sleep duration. In general, substance use was not related to sleep. Lower pre-sleep cognitive and emotional arousal decreased sleep latency across countries, and was related to longer total sleep length for Australian and Canadian adolescents.

Demographic Risk and Protective Factors

The effects of age on bedtime and total sleep time were smaller after adding additional variables, for both Australian and Dutch data, although age remained the largest factor associated with Dutch adolescents' total sleep, with older age predicting less sleep. Although age was unrelated to bedtime or sleep duration for the Canadian adolescents, older Canadian adolescents also had shorter sleep onset latencies. No effects of gender were found for any sleep variables, for any country. This is contrary to previous meta-analysis findings of gender differences in adolescents' time in bed (Olds et al., 2010), however, the present results of weekday data may reflect previous findings that gender differences are smaller on weekdays than weekends (Olds et al., 2010).

Behavioural Risk and Protective Factors

Regarding *technology use*, the time adolescents stopped using either the internet or their mobile phone had the largest harmful association with bedtime, in each country. Internet stop time also had the largest negative relationship with Australian and Canadian adolescents' sleep duration. Among Dutch adolescents, mobile phone stop time had a smaller association than adolescents' age, on decreasing sleep. Overall, this suggests that adolescents are using at least one of these devices, until close to bedtime, and that this is interfering with choosing an appropriate bedtime, thus reducing the amount of sleep they obtain during the week.

Concerning *substance use*, neither tobacco use nor alcohol consumption, after 6pm, was related to adolescents' bedtimes. Among Australian adolescents, alcohol consumption led to more sleep, however, it should be noted that of the significant protective factors, alcohol had the smallest association. Caffeine after 6pm was unrelated to total sleep time. Although the alerting effects of caffeine have been previously documented (see Snel & Lorist, 2011 for a review), and a relationship between evening caffeine use and sleep duration exist (Bartel et al., 2015), the current study's results suggest that other factors, such as technology use, are more of a risk to sleep than stimulant use. This could be due to increased accessibility of technology (e.g., up to 94% of Canadian adolescents have home WiFi; Shaw Rocket Fund, no date) comparatively diminishing the relationship between caffeine and sleep.

Having less *pre-sleep cognitive emotional arousal* resulted in earlier bedtimes for Canadian adolescents. Importantly, less pre-sleep cognitive emotional arousal significantly decreased sleep latency for all adolescents. Among Australian and Canadian adolescents, less pre-sleep cognitive emotional arousal also resulted in longer sleep. This shows that better cognitive and emotional pre-sleep hygiene is an important factor in aiding adolescent sleep, and should be used when designing intervention or educational programs for adolescent sleep (de Bruin, Bögels, Oort, & Meijer, 2015; Harvey, 2015).

Home environment was only a contributing factor for Australian adolescents. A more chaotic household was associated with longer sleep latency. A non-significant trend occurred among Australian adolescents between higher household chaos and going to bed earlier, hence it is possible that these adolescents went to bed earlier, yet took longer to fall asleep, therefore their overall sleep duration remained unaffected. Previous research suggested that sleep hygiene fully mediated the relationship between chaotic household environments and sleep latency, and partially mediated the relationship between chaotic household environments and total sleep (Billows et al., 2009). Although not measuring sleep hygiene broadly, pre-sleep cognitive emotional arousal accounted for more variance than a chaotic household for bedtime, sleep latency, and sleep duration, for all countries (other than total sleep for Dutch adolescents). This supports the hypothesis that in less disorganised homes, good sleep hygiene enables healthy sleep habits to form (Billows et al., 2009). Thus it appears that good sleep hygiene has a stronger relationship with sleep than a disorganised home environment. Another factor to consider, although not measured in the present study, is that adolescents' sleep latency may be related to parent sleep patterns, in particular mothers' sleep latency and night awakenings (Bajoghli et al., 2013), hence for a full picture of the relationship between adolescent's home environment and sleep, parent sleep patterns may need to be simultaneously measured.

Surprisingly, a *parent-set bedtime* was not related to bedtime, and only lengthened sleep for Australian adolescents. It could be that the effects of age were larger for the Canadian and Dutch adolescents, therefore overriding any potential significance of parent-set bedtime on total sleep, particularly as older adolescents are less likely to have a parent-set bedtime (Short et al., 2011). Increased parental monitoring (e.g., the extent to which parents are aware of their adolescent's whereabouts after school) is related to earlier bedtimes and longer sleep duration (Meijer et al., 2016). Therefore, given the large effects of mobile and internet phone use, it may be that parents also need to increase their involvement by setting a "bedtime" for electronic devices (Exelmans & Van den Bulck, 2015), rather than just adolescents themselves.

Doing more *after school sport* was associated with an earlier bedtime for Australian adolescents only, whereas sport was not related to sleep duration in any country. It can be seen that, on average, adolescents played less than 2.5 hr of sport after school per week. However, we did not measure the intensity of the exercise performed. Delisle and colleagues (2010) asked adolescents how frequently and how intensely they exercised per week. High intensity exercise was associated with longer sleep duration, when engaged in more often. However, there was no difference in sleep length among adolescents who performed moderate physical exercise, regardless of the number of times performed per week (Delisle et al., 2010). The timing of after-school exercise is also important (Buxton, Lee, L'Hermite-Balériaux, Turek, & Van Cauter, 2003; Richardson, Gradisar, Short, & Lang, accepted). Physical activity performed after school and in the early evening may bring adolescents' bedtimes earlier, hence should be seen as a protective factor, whereas after school sports played at night (i.e., within 3 hr of dim light melatonin onset) may result in later bedtimes

(Richardson et al., accepted). Exercise which is conducted on a regular basis may also promote healthy sleep (Chennaoui, Arnal, Sauvet, & Léger, 2015). It may be that intensity, timing, and/or regularity, rather than duration, has a greater impact on adolescent sleep.

One strength of the present study is the assessment of protective and risk factors within different countries allowing determination of whether a one-size-fits-all approach can be taken regarding factors related to adolescent sleep. Underlying cultural discrepancies between samples may include legislation regarding legal drinking age (Simons-Morton, Pickett, Boyce, Ter Bogt, & Vollebergh, 2008); promotion of cycling and active lifestyle in The Netherlands (Bere, van der Horst, Oenema, Prins, & Brug, 2008; Pucher & Buehler, 2008); and health care (Mossialos, Wenzl, Osborn, & Sarnak, 2016), including perceived availability of help for mental health problems (Prins et al., 2011). Although this paper did not assess the direct impact of these factors on sleep, it is plausible that these differences in culture at a broader social level create cultural differences that allow factors to manifest differently between countries as helpful, harmful, or of little influence, in relation to adolescent sleep.

Limitations and Future Directions

We examined the sleep of adolescents in three different countries. However, future research could include countries from other continents, particularly Asia, where greater sleep restriction occurs (Gradisar, Gardner, & Dohnt, 2011), which would provide further insights into the role of ‘country’ in adolescents’ sleep. The online survey was self-report, introducing the potential of reporting error. Moreover, the study only measured adolescents’ sleep and behavioural habits at a single time point, therefore the association between the long-term impact of protective and risk factors on sleep could not be determined. Also, as the present study was not experimental, causality cannot be assumed. This also gives rise to the possibility that ‘country’ is in fact an epiphenomenon, thus less relevant than other extrinsic variables. Future research should use experimental designs to investigate the link between factors consistently linked to sleep, such as internet and/or mobile phone use and cognitive and emotional pre-sleep hygiene, to determine cause and effect, as well as the best manner in which to intervene to assist adolescents' sleep.

Conclusion

In conclusion, behavioural factors share a small-to-large portion of variance on sleep parameters. In terms of individual protective factors, less pre-sleep cognitive emotional arousal is related to shorter sleep latencies, and is beneficially related to total sleep. Later use of a mobile and/or internet is associated with later bedtimes and short sleep duration, with the strength of the association differing for each device between countries. Internet stop time had higher associations for Australian and Canadian adolescents, whereas the time Dutch adolescents stopped using their mobile phones showed a stronger relationship. Future experiments are needed to determine the cause and effect direction of protective factors, particularly cognitive emotional arousal, and risk factors, in particular pre-sleep technology use, as well as interventions employing helpful strategies to minimise pre-sleep cognitive emotional arousal or technology use. Experiment and intervention designs should take into account the relative importance of each factor, which has the potential to vary depending on country of residence. Moreover, clinicians should consider that whilst similar patterns for the most pertinent protective and risk factors exist between countries, some factors may be more relevant in their country of residence, and hence their adolescent clients.

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CHAPTER 5. Altering Adolescents' Pre-bedtime Phone Use to Achieve Better Sleep Health

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KB led experimental design, survey design, recruitment, data analysis and manuscript preparation. RS assisted with recruitment and data collection and manuscript preparation. MG assisted experimental design, survey design, recruitment, data analysis and manuscript preparation.

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Abstract

Mobile phone use is often blamed for adolescent sleeping difficulties in the popular and scientific literature, with correlations observed between adolescents' mobile phone use and their bedtime. We aimed to obtain experimental evidence to support these causal claims. A within-subjects experiment (baseline, intervention) was conducted in adolescents' homes, to determine the effect of restricting adolescents' pre-bed mobile phone use on school night sleep habits. Following a baseline week, adolescents were given individualised phone stop times, 1 hour before bed for one school week. An online sleep diary was used to monitor bedtime, lights out time, sleep latency and total sleep. Sixty three adolescents (age range 14-18, M=16.3, SD=0.93yrs; 17%male) provided data. During one week of phone restriction, adolescents stopped using their phones earlier (80min, p <.001), turned their lights off earlier (17min, p =.01) and slept longer (19min, p =.01). Participant recruitment was low (26%), indicating many adolescents lack motivation to negotiate changes to their evening phone use. Overall, there are potential benefits of restricted mobile phone use during the pre-sleep period, yet, future research is needed to identify non-technological interventions to increase adherence to phone restriction (e.g., motivational interviewing) or otherwise decrease pre-sleep arousal (e.g., cognitive strategies).

Altering Adolescents' Pre-bedtime Phone Use to Achieve Better Sleep Health

It has been claimed that mobile phones have become a part of our self-identity, in part due to the social interaction they enable (Vincent, 2006), and their uptake is starting at an early age. In 2010, 82% of Australian adolescents above the age of 13 years were using a mobile phone (Inyang et al., 2010). Despite their popularity, mobile phones have long been purported to negatively influence adolescent sleep (Adams, Daly, & Williford, 2013; Van den Bulck, 2003). Indeed, a recent meta-analysis found that mobile phone use was related to delayed bedtimes among adolescents, but not related to sleep latency (i.e., the time taken to fall asleep; Bartel, Gradisar, & Williamson 2015). Specifically, survey-report data have indicated that the frequency and intensity of mobile phone use is correlated with later school night bedtimes, but not sleep latency (Pieters et al., 2014). However, the meta-analytic results were less clear when regarding the relationship between phone use and adolescent total sleep time, suggesting that other factors influence this relationship, potentially leading to less sleep as phone use increases (Bartel et al., 2015). That is, problematic phone use was not associated with short sleep duration (<6hr) when other demographic and lifestyle factors, such as having self-reported depression, were considered (Yen, Ko, Yen, & Cheng, 2008). Furthermore, any consequences of phone use on sleep appear to impact daytime functioning, with night time messaging related to poor school performance and daytime sleepiness, after controlling for sleep duration (Wang et al., 2017). Adolescents who use the internet, social media, games with crude humour and violence, check emails and/or watch videos on mobile devices, all of which can be performed from mobile phones, have been reported to have higher daytime sleepiness (Eggermont & Van den Bulck, 2006; Johansson, Petrisko, & Chasens, 2015).

To the authors' knowledge, *experimental* research involving mobile phone use, conducted in adolescents' homes among the general population, is not available. Regarding technology and adolescent sleep, one experiment assessed the impact of restricted electronic media use after 10pm, among adolescent athletes (Harris et al., 2015). After 4 weeks of restricted use, no differences in sleep were found. However, the instructed media stop time was only 10 minutes before the experimental group's baseline bedtime, therefore the use of technology may not have significantly changed during intervention (Harris et al., 2015). Another home based cross-over experiment assessed videogame playing, film watching and control conditions, 2-3 hours before bed. Objective sleep assessment (i.e., electroencephalograph [EEG] polysomnography) indicated total sleep time did not differ between conditions, although sleep latency increased after video gaming. Although participants were instructed to adhere to their normal daytime routine, pre-bed activities were not reported, and bedtime was not an experimental outcome (Dworak, Schierl, Bruns, & Strüder, 2007). Thus, although much speculation exists that the use of technology prior to bedtime delays adolescents' bedtimes (Bartel et al., 2015; Gamble et al., 2014; Kubiszewski Fontaine, Rusch, & Hazouard, 2014; Lemola, Perkinson-Gloor, Brand , Dewald-Kaufmann, & Grob, 2015; Pieters et al., 2014), increases sleep latency (Adams et al., 2013), or leads to shorter sleep duration (Gamble et al., 2014; Lemola et al., 2015), causation cannot be concluded due to the correlational nature of such studies.

In fact, it is plausible for a bi-directional relationship between adolescents' pre-bedtime phone use and sleep. That is, adolescents who have difficultly initiating sleep may be the ones using technology to fill in time until they feel able to sleep (Eggermont & Van den Bulck, 2006). Although a longitudinal study design could test for temporal relationships between pre-bedtime mobile use and adolescents' sleep (Tavernier & Willoughby, 2014), evening phone use is so ubiquitous and associated with meaningful sleep and daytime impairments (National Sleep Foundation, 2011) that interventions, which may not only improve sleep health but also test causality, are crucial. We thus aim to address this gap in the literature by experimentally manipulating adolescents' phone use. Our protocol was to target phone use in the typical hour before bed, due to the correlation between pre-bed mobile phone use and bedtimes (Kubiszewski et al., 2014; Lemola et al., 2015).

It is hypothesised that after 1 week of restricted pre-bedtime mobile phone use, adolescents will:

1) have earlier bedtimes and longer total sleep

Given the lack of empirical support for a relationship between mobile phone use and sleep latency, no predictions are made, yet we nevertheless intend to measure any possible changes in these variables.

Method

Participants

A total of 243 adolescents were approached, from 3 secondary schools in Adelaide, South Australia (N=168), as well as through University open days and a sample of convenience (N=75). Baseline demographics and sleep timing did not differ between the students recruited through secondary schools and those recruited through other means (p >.05). All schools were government schools, and ranged from the 46th percentile to the 81st percentile in socio-economic status (with lower percentiles being relatively disadvantaged, compared to higher percentiles; Australian Bureau of Statistics, 2014). Fig. 5.1 presents a flowchart of participants through the present study. Sixty three adolescents (age range 14-18 years, M=16.3 years, SD=0.93 years; 17%male) provided data. Ethics approval was obtained from the Social and Behavioural Research Ethics Committee, Flinders University and the Department of Education and Child Development, South Australia. Informed consent was obtained from all adolescent participants, and the parents of adolescents recruited through secondary schools, if adolescents were younger than 18 years.

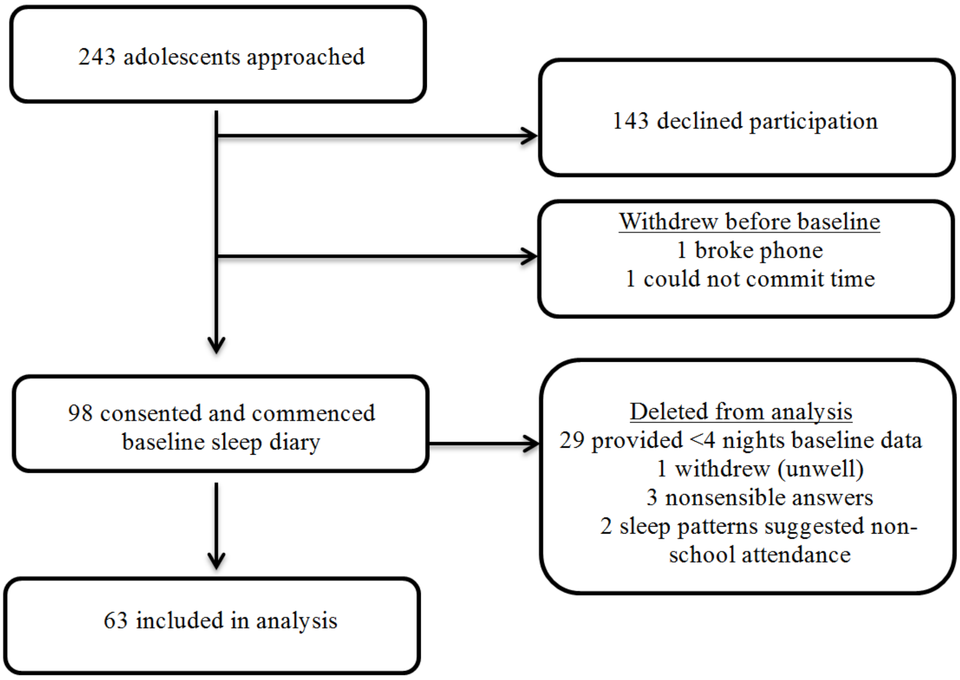

Figure 5.1. Participant flow chart.

Materials

Sleep diary.

An online sleep diary collected data on bedtime, light out time, sleep onset latency, total sleep time, naps, awakenings during the night, and mobile phone stop time. Sleep diaries have been found to be an accurate measure of adolescent sleep compared to objective measures, such as actigraphy (Arora, Broglia, Pushpakumar, Lodhi, & Taheri, 2013) especially for total sleep (Short, Gradisar, Lack , Wright, & Carskadon, 2012). Moreover, actigraphy is unable to measure bedtime, as it is limited to physiological, rather than behavioural, sleep measurements (Short, Gradisar, Lack , Wright, & Chatburn, 2013). Sleep diaries are also more accurate than parent report (Short et al., 2013). The online sleep diary program used an algorithm on these data to calculate total sleep time. Four nights weekday sleep data are sufficient to reliably measure Australian adolescents' sleep (Short, Arora, Gradisar, Taheri, &

Carskadon, in press). Only weekday data were used so as to make comparisons with previous studies and a meta-analysis (Bartel et al., 2015; Bartel et al., 2016).

Questionnaire.

An online questionnaire was created using Qualtrics (Qualtrics.com; Provo, Utah). Information on age and sex were collected. In order to assess subjective efficacy of the intervention, adolescents were asked if their sleep during the intervention week was either '*better than usual*', '*the same*', or '*worse than usual*'; whether they thought their sleep improved due to the intervention ('*improved a bit'*, '*stayed the same'*, '*got worse'*); and finally whether they thought the intervention was '*highly effective*', '*somewhat effective*', '*neither effective nor ineffective*', or '*ineffective*'.

Procedure

Schools across Adelaide from varying socio-economic strata were invited via email to participate, with permissions from school principals and teachers sought from schools who expressed interest. Adolescents were also recruited through university open days, and a sample of convenience. Adolescents were informed that the study involved altering their mobile phone use, however, were not told explicitly how it would be altered, to minimise false data entry during the baseline week, (e.g., creating false and later bedtimes). Adolescents were instructed to complete an online sleep diary daily, for 2 consecutive weeks (baseline and intervention), using an individual username and password. At the end of the baseline week, average bedtimes were used to calculate the time which each adolescent needed to stop their mobile phone use, for the school week only (Sunday-Thursday night). This was 1 hour prior to their average baseline weekday bedtime. Instructions were sent to individual email addresses.

As an objective measure of compliance, Android phone users were instructed to download the free application ‘Screen On/Off Logger Lite’[3]. This application recorded when the phone screen was turned on, but no other information (e.g., activities completed on the phone), hence protecting participants’ privacy. During the intervention week, adolescents were asked to take a screen shot of their ‘Screen On/Off Logger Lite’ application page each morning, and email it to author KB. There was no equivalent application for iPhone users. Only 2 adolescents emailed screen shots as requested during the intervention week. Both of these adolescents were compliant with not using their mobile phone after the specified stop time, although 1 used their phone on 2 occasions over the week, for < 3 secs on each occasion, and the other used it on one occasion, for 10 secs. For each of these adolescents, self-report stop time for mobile phone use during intervention week was generally within 10 min of objective stop time.

Statistical Analysis

Data were analysed using IBM SPSS Statistics v.22. Skewness was assessed visually using histograms (Tabachnick & Fidell, 2007). Outliers were altered to 1 unit lower/higher than values within appropriate limits (i.e., the lowest/highest value with standardised *z*-score within ±3.29; Tabachnick & Fidell, 2007). Sleep onset latency appeared negatively skewed at both times points, yet was not transformed in order to retain meaningful values. Linear mixed model regressions (LMMR), using restricted maximum likelihood as the method of estimation, were performed to determine the effect of the intervention on sleep parameters and mobile stop time. Time was coded as 0 = baseline, 1 = intervention week. Subjects were entered as random effects, to handle the correlation between time points, with the intercept included in the model. Participant data were only included when a participant had completed

[3]Downloadable from https://play.google.com/store/apps/details?id=com.vstudiohk.lastscreentimelite&hl=en

4 or more school nights' of sleep diary (Short et al., in press). Participants' baseline sleep data remained in the analysis even if they had completed <4 nights sleep diary during the intervention week (and the intervention week deleted). Thus, 48% of participants who completed baseline had missing sleep diary data during the intervention week. LMMRs are advantageous due to their ability to cope with missing data and unequal sample size (Shek & Ma, 2011). Nevertheless, LMMRs were re-run using only adolescents who had completed ≥4 nights both weeks, to compare results when using adolescents who completed ≥4 nights sleep diary data during the intervention week, and those who did not. As the pattern of results remained unchanged, reported results include all adolescents (i.e., those who only had sufficient baseline data). Estimated marginal means were calculated for each time point, using Bonferroni correction. Cohen's *d* effect size was calculated as the difference between baseline and end of treatment (week 1) estimated marginal means, divided by baseline standard error*(√n) (Taylor, 2014).

Results

From baseline to intervention, main effects were found for lights out time, total sleep time, and mobile phone stop time (see Table 5.1). Adolescents stopped using their mobile phones 80 min earlier during the intervention week, turned off their lights 17 min earlier, and slept 19 min longer. Although they did not go to bed any earlier, their earlier lights out time did not result in a longer sleep latency.

Table 5.1.

Estimated Marginal Means, Standard Errors, Inferential Statistics and Effect Sizes for Mobile Phone and Sleep Variables During the Baseline and Intervention Weeks

	Baseline *M* (*SE*)	Week 1 *M* (*SE*)	F	*df*	*p*	Cohen's *d*
Mobile stop time (clocktime)	22:19 (0:11)	20:59 (0:14)	39.94	1, 35.35	<.001	0.93[c]
Bedtime (clocktime)	22:17 (0:07)	22:13 (0:08)	0.46	1, 33.07	.50	0.06[-]
Lights out time (clocktime)	22:57 (0:07)	22:40 (0:08)	9.00	1, 32.06	.01	0.30[a]
Sleep latency (min)	20.94 (2.15)	19.89 (1.90)	0.34	1, 39.31	.57	0.06[-]
Total sleep time (hour:min)	7:36 (0:07)	7:57 (0:08)	7.98	1, 39.39	.01	0.34[a]

Note. [-] indicates negligible difference (i.e., $d = <.20$), [a] indicates small effect size (i.e., *d* =.20-.49), [b] indicates moderate effect size (i.e., *d* = .50-.79), [c] indicates large effect size (i.e., $d > .80$; Cohen, 1988).

In terms of effectiveness, 29 out of 33 adolescents who completed ≥4 nights sleep diary during the intervention week also completed the questionnaire. Of those who completed it, 45% reported that due to the intervention their sleep *improved a bit*, 45% reported their sleep *stayed the same*, and 7% reported that their sleep became *worse.* Seven percent reported the intervention to be *highly effective*, 38% reported it to be *somewhat effective*, 48% reported it to be *neither effective nor ineffective*, and 7% reported it to be *ineffective.* In contrast, 63%

(15/24 responders) stated that they would consider not using their phone in the hour before bed, if it helped them to sleep better.

Discussion

The current generation of adolescents possess a high affinity for mobile phone use (Inyang et al., 2010; National Sleep Foundation, 2011), to the extent that they will use such devices during the pre-sleep period (Eggermont & Van den Bulck, 2006; Kubiszewski et al., 2014; Lemola et al., 2015) and even during the night (Munezawa et al., 2011; Van den Bulck, 2003). Despite the potential harm to their sleep health, only 40% of adolescents chose to participate in the present investigation of mobile phone use alteration, with even less (26%) providing data. Of those adolescents who participated in the intervention, benefits were found for their sleep. Overall, adolescents stopped using their phone 80 min earlier, resulting in an earlier lights out time and total sleep increasing. These results are of clinical relevance, not only for such a meaningful change in adolescents' mobile phone use, but also on their total sleep time, as adolescents obtained an average of 19 min more sleep, *per school night*, during the intervention week. This equates to an extra 1 hr and 35 min per school week, which would help to offset the significant sleep debt experienced by many adolescents (Owens et al., 2014; Touitou, 2013; Warner, Murray, & Meyer, 2008; Wolfson & Carskadon, 1998). This differs from previous research, which found no effect of a 10pm stop time on electronic devices on sleep in adolescent athletes (Harris et al., 2015). A subgroup analysis of those with a weekend bedtime 1 hour after instructed stop time found a trend toward earlier bedtimes following the intervention (Harris et al., 2015), suggesting that stopping the use of electronic devices 1 hour before bed does indeed impact sleep. Previous experiments and clinical trials have attempted various singular (e.g., go to bed earlier) and multi-component (e.g., cognitive-behaviour therapy; light therapy) strategies in order to increase adolescents' total sleep time (e.g., Bei et al., 2013; Bonnar et al., 2015; De Bruin, Dewald-Kaufmann, Oort, Bögels, & Meijer, 2015; De Bruin, Oort, Bögels, & Meijer, 2014; Dewald-Kaufmann, Oort, & Meijer, 2013; Gradisar et al., 2011; Hendricks, Ward, Grodin, & Slifer, 2014; Kira, Maddison, Hull, Blunden, & Olds, 2014; Saxvig et al., 2014). Thus, the most notable finding from the present study was the ability of a brief intervention to provide a meaningful extension of sleep in a sample of adolescents. We also note in the current experiment that average total sleep at baseline was <8 hr, and ~8 hr (7hr 57min) during the intervention week. Based on previous research, this suggests that potentially, adolescents who refrain from using a mobile phone in the hour before bed may have improved functioning. For example, a previous experiment resulting in a 13-min extension of adolescent sleep has led to improvements on cognitive tasks (Dewald-Kaufmann et al., 2013). Moreover, adolescents who obtain more than 8 hr sleep have shown to perform better on working memory tasks than those who acquire < 8 hr of sleep per night (Gradisar, Terrill, Johnston, & Douglas, 2008). Eight or more hr of sleep is also correlated to better overall cognitive performance among adolescent males (Ortega et al., 2010). Future experiments, however, are needed to simultaneously measure sleep, cognitive performance and memory, to validate these assumptions.

Due to the subjective nature of reporting in this experiment, some caution needs to be exercised when considering these effects of pre-bed mobile phone restriction on adolescents' sleep. Although not specific to adolescents, Vincent (2006) argues that people may be emotionally attached to their mobile phone. This may explain why adolescents were reluctant to partake in the experiment. Of note, nearly 2 out of every 3 adolescents (63%) of adolescents who participated in the intervention week, and completed the questionnaire, stated that they would consider not using their phone in the hour before bed, *if* it was beneficial for their sleep. It could be argued that these adolescents already had a higher level of motivation, and willingness to have their technology use altered, than the adolescents who declined to participate, as evidenced by their willingness to partake in the study and complete the intervention and measures. If this were true, the reluctance of the general adolescent population to part with their phones leading up to bedtime may be even greater. Anecdotally, teachers summarised reasons for adolescents' decline to participate as being "*a little worried it would be too much with school work*"; "*too busy…to think about anything else*", and; "*I don't want to alter my use of technology*". The refusal to participate in an experiment which suggested altered phone use, for even one week, is also an indication of how unmotivated adolescents are in having their technology use restricted. Indeed, similar results have been found among young adult video gamers asked to abstain for 3 days (0.3% response rate; Kaptsis, 2015). This suggests that future studies need to seriously consider what additional information (e.g., explicit mention the intention to cease mobile phone use by 1 hr earlier) and/or strategies they apply above and beyond our vague instruction of "altering mobile phone use" to adolescents' motivation to change.

Motivational interviewing may be one such technique used to enhance the desire for adolescents to decrease pre-bed phone use, with discussions targeting their motivational stage of change (Bonnar et al., 2015; Cain, Gradisar, & Moseley, 2011; Gradisar, Smits, & Bjorvatn, 2014). For example, during the *pre-contemplation stage* where adolescents do not perceive a problem, discussion could centre on didactic education about the positive effect of stopping 1 hr earlier has on total sleep time, and the possible benefits for adolescents' school performance. If such education moves more adolescents into the *contemplation stage*, then listing the pros and cons of decreasing pre-bed phone use with a decisional balance sheet (Miller & Rollnick, 2012), as well as the adolescents' personal values could be performed. Noting discrepancies between values and behaviour can be explored (e.g., a goal of top academic performance, and being "*too busy…to think about anything else*"), which may move more adolescents to the *determination stage*, where change talk can be reinforced and potential barriers problem solved. These series of brief strategies could potentially prepare adolescents for the *action stage* (i.e., perform the intervention), thus testing larger sample sizes. Moreover, it may be useful for boundaries involving technology use to be encouraged by parents (Piotrowski, Jordan, Bleakley, & Hennessy, 2015). However, it may be worthwhile for the scientific community to focus on experimental research that may be more popular among adolescents. For example, focussing on decreasing pre-sleep arousal using cognitive techniques (e.g., mindfulness, constructive worry; Bei et al., 2013; Carney, & Waters, 2006) may be strategies that encounter less resistance. This would be of particular value for adolescents who use technology as a means of escaping anxious or catastrophising thoughts prior to sleep (Eggermont & Van den Bulck, 2006; Hiller, Lovato, Gradisar, Oliver, & Slater, 2014).

Several limitations of the present study must be addressed. Despite our attempts to validate self-reported mobile stop times with an objective measure (i.e., Screen On/Off Logger Lite), the response rate was low, thus introducing some measurement error. Although compliance could not be objectively monitored, this more closely mimics a real-world scenario, if parents or health professionals were to request adolescents stop using their phone in the hour before bed. Thus, this ‘bedtime’ for phones appears to have beneficial effects on self-reported sleep latency and subsequent sleep duration, in a real-world environment. Furthermore, although the present study used a within-subjects design, which possesses the strength of controlling for confounding variables (over a between-subjects design)[4] the small sample size nevertheless warrants caution when interpreting results to the wider tech-savvy adolescent population. Finally, the present study did not measure adolescents’ daytime functioning during the study, thus it is not known whether there is an added meaningful effect on the quality of these adolescents’ lives.

[4]Also worth noting is that significant and meaningful effects were found on sleep, suggesting the small sample size did not deem the study to be underpowered.

Conclusion

These findings show that restricted mobile phone use during the hour preceding adolescents' bedtime has the potential to advance their lights out time, and increase their total sleep time. This is likely to benefit their daytime functioning. Future experimental research should investigate motivational interviewing to increase the likelihood of adolescents decreasing their phone use in the hour before bed, and/or cognitive strategies aimed at decreasing pre-bed arousal. This would assist health professionals, adolescents, and their families to employ the most effective interventions for improving adolescent sleep health, as well as promoting adolescent autonomy and teaching them effective healthy lifestyle habits.

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CHAPTER 6. Brief School-Based Interventions to Assist Adolescent Sleep: Comparing Mindfulness and Constructive Worry Versus Controls

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KB led experimental design, survey design, recruitment, data analysis and manuscript preparation. CH assisted with recruitment, data collection, and read the draft manuscript. BM designed the survey website and assisted with survey design and data cleaning. PW assisted with statistical analysis and read the draft manuscript. MG assisted with organisation of the experimental design, survey design, recruitment, data analysis and manuscript preparation.

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Abstract

Difficulties falling asleep can be common among adolescents, especially during stressful times. It is important for adolescents, and those who care for them, to have an effective means for decreasing the time it takes them to fall asleep and reducing pre-sleep cognitive emotional arousal. This study used a 3 (treatment: control, mindfulness, constructive worry) by 3 (time: baseline, week 1, week 2) design to test whether brief (15 min) interventions are capable of decreasing adolescent (N = 190; M age=15.94, SD=0.79, range = 14-17 years; 15.3%m) sleep latency and worry, and improving pre-sleep cognitive emotional arousal and daytime functioning, especially in adolescents with prolonged sleep latency (i.e., ≥30 min). An interaction between treatment and time was observed for sleep latency among adolescents with prolonged baseline sleep latency, $F(4,100.80) = 5.28$, $p = .001$. The mindfulness bodyscan was an effective means of decreasing sleep latency, while constructive worry had little effect on sleep latency. However, neither tool was able to decrease pre-sleep worry or improve pre-sleep cognitive emotional arousal, or associated daytime functioning. The findings suggest that a mindfulness mp3 is a promising means by which adolescents with prolonged sleep latency can decrease the time it take them to fall asleep. This is a simple tool which could be distributed by teachers, or others not skilled in treating adolescent sleep difficulties. However, further treatment may be necessary to improve pre-sleep arousal.

Brief School-Based Interventions to Assist Adolescent Sleep: Comparing Mindfulness and Constructive Worry versus Controls

Adolescence is a time of many challenges (Tavernier, Choo, Grant, & Adam, 2016), so it is hardly surprising that recent data indicate over one third of adolescents lie awake at night due to stress (American Psychological Association [APA, 2014). When anxious thoughts are experienced at bedtime, this may lead to pre-sleep arousal, rumination and/or catastophising (Bartel, Gradisar, & Williamson, 2015; Dahl, & Harvey, 2007; Dahl, & Lewin, 2007; Danielsson, Harvey, MacDonald, Jansson-Fröjmark, & Linton, 2013; Hiller, Lovato, Gradisar, Oliver, & Slater, 2014). Indeed, adolescents who experience worrying thoughts at bedtime (e.g., thoughts about their ability to achieve good next-day academic functioning, or planning for the next day; Hiller et al., 2014) are more likely to experience increased anxiety, leading to longer sleep latency (i.e., the time it takes to fall asleep; Hiller et al., 2014).

Stressful situations, such as the pre-exam period, also leave adolescents vulnerable to prolonged sleep latency and self-perceived sleep difficulties (Aysan, Thompson, & Hamarat, 2001; Ellis, & Fox, 2004). For example, over 70% of Chinese adolescents experiencing sleep latency greater than 30 min leading up to exams (Wang et al., 2016). When school pressures are compounded by further stressors (i.e., stressful family environments), insomnia severity increases (Bernert, Merrill, Braithwaite, Van Orden, & Joiner Jr, 2007), yet, conversely, adolescents who experience more calmness have shorter sleep latencies (Tavernier et al., 2016).

Prolonged sleep latency is not only a concern because it is so pervasive, but it is also associated with adolescent depression (Dahl, & Harvey, 2007; Dahl, & Lewin, 2007; Short et al., 2013; Sivertsen, Harvey, Lundervold, & Hysing, 2014), self-reported poor school performance (Kilincaslan, Yilmaz, Batmaz Oflaz, & Aydin, 2013; Wang et al., 2016), emotional problems, hyperactivity or inattention and conduct problems (Kilincaslan et al., 2014), not to mention day time consequences, such as fatigue (APA, 2014; Short, Gradisar, Gill, & Camfferman, 2013) and loss of energy and sleepiness during the day (Dewald, Short, Gradisar, Oort, & Meijer, 2012; van Maanen et al., 2014). The good news, is that previous research has demonstrated the potential benefits of brief interventions on decreasing pre-sleep arousal, worry and sleep latency.

Constructive worry (i.e., writing down current worries, aligned with a possible solution, early in the evening) is a promising technique to relieve the burden of sleep initiation difficulties. For example, among college students with insomnia, 5 nights of constructive worry decreased pre-sleep cognitive arousal (Carney & Waters, 2006). Furthermore, college students who experienced 'mind racing' and worries at bedtime (which led to sleep difficulties) benefitted from constructive worry, imagery distraction or gratitude intervention, performed for 1 week (Digdon & Koble, 2011). These interventions, disseminated via email, managed to decrease college students' pre-sleep cognitive arousal and bedtime worry. Surprisingly though, sleep latency remained unchanged in either study (Carney & Waters, 2006; Digdon & Koble, 2011). However, such studies have lacked control groups, and provided individuals with only limited time to practice (i.e., 5-7 days). The first aim of the present study will be to compare 2 consecutive weeks of constructive worry (against controls) in adolescents, which to authors' knowledge, is a population in dire need for such a brief intervention.

Mindfulness is another technique that has been used to reduce adolescents' pre-sleep anxiety and sleep latency. Studies to date have focussed on techniques from mindfulness-based stress reduction (MBSR) as opposed to mindfulness-based cognitive therapy (MBCT) – with MBSR being a structured program incorporating meditation, body scan (i.e., focusing on one's body) and body movements, and MBCT being an adapted MBSR to allow the individual to detach themselves from their thoughts (Fjorback, Arendt, Ørnbøl, Fink, &

Walach, 2011). For example, adolescents with self-reported poor sleep found a 6-session, in-school program incorporating MBSR (among other techniques) managed to decrease sleep latency and improved sleep quality post-treatment (Bei et al., 2013). This study replicated the findings of an earlier 6 session sleep intervention that included MBSR among adolescents experiencing sleep problems and substance use disorders (Bootzin & Stevens, 2005; Britton et al., 2010). Unfortunately, as mindfulness was one of many techniques employed in these abovementioned studies, the unique effect of mindfulness to reduce both pre-sleep arousal and sleep latency in adolescents is still unknown. Furthermore, the field of mindfulness has been hampered with a lack of control groups (Fjorback et al., 2011). Thus, the second aim of the present study is to evaluate the effect of a brief mindfulness technique (body scan) against a control condition on adolescents' pre-sleep cognitive emotional arousal, worry and sleep onset latency.

Due to the negative impact prolonged sleep latency can have on daytime functioning, the third aim of the study is to determine whether any decreases in sleep latency and pre-sleep arousal or worry, resulting from interventions, are sufficient to improve daytime consequences (e.g., fatigue).

Given the high prevalence of sleep difficulties and associated distress experienced by adolescents worldwide (APS, 2014; Gradisar, Gardner, & Dohnt, 2011; Short et al., 2013; Wang et al., 2016) there is a need to provide evidence-base interventions on a broad scale. This may also help to overcome the issue of adolescents being reluctant to seek treatment (Gulliver, Griffiths, & Christensen, 2010) and their high drop out rates when doing so (Bootzin & Stevens, 2005). Schools provide an accessible platform to provide such universal interventions to all adolescents, and it would be expected that those who need it most (i.e., adolescents with sleep latencies ≥30min; Short et al., 2013) would also benefit the most. This would also allow teachers, counsellors or other people not trained in treating sleep problems to be able to provide a simple method to assist adolescents who experience difficulties falling asleep. Further, to increase the length of time these techniques are practised (>1 week), they need to be as minimally invasive as possible. Hence, we aimed to determine whether a brief 15-min intervention (constructive worry or mindfulness at bedtime), performed for 2 weeks, could assist all adolescents to decrease pre-sleep arousal, worry and sleep latency, as well as those who experience prolonged sleep latency (i.e., ≥30min).

Method

Participants

Overall, 190 adolescents (M age=15.94, SD=0.79, range = 14-17 yrs; 15.3%m) contributed data (see Figure 6.1 for participant flow chart). To increase generalisability to a school setting, all adolescents were included, regardless of whether they reported a sleep problem (self-reported sleep problem; constructive worry = 22.5%; mindfulness = 27.3%; control = 40.0%), or receiving treatment for anxiety (self-reported receiving anxiety treatment; constructive worry = 10.0%; mindfulness = 10.9%; control = 16.4%). Similar to previous research, adolescents were required to have completed the intervention for 3 or more nights per week (Digon & Koble, 2011), for at least one week, unless in the control group (27 and 15 were deleted from constructive worry and the mindfulness group, respectively, as they completed the intervention for <3 nights per week in *both* weeks). Overall, intervention groups had a similar percentage of adolescents who commenced the study and were included in analyses (constructive worry = 68%, mindfulness = 70%). Ethics approval was granted from the Social and Behavioural Research Ethics Committee, the Department for Education and Child Development, and Catholic Education South Australia. The trial was also registered on the Australian Clinical Trials Registry (trial number 367478).

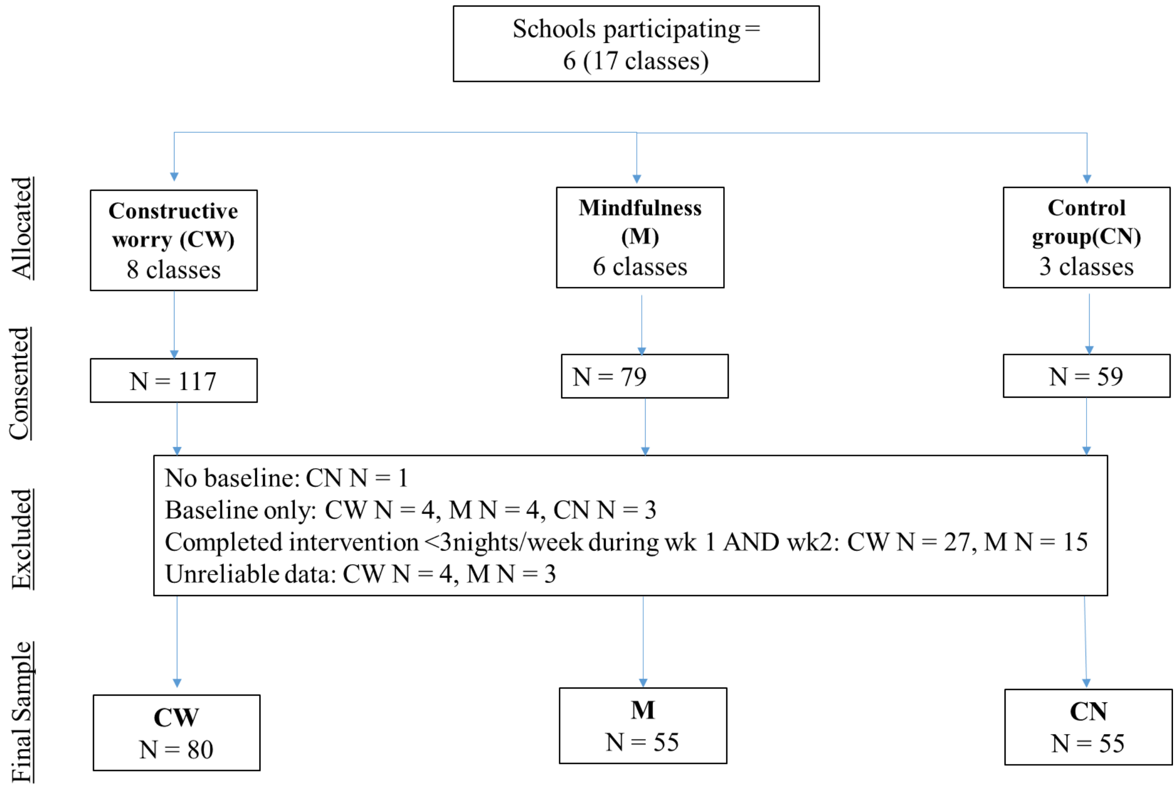

Figure 6.1. Participant flow chart

Design

A 3 (intervention; constructive worry, mindfulness, control) by 3 (time; baseline, week 1, week 2) mixed-model experimental design assessed the effects of the brief interventions on adolescents' pre-sleep arousal and sleep latency.

Materials

Demographic information.

Baseline information was collected concerning adolescents' age, year level, gender, whether they thought they had a sleep problem and whether they were currently receiving treatment for anxiety. No exclusion criteria existed, in order to obtain results generalisable to students within a school setting.

Sleeping patterns.

Adolescents were asked how long it took them to fall asleep (in minutes) during the past week, separately for school (Sunday-Thursday) and weekend (Friday-Saturday) nights.

Cognitive emotional adolescent sleep hygiene.

The 6-item Cognitive Emotional subscale of the Adolescent Sleep Hygiene Scale-Revised (ASHS-R; Storfer-Isser et al., 2013) was used to measure cognitive-emotional sleep hygiene. Items include *“I go to bed and worry about things happening at home or at school”* and “*I go to bed and replay the day’s events over and over in my mind*”. Participants were asked to respond in relation to the past week, using a 6-point scale, ranging from *1* (*never*, *0%*) to *6* (*always*, *100%*). Scores were reversed then summed and divided to obtain the average (i.e., divided by 6; range = 1-6), so that higher scores indicated better cognitive-emotional sleep hygiene. Internal consistency for the 6 items was good for baseline (Cronbach’s $\alpha = .81$, $N = 190$), week 1 (Cronbach’s $\alpha = .87$, $N = 161$) and week 2 (Cronbach’s $\alpha = .89$, $N = 160$).

Evening rumination.

The Perseverative Thinking Questionnaire – Child Version (PTQ-C; Bijttebier et al., 2014) is a 15-item questionnaire validated among adolescents (Bijttbier et al., 2014) to assess repetitive thinking at bedtime. Adolescents were asked to *“rate how often the following have happened to you over the past week while trying to fall asleep at night”*, using a 5-point scale (*never, almost never, sometimes, often, almost always*). Scores were summed, with higher responses indicating more rumination. Internal consistency for the 15 items was excellent for baseline (Cronbach’s $\alpha = .96$, $N = 189$), week 1 (Cronbach’s $\alpha = .97$, $N = 158$) and week 2 (Cronbach’s $\alpha = .98$, $N = 160$).

Daytime consequences.

The Sleep Reduction Screening Questionnaire (SRSQ; van Maanen et al., 2014) is a 9-item scale, used to assess the daytime consequences of chronic sleep reduction (e.g., *“Do you feel* *sleepy during the day?", "Do you have trouble getting up in the morning?")*. It has been validated against objective measures of sleep (i.e., wrist actigraphy), with moderate-to-strong correlations found between SRSQ scores and objective sleep measures (van Maanen et al.). Items are scored on a 3-point ordinal scale, and adolescents were asked to consider the past week when answering questions. Scores were summed, with higher scores indicated more chronic sleep reduction. Internal validity for the 9 items was acceptable (Cronbach's α =.70, N = 190, for baseline; Cronbach's α = .75, N = 161, week 1; Cronbach's α =.74, N = 156, week 2).

Treatment efficacy and compliance.

To measure adherence, both intervention groups were asked, at the end of weeks 1 and 2, how many nights they had completed the intervention. At week 2, they were also asked questions relating to treatment efficacy; *"After doing the self-help intervention my problems falling asleep have…"* with 4 options available (*improved a lot, improved a bit, stayed the same, got worse*); and, *"My overall impression of the self-help intervention is that it was…"* with 4 response options (*highly effective, somewhat effective, neither effective nor ineffective, ineffective*). Adolescents were provided the opportunity to comment as a free text response to the question *"Based on your experiences doing this intervention, what are your suggestions for improving this intervention?"*

Procedure

Signed parental consent, and adolescent assent, were sought. Schools across Adelaide, South Australia, were contacted via email with brief study details, requesting interested schools to respond to the lead researchers. Schools were also contacted through researcher contacts, with 7 schools responding regarding their interest in involvement. From here, 6 schools decided to participate (1 to 4 classes per year level). Information concerning the study, including consent forms, were distributed and collected by teachers prior to the first session. Effect of bias was minimised as groups were pre-allocated to condition, prior to any contact with adolescents. All students within the same year level who attended the same school were allocated to the same condition, to minimise any contamination which may have occurred if adolescents discussed their intervention homework among themselves. Adolescent classes were enrolled, and intervention group allocated by lead author, KB. Adolescents, caregivers and teachers were blind to their treatment condition until after baseline data had been collected, as well as to the other intervention groups throughout the study. Research assistants were aware of the different conditions, in order to provide the weblink associated with the appropriate intervention instructions to each class. All adolescents who attended the classes involved in the study were eligible to participate.

Data were collected in the classroom setting, with online questionnaires administered once per week, with the day of data collection consistent within subjects. Adolescents were given a unique identification number, to assess within-subjects differences over time. Instructions for the appropriate intervention were provided on the final page of the baseline questionnaire, as well as verbally in class by researchers.

The constructive worry group was instructed to record, between 6-8pm each night, at least 3 worries that may keep them awake, as well as the next step to resolve the issue (Carney & Waters, 2006). If the worry surfaced when they went to bed, they were asked to remind themselves they had dealt with the problem as best as they could, and that there is nothing better they could do to solve the problem until the morning (Carney & Waters, 2006). Adolescents were provided with a verbal example of a worry, and solutions they might generate. Adolescents were not required to share worries or thoughts they recorded, nor the solutions. The mindfulness group was provided a non-copyrighted 15-min mp3 audio file of a mindfulness body scan on the final instruction page on the questionnaire, for adolescents to take home and use at bedtime. They were instructed to listen to the audio file each night when they got into bed, and continue relaxing after the audio file had finished. The control group were instructed to continue their sleep/wake habits as usual.

Adolescents were also told that a researcher would return a second and third time, one week apart, respectively, in order to administer another online questionnaire (see Figure 6.2 for study protocol). At completion of the third visit, adolescents were debriefed and fully informed of the study, including details of all interventions, and given the opportunity to ask questions, or contact the researcher, if they would like to implement these techniques outside of the research study. As reimbursement for their time, classes were provided with an information session about sleep, or another topic at their request, such as research methods.

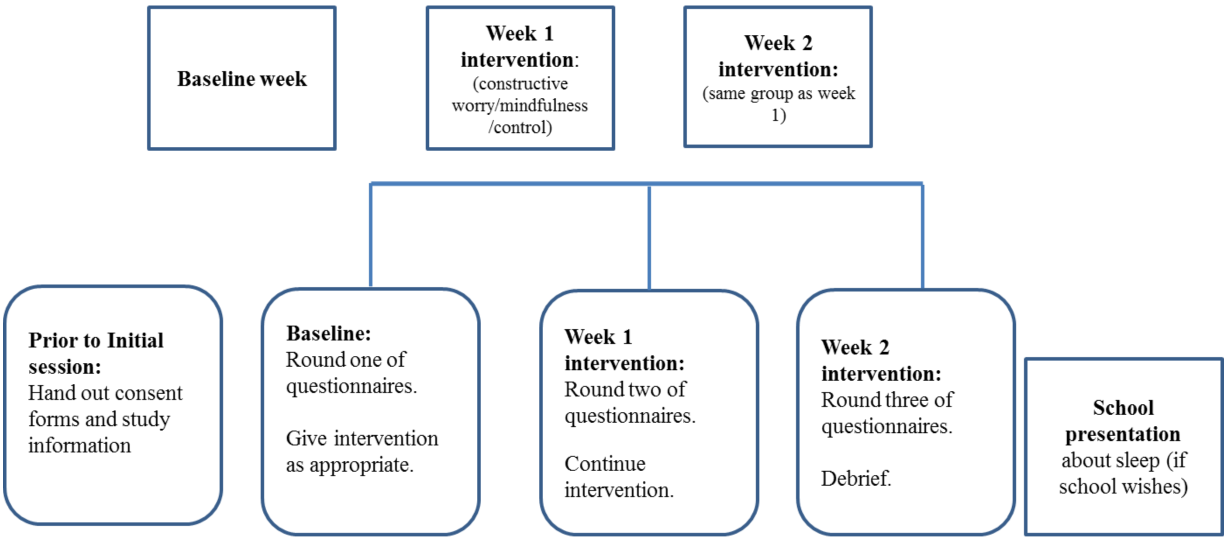

Figure 6.2. Study protocol

Statistical Analysis

Data were analysed using IBM SPSS Statistics 22. Outliers were determined as values with standardised *z*-scores ±3.29, and altered to 1 unit lower/higher than values within appropriate limits (Tabachnick & Fidell, 2007). Skewness was assessed visually using histograms (Tabachnick & Fidell). Sleep onset latency appeared negatively skewed at all times points, yet was not transformed in order to retain meaningful values, particularly so that those with baseline SOLs ≥30min could be assessed. Linear mixed model regressions (LMMR), using restricted maximum likelihood as the method of estimation, were performed to determine interaction effects between condition and time. Time and group, and the time*group product term were entered as fixed effects. Time was coded as 0 = baseline, 1 = week 1, 2 = week 2. Subjects were entered as random effects, to handle the correlation between time points, with the intercept included in the model. Participant data were only included when an adolescent had completed the baseline *and* week 1 *or* week 2 questionnaires. They also needed to have completed the intervention for ≥3 during the intervention week. For participants who did not complete the intervention for ≥3 nights for one of the two intervention weeks, the incompliant week (but not the participant) was deleted from the dataset, so that the effects of treatment when actually performed could be ascertained. LMMRs are advantageous due to their ability to cope with missing data and unequal sample size (Shek & Ma, 2011). Estimated marginal means for each group across each time point were calculated, using Bonferroni correction. Baseline data were equated to the overall mean value when represented graphically (see Figure 6.3), for easier visual comparability. Cohen's *d* effect size was calculated as the difference between baseline and end of treatment (week 2) means, divided by baseline standard deviation (Cohen, 1988). Participant comments on the intervention were scored independently by authors KB and MG, to determine common themes (Fossey, Harvey, McDermott, & Davidson, 2002). From here, comments were appropriately grouped to obtain qualitative feedback on the brief interventions.

Results

Evaluation of interventions compared to control on pre-sleep behaviours, sleep latency and daytime consequences.

For the entire sample, analyses showed no significant interaction effects between group and time for sleep latency, $F(4,185.00) = 2.35$, $p = .06$. A small decrease in sleep latency was seen in the mindfulness and control group, with negligible decrease in the constructive worry group (see Table 6.1 for effect sizes and Table 6.2 for means and 95% confidence intervals). To evaluate possible effects of interventions for adolescents who experienced prolonged sleep latency, analyses were conducted using only the 97 adolescents with SOL ≥30min (41 constructive worry, 20 mindfulness, 36 control; Short et al., 2013; Wang et al., 2016). Results revealed an interaction between group and time for sleep latency, $F(4,100.80) = 5.28$, $p = .001$, with a large decrease in sleep latency observed in the mindfulness group from baseline to week 2, a small decrease for the control group, and negligible difference for the constructive worry group for the same time period (see Figure 6.3 and Tables 6.1 and 6.2).

Table 6.1

Cohen's d Effect Size Between Baseline and Week 2 Scores, for all Adolescents, and Those With Baseline SOL ≥30min

	All Adolescents				SOL ≥ 30 min			
Treatment	SOL	ASHS	PTQ-C	SRSQ	SOL	ASHS	PTQ-C	SRSQ
Constructive worry	0.05[-]	0.34[a]	0.55[b]	0.09[-]	0.04[-]	0.26[a]	0.44[a]	0.07[-]
Mindfulness	0.29[a]	0.20[a]	0.36[a]	0.08[-]	1.03[c]	0.29[b]	0.22[a]	0.16[-]
Control	0.31[a]	0.34[a]	0.48[a]	0.14[-]	0.45[a]	0.55[b]	0.59[b]	0.21[a]

Note. [-] indicates negligible difference (i.e., *d* = <.20), [a] indicates small effect size (i.e., *d* =.20-.49), [b] indicates moderate effect size (i.e., *d* = .50-.79), [c] indicates large effect size (i.e., *d*>.80; Cohen, 1988).

ASHS = Adolescent Sleep Hygiene Scale-Revised – cognitive emotional scale, PTQ-C = Perseverative Thinking Questionnaire – Child Version, SOL = Sleep onset latency, SRSQ = Sleep Reduction Screening Questionnaire.

Table 6.2

Means and 95% Confidence Intervals for Each Treatment Group Across Treatment for Sleep Latency, Pre-Sleep Arousal, Rumination and Daytime Tiredness, for all Adolescents, and Those With Baseline SOL ≥30min

	Treatment Group								
	Constructive worry			Mindfulness			Control		
	B	Wk1	Wk2	B	Wk1	Wk2	B	Wk1	Wk2
All adolescents									
SOL (min)	27.90 (22.74-33.06)	23.87 (19.33-28.42)	26.08 (21.14-31.02)	32.09 (25.87-38.31)	23.81 (18.29-29.33)	20.29 (14.33-26.24)	35.75 (29.53-41.97)	30.46 (25.17-35.76)	27.38 (21.62-33.14)
ASHS	4.13 (3.88-4.38)	4.41 (4.18-4.64)	4.45 (4.20-4.70)	3.72 (3.42-4.02)	3.82 (3.54-4.10)	4.01 (3.70-4.31)	3.69 (3.39-3.99)	3.79 (3.52-4.06)	4.00 (3.70-4.30)
PTQ-C	26.18 (22.86-29.50)	20.69 (17.48-23.89)	17.86 (14.52-21.20)	33.58 (29.60-37.56)	29.13 (25.24-33.02)	27.20 (23.19-31.21)	33.62 (29.64-37.60)	28.85 (25.09-32.60)	27.74 (23.81-31.67)
SRSQ	17.99 (17.24-18.74)	17.80 (17.06-18.55)	17.77 (16.95-18.59)	18.64 (17.73-19.54)	18.15 (17.24-19.06)	18.18 (17.20-19.16)	19.62 (18.71-20.52)	19.81 (18.94-20.68)	19.34 (18.38-20.31)
Baseline SOL ≥30									
SOL (min)*	40.10 (32.67-47.52)	32.22 (25.41-39.03)	37.48 (30.04-44.93)	65.35 (54.72-75.98)	42.59 (32.38-52.80)	34.60 (24.55-44.65)	46.67 (38.74-54.59)	37.72 (30.65-44.78)	34.78 (27.21-42.35)
ASHS	3.91	4.20	4.22	3.40	3.69	3.85	3.37	3.56	3.81

	(3.55-4.27)	(3.87-4.53)	(3.85-4.58)	(2.88-3.92)	(3.20-4.17)	(3.34-4.36)	(2.99-3.76)	(3.21-3.91)	(3.42-4.19)
PTQ-C	29.98 (25.26-34.70)	23.90 (19.62-28.18)	22.27 (17.55-27.00)	35.75 (28.99-42.51)	32.46 (26.22-38.70)	30.77 (24.20-37.34)	35.94 (30.91-40.98)	29.74 (25.22-34.25)	28.83 (23.91-33.75)
SRSQ	18.39 (17.37-19.41)	18.27 (17.24-19.30)	18.17 (17.01-19.33)	19.10 (17.64-20.56)	19.31 (17.78-20.84)	18.41 (16.84-19.98)	20.22 (19.13-21.31)	20.31 (19.23-21.38)	19.70 (18.50-20.89)

Note. ASHS = Adolescent Sleep Hygiene Scale-Revised – cognitive emotional scale, B = Baseline, PTQ-C = Perseverative Thinking Questionnaire – Child Version, SOL = Sleep onset latency, SRSQ = Sleep Reduction Screening Questionnaire.

*denotes significant interaction effect

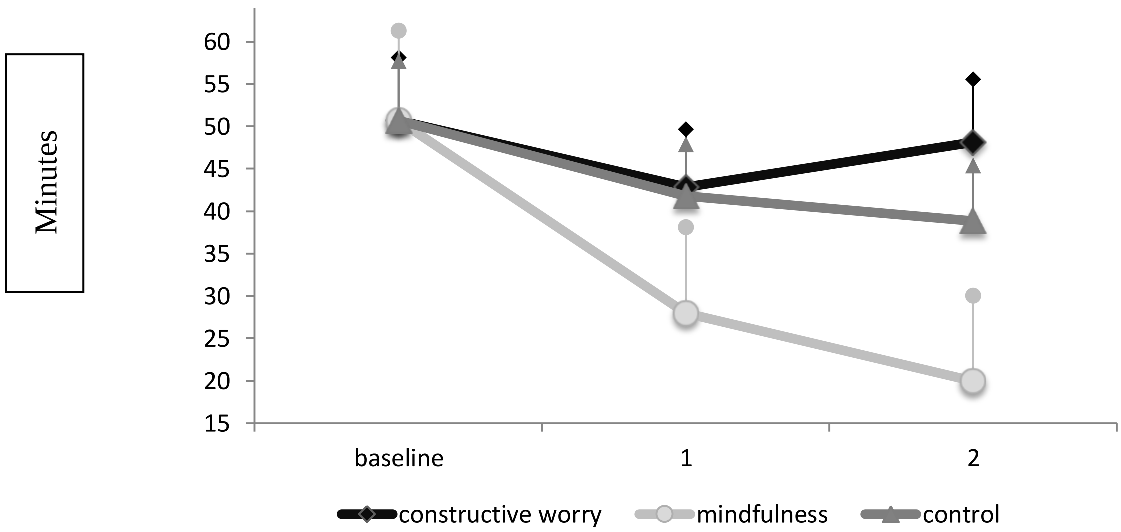

Figure 6.3. Mean sleep onset latency (equated at baseline) and upper 95% upper confidence internals for adolescents with baseline sleep latency ≥30min

No further interactions occurred for pre-sleep arousal and rumination (i.e., ASHS-R, PTQ-C) or daytime functioning (i.e., SRSQ), either for all adolescents, or those with sleep latencies ≥30min (See Tables 6.1 and 6.2). This demonstrates that listening to a mindfulness MP3 before bed can reduce adolescents' sleep latency for those with prolonged SOL, yet it was not sufficient to influence pre-sleep cognitive emotional arousal or rumination.

Self-Reported Treatment Efficacy

A higher percentage of adolescents in the mindfulness group appeared to rate the intervention as effective and useful for improving their sleep compared to constructive worry (see Table 6.3 for results). Eighty adolescents across both interventions groups provided qualitative feedback in regards to how the interventions could be improved. Answers could be grouped into 3 broad themes. Ten out of 40 adolescents (25%) from the mindfulness group, and from the constructive worry group reported 'no changes' were needed. Complaints about the 'study procedure', especially the repetitive nature of the questionnaires, were reported by 5 of 40 (13%) adolescents in the mindfulness group, and 8 out of 40 (20%) from the constructive worry group (e.g., "*Change questions or mix them up so we don't repeat ourselves*"). Finally, 'suggestions for improving the interventions' were reported by 27 of the 40 adolescents (68%) in the mindfulness group, and 18 out of 40 (45%) from the constructive worry group. The main suggestions from those in the mindfulness group were that the mp3 be shorter (N=9/27, 33%; e.g., "*With the audio file, maybe have it shorter for participants to listen to. It was a bit long…*" and "*The body scan was quite long and which meant I fell asleep half way through most times and then woke up again throughout, so it could be shortened to have the same effect*"), and to have more calming audio (N=10/27, 37%; "*Find a more calming voice for the recording*", and "*Perhaps an improvement of audio choice as at times, I found that the intervention kept me awake, rather than allowed me to sleep. The addition of soft music may* *have helped with this*.”). For the constructive worry intervention, suggestions were mixed, including seeking extra assistance (N=2/18, 11%; “*Help the participant to relax*” and “*Talking to someone about the problems and your solutions, parents, friends, etc.*”); to try different techniques (N=5/18, 28%; “*For the next experiment maybe try to discuss more on ways to help your sleep instead of just writing down what’s keeping you up at night*” and “*Try different things to get people to help themselves with*.”), and additions to the technique (N=6/18, 33%; “*Have a sleep log book where you can write your thoughts as well*” and “*It would have been really handy to have some sort of table to fill in (to still keep to yourself) to write your worries or thoughts*”). Indeed, adolescents from both groups suggested to set an alarm to remind them to perform these brief interventions (e.g., “*I struggled to remember to play the recording every night as year 12 is a lot of stress and it wasn’t something I was focusing on much*”).

Table 6.3

Self-reported Efficacy of Treatment, Reported as a Percentage of Responses

Treatment	Problems falling asleep have…			
	Improved a Lot	Improved a Bit	Stayed the Same	Got Worse
Constructive worry	1.5	48.5	53.8	6.2
Mindfulness	9.1	50	40.9	0
	Impression of intervention			
	Highly Effective	Somewhat Effective	Neither Effective nor Ineffective	Ineffective
Constructive worry	0	46.2	46.2	7.7
Mindfulness	9.1	54.5	34.1	2.3

Discussion

The current study provides evidence that listening to a mindfulness mp3 at bedtime is able to reduce sleep latency in adolescents for those with long sleep latency. Constructive worry, however, does not appear to effectively decrease sleep latency, and neither technique is able improve pre-sleep cognitive emotional arousal or rumination, or reduce daytime tiredness.

Our findings contradict previous research (Carney & Waters, 2006; Digdon & Koble, 2011), which found constructive worry decreased pre-sleep cognitive arousal. Carney and Waters recruited participants with insomnia and compared the constructive worry group to a worry monitoring group (i.e., they asked participants to concentrate on worries without thinking of solutions). Potentially, that this may have exacerbated insomnia symptoms (e.g., increasing sleep latency), as key processes for people with Insomnia include worry, selective attention and monitoring, and inaccurate perceptions of their sleep and daytime functioning (Harvey, 2005). Hence, differences in findings could be due to a lack of adequate control group in Carney and Water's experiment. Digon and Koble (2011) collected daily measures of pre-sleep arousal, hence their study may have more accurately been able to capture arousal relative to sleep on a nightly basis. Regardless, results replicated previous literature which showed one week on constructive worry was unable to decrease sleep latency, with our study showing no benefit from even 2 weeks of constructive worry.

Regarding mindfulness, to our knowledge, the current study is the first to use a body scan at bedtime as a standalone intervention. Our findings add to previous research which has used mindfulness as part of a multi-component treatment (Bei et al., 2013; Britton et al., 2010). Bei and colleagues gave adolescents in-depth training on mindfulness, including a body scan, breathing exercises and focussing on addressing worries and thoughts. Although our brief, simple, and easy to disseminate mindfulness exercise decreased sleep latency comparably more than the study by Bei and colleagues (19 min for Bei et al. compared to 31 min in the present study among adolescents with long baseline SOL), it is possible that Bei and colleagues' more complex approach is advantageous for decreasing pre-sleep arousal and bedtime rumination. Nevertheless, our results are of important clinic relevance, as a 31 min decrease for adolescents who experienced long baseline sleep latency, was observed. The odds of an adolescent reporting a sleep issue increases 1.40 times for every 10 min increase in sleep latency (Short et al., 2013). Furthermore, adolescents who fall asleep 15 min faster also experience less sleepiness, less depressed mood, and better physical, emotional, social, school and psychosocial quality of life (Tzischinsky & Shochat, 2011). This demonstrates the clinical significance of our findings, although, unfortunately, the improvements in sleep latency did not affect subsequent daytime functioning in the present study. A more comprehensive analysis of daytime symptoms, such as affect, social functioning and physical health, may have been useful for discerning effects of mindfulness on daytime functioning.

Our study shows further benefits compared to longer sleep programs. For example, other brief interventions, such as a single 30-45 min session focussing on sleep education and sleep hygiene, conducted in schools for adolescents experiencing short sleep duration, irregular circadian rhythms and chronic sleep deprivation, have decreased self-reported sleep latency, stress and anxiety, yet not objective sleep latency (as measured by wrist actigraphy; Paavonen, Huurre, Tilli, Kiviruusu, & Partonen, 2016). This intervention was tailored to the individual, and conducted by trained health professionals (Paavonen et al., 2016). Tailored programs, requiring specific and expert sleep knowledge, are not possible for untrained professionals, such as teachers and school counsellors, hence the ability to provide a mindfulness mp3 to improve the time adolescents feel it takes them to fall asleep is a valuable resource. Moreover, this resource can be used effectively even among adolescents who do not usually experience difficulty falling asleep. This is pertinent, as adolescents have longer sleep latencies on days of high arousal, even due to positive emotions, compared to days without higher arousal (Tavernier et al., 2016).

Limitations and Future Directions

One limitation of the present study was the inability to objectively measure sleep, due to the unfeasible nature of such a design. Polysomnography (PSG) is the gold standard for measuring sleep latency, with other measures, such as actigraphy, providing variable accuracy (van de Water, Holmes, & Hurley, 2011). Measuring sleep using PSG would thus be recommended where feasible. Similarly, compliance was only measured subjectively. Considering some adolescents admitted that they did not complete the required tasks nightly, this demonstrates that many adolescents were likely giving a somewhat accurate subjective report (i.e., not intentionally lying). Furthermore, qualitative feedback from adolescents listening to the mindfulness suggests that the audio could be improved. Hence, future research could investigate whether more preferable audio (e.g., a voice that is liked by more adolescents or a decrease in length) has further beneficial outcomes. Additionally, it is possible that listening to the audio, rather than mindfulness *per se*, was helpful for decreasing sleep latency. Hence, comparing mindfulness to another type of audio would ascertain more clearly the role of mindfulness in assisting sleep. Despite constructive worry not being an effective treatment, just less than half of adolescents in the constructive worry group reported the intervention to be somewhat effective. Hence, incorporation of adolescent feedback may increase the chance of constructive worry successfully being able to decrease sleep latency and rumination, and improve pre-sleep cognitive emotional arousal. For example, adolescents completing constructive worry suggested discussing their problems and potential solutions with supportive people, or incorporating sleep education into the intervention.

Additionally, asking adolescents to set a reminder to complete the activity may also improve the likelihood that they complete the activity each night.

Conclusion

Overall, mindfulness appeared to be effective for decreasing sleep latency in adolescents with prolonged sleep latency, yet constructive worry appeared to have no benefit. More elaborate interventions, or improvement of the current interventions through incorporation of adolescents' feedback, is needed to enhance treatment outcomes, particularly pre-sleep arousal and daytime tiredness.

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CHAPTER7. Discussion on Protective and Risk Factors for Adolescent Sleep Health

Discussion on Protective and Risk Factors for Adolescent Sleep Health

Summary of Findings

Overall, this thesis demonstrated the vast array of factors which impact on adolescents' bedtimes, sleep latencies and sleep durations. Meta-analysed literature, as well as inter-country surveys, showed that sleep hygiene appeared to be the most consistent factor that positively contributed to adolescent sleep health.

Meta-analytic data also revealed that technology use, in particular, computer use, mobile phone use, internet use and video gaming, were associated with later bedtimes. Across Australia, Canada and The Netherlands, later mobile phone and/or internet stop times were associated with later bedtimes and less sleep across the school week. Conversely, in an experimental manipulation, Australian adolescents who were instructed to stop using their mobile phone 1 hr before their weekday bedtime turned their lights out earlier and slept longer.

The international surveys also demonstrated an association between pre-sleep worry and longer sleep latency. Subsequently, brief techniques (constructive worry or mindfulness body scan technique) to counteract pre-sleep worry, and decrease sleep latency were investigated. Mindfulness decreased sleep latency among adolescents who took 30 min or longer to fall asleep at baseline. Neither constructive worry nor mindfulness were sufficient to decrease pre-sleep worry, or improve daytime functioning.

How Thesis Findings Extend Current Knowledge of Adolescent Sleep Health

The assessment of factors pertaining to adolescent sleep health was novel, as firstly, it systematically identified relationships which were related to adolescents' bedtimes, sleep latencies and total sleep, including both published and unpublished data (Chapter 2; Bartel, Williamson, & Gradisar, 2015). Although systematic reviews and meta-analyses on behavioural factors influencing adolescent sleep have previously been published, these usually focus on one factor or cluster of factors (e.g., technology use; Carter, Rees, Hale, Bhattacharjee, & Paradkar, 2016; Cain & Gradisar, 2010). The broad nature of Chapter 2's meta-analysis had the advantage of giving insight into the relative strength and weakness of associations between each behavioural factor with adolescents' sleep parameters. In essence, 62 meta-analyses were performed and results synthesised into a single paper. Consequently, researchers are able to directly compare *which* variables are linked to adolescent sleep, as well as the *size of the effect*. This contrasts and enhances another review article published at a similar time, which did not measure the strength of associations for factors related to adolescent sleep health (Owens & Adolescent Sleep Working Group, 2014).

Subsequently, variables which were associated with sleep parameters in Chapter 2 were assessed simultaneously across multiple countries, spanning different latitudes (Chapters 3 & 4; Bartel, van Maanen et al., submitted; Bartel, Williamson et al., 2016). While the meta-analysis revealed which factors were related to sleep parameters in isolation, the nature of the international survey allowed for the assessment of the strength of associations for each individual factor, when taking into account other protective and risk factors. Similar to the meta-analysis, the surveys allowed for comparative assessment of protective and risk factors, whereas the focus of previous literature has been on fewer risk and protective factors (e.g., extracurricular load and parent-set bedtimes; Short et al., 2013). Furthermore, measuring these factors in multiple continents and hemispheres increased confidence that results are applicable to adolescents across the globe. The nature of this investigation also furthered previous literature (e.g., findings concerning daylength; Borisenkov, 2011; Borisenkov et al., 2016), as it suggested areas in which research in this area from one country may be applicable to adolescents in another country (e.g., sleep hygeine), and where inter-country/continent extrapolation may be cautioned (e.g., parent-set bedtime).

Through these initial studies, a comparatively strong relationship emerged between phone use, particularly phone stop time, and adolescent bedtime and sleep duration, even after taking into account other potentially influential variables (e.g., parent-set bedtime, after school sports). Experimental data on pre-bed technology use are lacking (Hale & Guan, 2016). In relation to screen use among children and adolescents, 4.5% out of 67 included in a recent review were experimental, and each had sample sizes smaller than 20 adolescents (Hale & Guan, 2016). One experiment randomised 85 adolescent athletes to either a control group (technology use as normal), or intervention group (technology restriction after 10pm). No differences in the sleep of athletes were found after restriction, yet the average baseline bedtime was 10:10, meaning the “restriction” period was not long before bedtime (Harris et al., 2015). The current pre-bed mobile phone restriction study was novel in its approach to altering adolescents’ technology use individually, and for a substantial length of time prior to bed (1hr), especially among a larger sample of adolescents (i.e., N = 63). Thus, benefits to sleep health for adolescents among the general population were established (Chapter 5; Bartel, Scheeren, & Gradisar, submitted). Moreover, this experiment was field based, hence it mimicked more closely a real world situation if a parent were to impose a restriction on pre-bed phone use. Therefore, not only can cause and effect be determined, but benefits of pre-bed phone restriction on sleep, outside of a controlled laboratory, were ascertained. The low recruitment rate (26%) also shed light on adolescents’ lack of motivation to engage in a study which altered their mobile phone habits. This would not have been brought to light through a laboratory investigation with a smaller sample size.

Furthermore, as pre-sleep worry was found to be associated with longer sleep latency (Chapter 4; Bartel et al., 2016), we tested the ability of two brief interventions to decrease sleep latency among adolescents in a school setting. It was found that mindfulness was a short, easy to disseminate strategy, which decreased sleep latency among adolescents who had prolonged baseline sleep latency (i.e., ≥ 30 min). Constructive worry had no influence on sleep latency. Contrary to results investigating the use of constructive worry among college students (Carney & Waters, 2006; Digdon & Koble, 2011), neither technique reduced adolescents' pre-sleep worry. This suggested that when an adequate control group was monitored, constructive worry did not appear to decrease adolescent pre-sleep arousal. Yet, the benefit of a brief mindfulness intervention on sleep latency, which has the potential for easy distribution, was exhibited (Chapter 6; Bartel, Huang, Maddock, Williamson, & Gradisar, submitted).

Theoretical Implications

Sleep hygiene.

A resounding, recurrent theme that has emerged throughout this thesis, was that good sleep hygiene is a protective factor for adolescents' sleep health. Meta-analytic data (Chapter 2; Bartel, et al., 2015) demonstrated that good sleep hygiene was related to earlier bedtimes, shorter sleep latency and longer sleep duration. When sleep hygiene was measured in multiple countries (Chapter 3; Bartel, van Maanen et al., submitted), it was a stronger predictor of sleep parameters than demographic factors (age and gender), behavioural factors (parent-set bedtime, tobacco and alcohol use), and environmental factors (day length). Moreover, it could be argued that the time evening screens are stopped is an aspect of sleep hygiene, with earlier stop time an indication of better hygiene. Internationally, both mobile and internet stop times were related to earlier bedtimes and longer sleep duration.

Cognitive-emotional sleep hygiene was also compared across countries (Chapter 4; Bartel et al., 2016), and emerged as the strongest predictor of sleep latency for each country. The significance and strength of results between countries varied more for bedtime and total sleep time, yet good cognitive-emotional sleep hygiene did appear to be of some benefit. For example, for each 20% increase in the number of nights good cognitive-emotional sleep hygiene was practiced per week, Canadian adolescents' bedtime advanced by 14 min, and their total sleep time increased by 28 min, yet increases in cognitive-emotional sleep hygiene did not alter Dutch adolescents' bedtime or sleep duration.

To further our confidence in these relationships, 15 min of nightly mindfulness or constructive worry were explored as interventions to decrease pre-sleep cognitive-emotional arousal, and sleep latency. Although pre-sleep arousal was not impacted after 2 weeks of either intervention, for those who experienced baseline sleep latency of 30 min or longer, mindfulness was able to decrease sleep latency by an average of 31 min (Chapter 6; Bartel, Huang et al., submitted). Consequently, theories of adolescent sleep health (e.g., Cain & Gradisar, 2010; Carskadon, 2011) may need to be altered, to incorporate cognitive-emotional sleep hygiene. That is, good cognitive-emotional sleep hygiene may attenuate the psychosocial pressure which contributes to a delay in bedtime, and resultant short sleep (Carskadon, 2011). Moreover, if media use leads to mental or emotional arousal (Cain & Gradisar, 2010), practicing good cognitive-emotional sleep hygiene (e.g., going to bed when feeling calm) may disrupt this mechanism proposed to lead to sleep problems and impaired daytime functioning.

Thus, it appears that adolescents' biological tendency to delay their circadian rhythm (Borisenkov, 2010; Borisenkov, 2011; Carskadon, 2011; Crowley, Acebo, & Carskadon, 2007; Randler, Bilger, & Díaz-Morales, 2009; Roenneberg & Merrow, 2007) can be combatted, to some extent, by employing good sleep hygiene. This may be especially applicable for adolescents which the majority of our sample was likely to represent - that is, those without clinically delayed sleep (i.e., Delayed Sleep Wake Phase Disorder). Additional techniques, such as mindfulness, are beneficial for reducing sleep latency in adolescents who experience prolonged sleep latency. Figure 7.1 displays how good sleep hygiene may oppose the ‘Perfect Storm’, which contributes to adolescents’ later bedtimes and shortened weekday sleep (Carskadon, 2011).

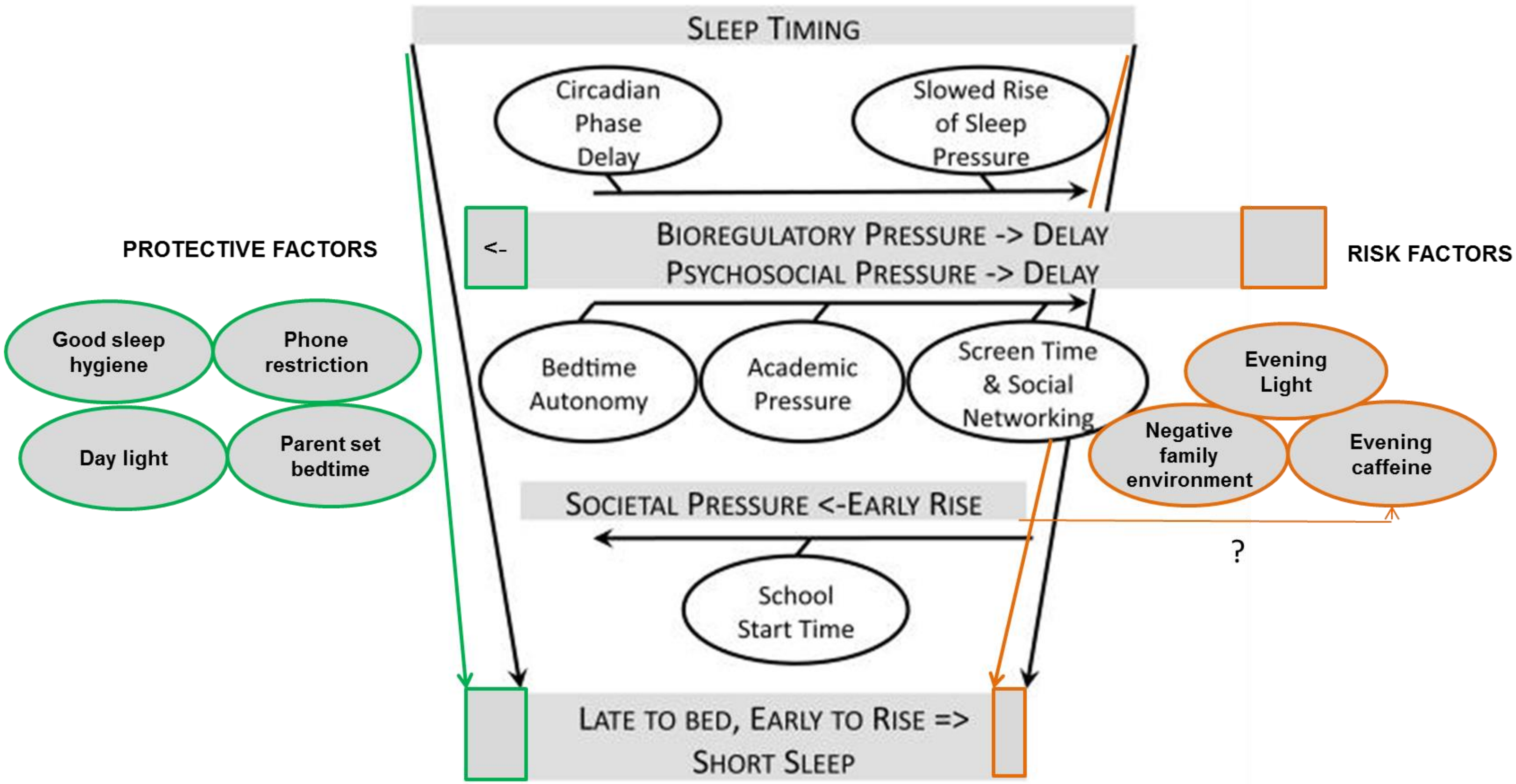

Figure 7.1. Risk and protective factors which contribute to the timing of adolescent sleep during the school week. Adapted from Caskadon's (2011) model. Circles with an orange border indicate risk factors, additional to the original model; those which contribute to delayed bedtime, longer sleep latency and/or less sleep. Circles with a green border indicate protective factors additional to the original model; related to earlier bedtime, shorter sleep latency and/or longer sleep.

Technology use.

Technology use is ubiquitous among adolescents, with rates of use on the increase (Shaw Rocket Fund, 2010). Adolescent consumerism is ensured to continue, considering the financial resources companies invest into new technologies. For example, technology giant Apple spends approximately $8.5 billion per annum on research and development, and Alphabet, Intel and Microsoft each spend up to $13.5 billion (Fox, 2016).

Over the past decade, as studied via the meta-analysis (Chapter 2; Bartel et al., 2015), phone, computer and internet use, and video gaming, have developed convincing relationships with later adolescent bedtimes, although television did not appear to hold any relationship (i.e., r range =0.12-.21 for other technology variables and bedtime, r = 0.04 for television; see Fig. 7.1; Chapter 2; Bartel et al., 2015; Hale & Guan, 2015). In contrast to popular belief, and theory (Cain & Gradisar, 2010), sleep latency was not associated with technology use. Only computer use was related to less sleep, with a trend for a decrease in sleep duration also occurring for phone use (Chapter 2; Bartel et al., 2015).

Some of the strongest and most consistent trends found in the meta-analysis were between mobile phone and internet use with adolescents' bedtimes - thus, the time adolescents stopped using these devices in the evening was measured across Australia, Canada and The Netherlands (Chapter 4; Bartel et al., 2016). Either internet or mobile phone use (or both), depending on country, were related to later bedtimes and less sleep, even when controlling for age, gender, tobacco and alcohol use after 6pm, cognitive-emotional sleep hygiene, home environment, parent-set bedtime and after school sports. This suggests that although the particular medium may differ between countries, adolescents who stop using their preferred device later in the evening are likely to have poorer sleep health. Although not measured, it is plausible that adolescents within the same country are communicating to their peers in the evening via a certain method, consistent within a country. For example, Australian and Canadian adolescents may prefer communicating with peers in the evening via the internet (e.g., on a laptop), whereas Dutch adolescents may prefer communicating via text messaging on a phone. This may explain the difference in the strength of relationship between media and countries.

Additionally, a recent meta-analytic review assessing access and use of portable screens by children and adolescents suggested that having access to, or using, portable devices near bedtime, increases the odds of insufficient sleep, and poor sleep quality (Carter et al., 2016). Therefore, portable screens, including mobile phones and devices with internet capabilities, may be risk factors for later adolescent bedtimes and reduced sleep duration. However, studies included in this recent review (Carter et al., 2016), as well as our international survey (Chapter 4; Bartel et al., 2016), were cross-sectional. Likewise, much of the literature included in our meta-analysis (Chapter 2; Bartel et al., 2015) involved cross-sectional research. Thus, evidence for the causal link between technology and later bedtimes was further substantiated through an experimental field investigation (Chapter 5; Bartel, Scheeren, & Gradisar, submitted).

After 1 week of baseline data collection, adolescents were given individual stop times for their mobile phones, 1 hr earlier than their average baseline bedtime. During the intervention week, adolescents reported ceasing phone use 80 min earlier, turning their lights out 17 min earlier, and sleeping 19 min longer. Therefore, evidence is provided that stopping phone use at least 1 hr prior to bedtime can improve sleep. This also adds to the model by Cain and Gradisar (2010), which hypothesised that one mechanism by which pre-bedtime media use leads to sleep problems is through displaced bedtime (Exelmans & Van den Bulck, in press; van den Bulck, 2004). In fact, sleep displacement, through the use of electronic devices, of which mobile phone use is the most common, may be a two-step process (Exelmans & Van den Bulck, in press). Firstly, bedtime (i.e., the time one goes to bed) may be displaced, through technology use. Secondly, the time one turns the lights out, with the intention to sleep, may be further prolonged by the use of technology (Exelmans & Van den Bulck, in press). Therefore, bedtime is not synonymous with lights out time (Exelmans & Van den Bulck, in press). The current experiment supported the idea of the two-step sleep displacement,, as although bedtime was not different between baseline and intervention weeks, it did appear that lights out time (i.e., the time adolescents attempted to sleep), was in fact displaced by pre-bed phone use, and subsequently affected school night sleep duration.

Parent-set bedtime.

Overall, when looking at the relationship between parent-set bedtimes and adolescent sleep duration, without considering other factors, adolescents whose parents set their bedtime obtain more sleep (Fig. 7.1; Chapter 2; Bartel et al., 2015). However, such parent-set bedtime did not mean adolescents unanimously had *earlier* bedtimes. This suggests that adolescents' bedtimes are likely contingent upon other factors (Chapter 2; Bartel et al., 2015).

As shown in Chapter 3 (Bartel, van Maanen et al., submitted), this relationship between earlier bedtimes and parent-set bedtimes appears to hold across countries, after considering age, gender, tobacco and alcohol use, sleep hygiene, and day length. However, when more factors are added into the equation (e.g., screen time), these relationships appear to be less consistent between countries (Chapter 4; Bartel et al., 2016). It may be that age is a stronger predictor of bedtime than parent-implemented bedtime. As adolescents mature, they become more autonomous (Carskadon, 2011; Oudekerk, Allen, Hessel, & Molloy, 2014; Wray-Lake, Crouter, & McHale, 2010), and parents are less likely to manage their older adolescent's bedtime. Thus, it is likely that an increase in age occurs simultaneously with an increase in autonomy (Carskadon, 2011; Oudekerk, Allen, Hessel, & Molloy, 2014; Wray-Lake, Crouter, & McHale, 2010). This means that not only do younger adolescents have fewer activities which compete with bedtime (e.g., homework), their bedtimes are more likely to be monitored by their parents. Thus, age may contribute to the relationship between parent-set bedtimes and sleep.

Moreover, homework, extracurricular activities and paid work did not appear to individually relate to bedtime, sleep latency or sleep duration (Chapter 2; Bartel et al., 2015). Increasing age and academic pressure may coincide with fewer parental boundaries (and thus the option of more evening screen time; Pieters et al., 2014). Consequently, screen time, homework, extracurricular activities and paid work could displace bedtimes when not monitored by parents, or lead to high cognitive-emotional arousal, and therefore long sleep latency and subsequent school night sleep loss. Supporting this possibility, a recent study found that autonomy granted to younger adolescents (M ages = 13.36 & 14.32 years) was not related to time in bed, however, middle-age adolescents (M age = 15.35 years) who were allowed more autonomy had less time in bed (Meijer, Reitz, & Deković, 2016). Moreover, the biological delay in the circadian rhythm throughout adolescent development may mean all these factors interact at once, leaving adolescents prone to poor school night sleep. Consistent across studies in this thesis (Chapters 2 & 3; Bartel et al., 2015; Bartel, van Maanen et al., submitted), adolescents with parent-set bedtimes did not take longer to fall asleep. Thus, in coherence with previous literature, parent-set bedtimes are likely to encourage adolescents to go to bed earlier, and obtain more sleep (Carskadon, 2011; Short et al., 2013), yet, parent-set bedtimes are unlikely in and of themselves to consistently resolve late bedtimes among adolescents. Their benefit would be enhanced through the practice of other protective factors for adolescent sleep health, for example, employing good overall sleep hygiene.

Physical activity.

The relationship between adolescent sleep and participation in physical activity appeared to be complex. On one hand, without considering other factors, physical activity may advance bedtimes and trended towards increasing sleep duration (Fig. 7.1; Chapter 2; Bartel et al., 2015). Similarly, both subjective and objective sleep are related to higher levels of physical activity (Lang et al., 2016). However, it is likely that the timing and duration of exercise influence the relationship between exercise and sleep (Buxton, Lee, L'Hermite-Balériaux, Turek, & Van Cauter, 2003; Richardson, Gradisar, Short, & Lang et al., in press). Timing and duration cannot completely explain this relationship, as after school sports participation was related to earlier bedtimes for Australian adolescents, but not for Canadian or Dutch adolescents, after considering other protective and risk factors (Chapter 4; Bartel et al., 2016). Likewise, after considering other factors, after school sport did not predict sleep duration (Chapter 4; Bartel et al., 2016). Thus, it appears that the mechanisms by which exercise influences sleep extend beyond duration, and may need to specify how close to bedtime exercise is performed, rather than simply “after school” (Richardson et al., in press). Exercise performed between school finishing and early evening may promote earlier bedtimes, whereas exercise later at night may delay bedtimes (Buxton et al., 2003; Richardson et al., in press). Moreover, it is likely that exercise intensity (not measured in this thesis) affects sleep, with higher intensity related to longer sleep duration (Delise, Werch, Wong, Bian, & Weiler, 2010) and shorter sleep latency (Lang et al., 2013). It is still possible, of course, that morning exercise may improve sleep quality, and decrease sleep latency, especially when performed at moderate intensity, for 3 consecutive school weeks (Kalak et al., 2012). Exercise may need to be performed at regular intervals, for example, daily, to alter bedtimes or increase sleep duration (Buxton et al., 2003; Chennaoui, Arnal, Sauvet, & Léger, 2015). Nevertheless, consistent with previous research, our results demonstrated the physical activity did not have a negative influence on adolescents' sleep (Lang et al., 2016).

Overall, it appears that general after school sports participation cannot be recommended as a means by which adolescent sleep health can be improved, without further experimental investigation into the intensity, specific timing, duration and regularity of participation (Irish, Kline, Gunn, Buysse, & Hall, 2015). On the other hand, there were no adverse effects of after school sports participation on adolescent sleep, therefore, exercise at this time of day can be encouraged, to achieve other physical, social, and cognitive rewards (Bauman, 2004; Hallal, Victora, Azevedo, & Wells, 2006).

Light.

Evening light (i.e., screen light, both artificial and natural outdoor and indoor light) was associated with later bedtimes and less sleep (see Fig. 7.1; Chapter 2; Bartel et al., 2015). Conversely, for adolescents residing in countries with different day lengths, shorter day length and thus less evening sunshine, predicted later bedtimes, shorter sleep latency and less sleep, whereas longer day length predicted earlier bedtimes (Chapter 3; Bartel, van Maanen et al., submitted). Shorter *daylight* hours are consistently related to later bedtimes within countries (Borisenkov, 2010; Borisenkov, Perminova, & Kosova, 2010; Borisenkov et al., 2016; Roenneburg & Merrow, 2007), thus our findings expand this knowledge to apply across continents and hemispheres.

Daylight is a stronger regulator of the circadian rhythm than the social clock (Borisenkov et al., 2016; Roenneburg & Merrow, 2007), yet, adolescents may be more vulnerable than adults to the effects of evening light on delaying their circadian rhythm (Borisenkov, 2011). This could result in later bedtimes, and longer sleep latency if attempting sleep too early for the biological clock, and shorter sleep on school days. In another study where adults were exposed to only natural light while camping for 2 weeks, the sunlight they received during the day was brighter than that normally received from indoor, electrical lighting, however, light after sunset was minimal (only from a campfire; Stothard et al., in press; Wright et al., 2013). The increase in light intensity during the day, coupled with a lack of evening light, helped to advance sleep timing (i.e., earlier sleep onset and wake up times; Stothard et al., in press; Wright et al., 2013). Additionally, bright light during the day, such as sun light, diminishes the effects of room light and screen light immediately preceding bedtime, such that bedtime is delayed by evening light to a lesser extent after day time exposure to bright light (Chang, Scheer, & Czeisler, 2011; Zeitzer, 2015; Zeitzer, Friedman, & Yesavage, 2011). Therefore, an increased photoperiod, with brighter intensity light, may moderate the effect of evening light on adolescent sleep. Furthermore, the delay in circadian rhythm observed during a lack of sun exposure may be cured by even 2 hr of sunshine per day (Roenneburg & Merrow, 2007). While an absence of daylight may leave adolescents more vulnerable to the effects of evening light, this delay could be combatted by practicing good sleep hygiene (Chapter 3; Bartel, van Maanen et al., submitted).

Overall, it is possible that a lack of bright sunshine during the day predisposes adolescents to later bedtimes, longer sleep latency and less sleep, possibly due to increased vulnerability to the effects of evening indoor light – from screens or artificial room lighting (Chang et al., 2011; Stothard et al., in press; Wright et al., 2013; Zeitzer, 2015; Zeitzer et al., 2011). When it is not possible for adolescents to obtain adequate sunlight (e.g., when the photoperiod is half-an-hour), good sleep hygiene may be able to decrease the negative ramifications on sleep. To add to Carskadon's (2011) model, bright evening light should be avoided, so that adolescents have the best chance of falling asleep earlier, and sleeping longer. Potentially of equal importance, however, is the *exposure* to bright light, such as sunshine, during the day, to moderate any negative effects of evening light exposure on adolescent sleep health (Chang et al., 2011; Stothard et al., in press; Wright et al., 2013; Zeitzer, 2015; Zeitzer et al., 2011).

Family environment.

A negative family environment was a risk factor for poor sleep – relating to later bedtimes, longer sleep latency and less sleep (Chapter 2; Bartel et al., 2015). In the international survey study, a chaotic household was related to a longer sleep latency for Australian adolescents, but not those from Canada or The Netherlands. It may be that when 'there is often a fuss at home' [5], or adolescents are 'drawn into other people's arguments at home' [5], or other stressful events occur, they may ruminate at bedtime, and thus sleep onset may be impeded (e.g., Guastella & Moulds, 2007; Thomsen, Mehlsen, Christensen, & Zachariae, 2003). Alternatively, if home is a 'good place to relax' [5] and the 'atmosphere…is calm' [5] sleep may be encouraged (Tynjälä, Kannas, Levälahti, & Välimaa, 1999). Yet, even for Australian adolescents, the negative effect of a chaotic home environment was smaller than the positive effect of employing good cognitive-emotional sleep hygiene (Chapter 4; Bartel et al., 2016). In Chapter 4, disorganisation at home was measured, however, potentially, other aspects of a negative family environment were not measured here, such as low parent attachment (Tu, Marks, & El-Sheikh, in press) or family conflict (Yen, Ko, Yen, & Cheng, 2008), which may pose a risk to adolescent sleep health. For example, poor maternal and paternal attachment are correlated with more adolescent sleep-wake problems, yet not sleep duration (Tu et al., in press). Conversely, better quality parent-adolescent relationships, and higher levels of parent monitoring, are both related to earlier bedtimes (Meijer et al., 2016). Moreover, low levels of monitoring are related to shorter time in bed, regardless of relationship quality (although

[5] These items are drawn from the Confusion Hubbub and Order Scale (Matheny, Wachs, Ludwig, & Phillips, 1995), used in Chapter 4.

sleep duration was not measured), whereas the combination of a better quality relationship and more parental monitoring predict longer time in bed (Meijer et al., 2016). Thus, it is possible that family environment does contribute to adolescent sleep, although disorganisation of a household may be of less influence than cognitive-emotional sleep hygiene.

Caffeine.

Meta-analytic data, similar to concurrent review findings, demonstrated the use of caffeine was not associated with bedtime or sleep latency (Chapter 2; Bartel et al., 2015; Bonnar & Gradisar, 2015). Increased caffeine consumption, across cultures, may be related to less sleep (Chapter 2; Bartel et al., 2015; Bonnar & Gradisar, 2015), with this negative relationship more likely to be true particularly for evening caffeine consumption (Chapter 2; Bartel et al., 2015). Among adults, 400mg of caffeine (equivalent to 3.3-6.7 cups of percolated coffee; Food Standards Australia New Zealand, 2015) 0, 3 or 6 hr before bedtime, decreased objective sleep and increased subjective sleep latency (Drake, Roehrs, Shambroom, & Roth, 2013). Most adolescents consume substantially less than this level, at an average of 83mg *per day* (Mitchell, Knight, Hockenberry, Teplansky, & Hartman, 2014), with regular consumers averaging 131mg per day (Aepli, Kurth, Tesler, Jenni, & Huber, 2015). When caffeine use after 6pm was measured in multiple countries, along with many other protective and risk factors, no relationship was found with any sleep variables (Chapter 4; Bartel et al., 2016). Although caffeine undoubtedly has a physiological effect on the body, whereby it increases alertness through the interference of the homeostatic sleep drive (Ribeiro & Sebastiao, 2010), these findings suggest that other factors (e.g., screen stop time) are more strongly associated with adolescent sleep duration (Chapter 4; Bartel et al., 2016). Furthermore, it is possible that the adolescents who consume more caffeine are those trying to compensate for sleep loss, and thus fatigue (Chapter 2; Bartel et al., 2015; Calamaro, Mason, & Ratcliffe, 2009). With increased weekly caffeine consumption, adolescents were more likely to have later bed (Aepli et al., 2015; Fleig & Randler, 2009) and rise times (Fleig & Randler, 2009), higher odds of feel tired in the morning, and having disturbed sleep (Orbeta, Overpeck, Ramcharran, Kogan, & Ledsky, 2006). Yet, timing of consumption was not measured. Although it is possible that that caffeine ingestion disrupts sleep (Orbeta et al., 2006), or inhibits deep sleep at the start of the night, as measured by polysomnography (PSG; Aepli et al., 2015), it is also possible that adolescents who could not sleep well felt more tired throughout the day, and thus consumed higher quantities of daytime caffeine. If this were true, it may mean that the early school start times proposed to shorten sleep (Carskadon, 2011) actually encourage caffeine consumption (Aepli et al., 2015), due to shorter sleep duration on school days and the intention of adolescents to reduce daytime tiredness (Calamaro et al., 2009). Yet, without experimental data, cause and effect of caffeine consumption remains elusive (Chapter 2; Bartel et al., 2015; Bonnar & Gradisar, 2015). Instead, reasons for caffeine consumption should be targeted in future, along with the promotion of healthy sleep habits. The timing and pattern of caffeine use, and its subsequent effects on sleepiness and sleep, should firstly be measured (Aepli et al., 2015; Irish, Kline, Gunn, Buysse, & Hall, 2015), and secondly, experimentally tested. This would allow for interventions to target either the reasons behind use, or the timing of caffeine consumption.

Clinical Implications

One promising aspect resulting from the findings in this thesis (i.e., meta-analysis in Chapter 2; international survey in Chapters 3 & 4), is the identification of simple behavioural changes which can be implemented by adolescents to improve their sleep health. The theoretical knowledge gained here (see Fig. 7.1 for summary) can easily be translated to assist adolescents and those who care for them in a practical sense. Firstly, sleep hygiene strategies consistently demonstrated positive effects on sleep. Overall sleep hygiene encompasses multiple dimensions, namely psychological, behavioural and cognitive-emotional arousal, as well as the sleep environment and sleep regularity (Storfer-Isser, Lebourgeois, Harsh, Tompsett, & Redline, 2013). Simple adjustments to one's pre-bedtime routine which promote physiological de-arousal (e.g., not running around before bed; LeBourgeois, Giannotti, Cortesi, Wolfson, & Harsh, 2005; Storfer-Isser et al., 2013), cognitive and emotional relaxation (e.g., not ruminating on the day's events at bedtime; LeBourgeois et al., 2005; Storfer-Isser et al., 2013), avoiding clock watching (Tang, Schmidt, & Harvey, 2007; Woods, Marchetti, Biello, & Espie, 2009), and ensuring the bedroom is quiet, dark and comfortable (LeBourgeois et al., 2005; Lee & Gay, 2011; Storfer-Isser et al., 2013), are all ways in which adolescent sleep may be improved. Although parent-set bedtimes may not directly and consistently improve adolescent sleep, they may encourage a regular sleep schedule, thus can be seen from that point of view as a way of encouraging good sleep hygiene. Furthermore, shorter daylength contributed in a small manner to poorer sleep health. Daylength is not under behavioural control, yet fortunately, good sleep hygiene is, and appeared to have a stronger relationship with bedtime, sleep latency and sleep duration. Thus, good sleep hygiene can easily be implemented to override the negative effects of shorter daylength. Additionally, physical activity directly before bed constitutes poor sleep hygiene. Alternatively, physical activity *may* advance bedtimes, yet experimental research is needed in order to be able to advise adolescents on the duration and intensity of after school exercise, in order to see benefits on their sleep (Richardson et al., in press).

A disorganised, chaotic family environment appeared to be less influential than the benefits shown from sleep hygiene. Nevertheless, it is necessary to consider other aspects of the home environment which may contribute to poor sleep. Poor relationships and attachment between parents and adolescents can have severe ramifications, especially when they interact with poor sleep (Tu et al., in press). For example, higher than average sleep-wake problems, combined with low parent attachment, decreases self-esteem (Tu et al., in press). Yet, better attachment to mothers and fathers, in conjunction with high sleep efficiency or low sleep-wake problems, decreases the likelihood of anxiety symptoms (Tu et al., in press). Thus, it is important to determine which aspects of the family environment influence sleep, in order to decrease the likelihood of adolescent mental health problems. Using psychological therapy to decrease family conflict or improve parent-adolescent relationships, or suggesting techniques to decrease family disorganisation, may be a way towards experimentally testing the relationships between adolescent sleep and home environment.

Findings from Chapters 2 and 4 suggested good cognitive-emotional sleep hygiene may decrease sleep latency (Bartel et al., 2015; Bartel et al., 2016). Fifteen minutes of nightly mindfulness or constructive worry were explored as interventions, disseminated through schools, to decrease pre-sleep arousal in Chapter 6 (Bartel, Huang et al., submitted). Surprisingly, these interventions were not sufficient to alter pre-sleep arousal, yet, for adolescents with a baseline sleep latency of 30 min or longer, mindfulness decreased sleep latency. Thus, listening to a mindfulness mp3, for 15 min at bedtime, can be considered a protective factor for adolescent sleep. Schools have been suggested as the ideal location from which to provide sleep interventions, as they are able to reach a large group of adolescents simultaneously, and overcome many obstacles usually present when attempting to treat adolescents experiencing difficulty sleeping (Moran & Everhart, 2012). These obstacles include transportation to a clinic to receive specialised sleep therapy, real or perceived social stigma associated with receiving treatment, and therapy costs. Moreover, many adolescents are unaware they could benefit from a sleep intervention, or do not experience sleep difficulties severe enough to warrant formal treatment (Moran & Everhart, 2012; Lovato, Gradisar, Short, Dohnt, & Micic, 2013; Short, Gradisar, Gill, & Camfferman, 2013). Providing strategies to an entire class, such as a mindfulness body scan mp3 file, overcomes these barriers, enabling improvement of sleep latency, even among adolescents who do not realise there is room for improvement.

Moreover, having a “bedtime” for mobile phones (and potentially other electronic devices) 1 hr prior to bedtime, is likely to advance lights out time (Bartel, Scheeren, & Gradisar, submitted; Exelmans & Van den Bulck, in press) and increase sleep duration, by almost 20 min. This is of clinically significant relevance, and able to improve daytime functioning and learning (Dewald-Kaufmann, Oort, & Meijer, 2013). The increase in total sleep time also enabled adolescents to obtain nearly 8 hr per night (7 hr 57 min), which seems to be a crucial tipping point, for example, to achieve efficient daytime working memory (Gradisar, Terrill, Johnston, & Douglas, 2008). However, there is a clear need for clinicians and researchers to focus on adherence and uptake of pre-bed mobile phone use restriction (i.e., of the 243 adolescents approached to participate, only 26% were included in analyses). This may be achieved, for example, through motivational interviewing (Bonnar et al., 2015; Cain, Gradisar, & Moseley, 2011; Gold, & Dahl, 2011; Gradisar, Smits, & Bjorvatn, 2014). Motivational interviewing, previously administered in classroom settings, has been used to enhance motivation to change, and the uptake and commitment to sleep health interventions (Bonnar et al., 2015; Cain et al., 2011). Improvements to behavioural change, such as bedtimes, sleep latency and sleep duration, may be seen when incorporating parental involvement (Bonnar et al., 2015). Therefore, parent involvement when attempting to employ a “bedtime” for technological devices may see improved rates of behaviour change. Alternatively, other strategies to decrease pre-sleep arousal could be used, such as the mindfulness body scan technique.

Caffeine use was not necessarily harmful for adolescent sleep, although evening consumption may be related to less sleep. Caffeine use, particularly in the evening, should be cautioned, at least until experimental investigation can provide evidence to the contrary. To date, there have been no studies in adolescent populations which employ pure experimental designs to test the relationships between caffeine consumption and adolescent sleep (Bonnar & Gradisar, 2015). Similarly, the effects of alcohol and tobacco on adolescent sleep did not appear to be straightforward. On one hand, tobacco use was associated with earlier bedtimes (Chapters 2 & 3; Bartel et al., 2015; Bartel, van Maanen et al., submitted), yet less sleep (Chapter 2; Bartel et al., 2015). On the other hand, alcohol may be related to earlier bedtimes when not taking other factors into account (Chapter 2; Bartel et al., 2015), as well as longer sleep (Chapter 3; Bartel, van Maanen et al., submitted). Regarding sleep, it appears that these substances require experimental investigation to determine true relationships. Nevertheless, from a broader clinical perspective, the negative ramifications on overall adolescent health and behaviour from such substances, such as increased violent and antisocial behaviour, unsafe sexual intercourse, obtaining physical injuries while intoxicated, anxiety and depression, have been described elsewhere (e.g., Bonomo et al., 2001) - thus, it would be unwise for consumption of these substances to be condoned regardless.

Worth noting is that none of the suggested techniques to improve sleep hygiene (i.e., practising mindfulness at bedtime or restricting pre-bed mobile phone use) require specialised training to implement. This is crucial for the easy distribution and administration of information about protective and risk factors for adolescent sleep, and what activities should be encouraged or avoided. Parents, teachers, and adolescents, as well as clinicians and researchers, should easily be able to provide these suggestions to adolescents. In fact, adolescents themselves can contribute to the monitoring of their own sleep health, as well as the implementing of many of the abovementioned strategies.

Finally, individual variability should always be considered from a clinical point of view. For example, the meta-analysis provided no evidence that homework, extracurricular activity and paid work were consistently related to bedtimes, sleep latency or total sleep time. However, there may be some individuals who experience poor sleep due to these factors. Hence, the adolescents' perspective must always be considered during therapy for sleep problems. It needs to be stressed that these research findings are based on large samples, thus for adolescents in the minority who have clinical sleep disorders (e.g., Delayed Sleep Wake Phase Disorder, prevalence estimated between 0.2-16.0%; Micic et al., 2016; Insomnia, prevalence estimated between 4.4-13.4%; Mindell, & Meltzer, 2008), extrapolation of results should be cautioned. For example, using a mindfulness mp3 may provide a small benefit to an adolescent experiencing insomnia, yet they may require more intensive cognitive therapy to deal directly with clinically significant rumination and worry. Nevertheless, integrating the above information into the care of adolescents who do experience clinical sleep disorders is unlikely to cause harm, and if anything, may benefit their sleep.

Limitations and Future Directions

Due to the large sample size, when acquiring data for the pre-sleep arousal experiment (Chapter 6; Bartel, Huang et al., submitted), and the large, multi-national nature of Chapters 3 and 4 (Bartel, van Maanen et al., submitted; Bartel et al., 2016), it was not feasible to obtain objective measurements of adolescents' sleep. The subjective sleep reporting used in these studies is thus subject to measurement error, however, sleep questionnaires and sleep diaries, employed in this thesis, have been validated elsewhere (e.g., Short, Arora, Gradisar, Taheri, & Carskadon, in press; Wolfson et al., 2003). Moreover, actigraphy may not be better than subjective reports of sleep (Short, Gradisar, Lack, Wright, & Carskadon, 2012). Similarly, questionnaire measures throughout the thesis, as well as reporting of intervention completion during the pre-sleep arousal study, were subjective, and may be subject to bias or incorrect reporting. Nevertheless, alpha values were acceptable for all questionnaire data.

In terms of future directions, the field of adolescent sleep health would benefit from further experimental research, to determine cause-and-effect of other factors found to be related to sleep in the meta-analysis, and Chapters 2 and 3 (e.g., caffeine consumption, tobacco use, alcohol use, negative family environment). Concurrent measurement of bioregulatory sleep processes (i.e., circadian rhythm delay and reduced homeostatic sleep pressure), should be considered alongside these behavioural risk and protective factors, due to the large interaction between biology, sleep and the environment (Carskadon, 2011; Crowley et al., 2007; Dahl, & Lewin, 2002; Jenni & O'Connor, 2005). For example, a decline in evening sleep propensity, due to a delay in circadian rhythm and decreased sleep pressure, may interact with evening caffeine consumption and a negative family environment to increase pre-sleep arousal, thus prolonging sleep onset and shortening weekday sleep. However, it is clear that such longitudinal and experimental data, using objective measures of sleep and biology, requires substantial time, energy, resources and funding.

Information regarding pre-bed mobile phone restriction could be incorporated into a sleep health program, which assesses adolescents' motivation to change screen habits, and subsequent sleep. This information can also be incorporated into sleep hygiene instructions (Barber & Cucalon, 2017). Moreover, it is possible the content of mobile phone use is influential on sleep, rather than use *per se*. For example, time spent on social media is related to symptoms of depression, less mindful attention (Baker, Krieger, LeRoy, 2016) and stress (Beyens, Frison, & Eggermont, 2016). Overall and nighttime-specific social media use also predict poor sleep quality (Woods & Scott, 2016). It is possible that online social media, accessible through a variety of devices, such as laptops and tablets, interferes with the natural ability to fall asleep by increasing pre-sleep arousal. Hence, limiting these devices, or allowing them (but restricting internet access), may be an area for experimental exploration. Moreover, the relationships between social media use and depressive symptoms and lack of mindful attention no longer exist after taking into account fear of missing out ('FOMO') - that is, the worry that peers are experiencing social interactions without you (Baker et al., 2016). Consequently, it could be argued that cognitive techniques, such as mindfulness (Kim, Park, & Seo, 2016) or attention bias modification (Milkins, Notebaert, MacLeod, & Clarke, 2016), could be developed as interventions to decrease FOMO. The consequences of social media use on cognitions and subsequent bedtime displacement or prolonged sleep latency could thus be attenuated.

Regarding the use of techniques specific to decreasing sleep latency, future research could further develop 'mindfulness' as a strategy, so that it not only decreases sleep latency, but also pre-sleep arousal. One means of enhancing mindfulness would be through the incorporation of adolescent feedback received during the intervention presented in Chapter 6, such as a more relaxing or soothing voice during the mindfulness mp3 (Bartel, Huang et al., submitted). Attention bias modification, whereby attention is directed away from negative sleep stimuli, effectively decreases sleep latency and pre-sleep cognitive arousal among undergraduate students (Milkins et al., 2016). Developing this technique for adolescents, to dissipate pre-sleep arousal related to FOMO, or other general worries, may also decrease sleep latency and improve sleep.

Conclusion

A vast number of behavioural protective and risk factors, of differing strengths, exist for adolescent weekday bedtime, sleep latency and sleep duration. Broadly speaking, good sleep hygiene is paramount as a protective factor for the sleep of the general adolescent population, across countries (and hemispheres). Sleep hygiene is broad in nature, and consists of a cluster of components. Yet, it may be that some aspects are more pertinent than others, such as decreasing pre-sleep cognitive emotional arousal. Although mindfulness at bedtime was unable to achieve this, it nevertheless successfully decreased the end-point of sleep latency among adolescents who experienced prolonged sleep latency at bedtime, and thus can be considered a useful technique to improve sleep health.

Certainly, the role of technology use should not be overemphasised in its contribution to poor sleep. However, it appears that later mobile phone and internet use, at the very least, are related to later bedtimes, and that ceasing phone use 1 hr before bed advances lights out time and lengthens sleep duration. Potentially, this use is related to the content, rather than the device itself, although this is an area for future exploration.

The field of adolescent sleep health would benefit from future experimental investigations, rather than cross-sectional research, in order to determine causal direction of other behavioural protective and risk factors on adolescent sleep health, thus informing future clinical practice.

Importantly, there is a need to educate adolescents and their caregivers on protective and risk factors pertaining to adolescent sleep, as well as others providing support in educational or therapeutic settings. Not only does this thesis contribute to theoretical knowledge of helpful and harmful relationships between behavioural factors and sleep health, but the findings easily translate into practical knowledge. That is, simple, effective and easily accessible information, which can be distributed to adolescents, caregivers, teachers, and clinicians, directly results from this thesis, and can be used to improve the sleep health of adolescents.

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Appendix A

Supplementary Tables for Chapter 2. Protective and Risk Factors for Adolescent Sleep: A Meta-Analytic Review

Table S2.1. Mean weighted *r* for bedtime and caffeine variables

Variable	Mean weighted *r*	σ_{e^2}	σ_{ρ^2}	*K*
Evening use (33, 34, 38, 7)	-.024	0.004	-.004	4
Energy drinks (58)	.070	0.005	-.005	1
Caffeinated soda (31, 43, 58)	.072	0.005	-.003	3
Coffee/tea (31, 40, 43, 44, 58)	*.100*	*0.002*	*.000*	*5*

Note. σ_{e^2}= sampling error variance; σ_{ρ^2} = variance of population correlations; *K* = number of studies; italicized = risk factors.

Table S2.2. Mean weighted *r* for sleep onset latency and caffeine variables

Variable	Mean weighted *r*	σ_{e^2}	σ_{ρ^2}	*K*
Coffee/tea (31, 40, 43, 44, 58)	-.030	0.002	.002	5
Evening use (33, 34, 38, 7)	-.005	0.004	.002	4
Caffeinated soda (31, 43, 58)	.027	0.005	.008	3
Energy drinks (58)	.152	0.005	-.005	1

Note. σ_{e^2}= sampling error variance; σ_{ρ^2} = variance of population correlations; *K* = number of studies.

Appendix B

Questionnaire Measures

Demographic Information

Age
- ❍ 13
- ❍ 14
- ❍ 15
- ❍ 16
- ❍ 17
- ❍ 18

Gender
- ❍ Male
- ❍ Female

Postcode

City/town

School

School start time

Sleep Patterns

The following questions relate to your sleeping habits, separately for school days and weekends. Think about your sleep in the last two weeks.

	School week days (Sunday to Thursday night)	Weekend nights (Friday-Saturday night)
	Time (AM/PM)	Time (AM/PM)
At what time do you usually go to bed to sleep at night?		
At what time do you usually wake up in the morning?		
At what time do you usually get out of bed in the morning?		

The following questions relate to your sleeping habits, separately for school days and weekends. Think about your sleep in the last two weeks.

	School week days (Sunday to Thursday night)		Weekend nights (Friday-Saturday night)	
	Hours	Minutes	Hours	Minutes
How long does it usually take you to fall asleep?				
Between when you fall asleep and when you wake up in the morning, how long are you awake for in the middle of the night?				
How many hours do you usually sleep?				

Adolescent Sleep Hygiene Scale -Revised

Please indicate how often the following things have happened during the past two weeks
Response options:
Never – has not happened; ***Once in a while*** – happened 20% of the time; ***Sometimes*** – happened 40% of the time; ***Quite Often*** – happened 60% of the time; ***Frequently, if not always*** – happened 80% of the time; ***Always*** – happened 100% of the time

After 6 p.m., I have drinks with caffeine (e.g. cola, pop, root beer, iced tea, coffee)

During the hour before bedtime, I am very active (e.g. playing outside, running, wrestling)

During the hour before bedtime, I drink >4 glasses of water (or some other liquid)

I go to bed with a stomach-ache

I go to bed feeling hungry

During the hour before bedtime, I do things that make me feel very awake (e.g. playing video games, watching TV, talking on the telephone)

I go to bed and do things in my bed that keep me awake (e.g. watching TV, reading)

I use my bed for things other than sleep (e.g. talking on the telephone, watching TV, playing video games, doing homework)

*I go to bed and think about things I need to do

*I go to bed and replay the day's events over and over in my mind

*I check my clock several times during the night

*During the 1 h before bedtime, things happen that make me feel strong emotions (sadness, anger, excitement)

*I go to bed feeling upset

*I go to bed and worry about things happening at home or at school

I fall asleep while listening to loud music

I fall asleep while watching TV

I fall asleep in a brightly lit room (e.g. the overhead light is on)

I fall asleep in a room that feels too hot or too cold

I fall asleep in one place and then move to another place during the night

During the school week, I stay up more than 1 h past my usual bedtime

At weekends, I stay up more than 1 h past my usual bedtime

At weekends, I sleep in more than 1 h past my usual wake time

During the day, I take a nap that lasts >1 h

After 6 p.m., I take a nap

[+]After 6 p.m., I smoke or chew tobacco

[+]After 6 p.m., I drink beer (or other drinks with alcohol)

Note: *denotes items in the Cognitive Emotional Sleep Hygiene subscale
[+] Not part of ASHS-R total score

Parent-set Bedtime

My parents set my bedtime

	Never	Almost never	Sometimes	Regularly	Often	Almost always	Always
Weekdays	❍	❍	❍	❍	❍	❍	❍
Weekends	❍	❍	❍	❍	❍	❍	❍

Sleep Reduction Screening Questionnaire

All questions refer to the previous two weeks.

	No	Sometimes	Yes
1. Do you have trouble getting up in the morning?	❍	❍	❍
2. Do you feel sleepy during the day?	❍	❍	❍
3. Are you immediately wide awake when you wake up?	❍	❍	❍
4. When I am at school for a while I have trouble keeping my eyes open	❍	❍	❍
5. Do you have enough energy during the day to do everything?	❍	❍	❍

6. I am active during the day
❍ Agree
❍ Partly agree
❍ Do not agree

7. I have to struggle to stay awake in class
❍ Never
❍ Once in a while
❍ Often

8. I don't feel like going to school because I feel too tired
❍ This never happens
❍ This happens once a week
❍ This happens more than twice a week

9. I am a person who does not get enough sleep
❍ Agree
❍ Partly agree
❍ Do not agree

Confusion Hubbub and Order Scale Items Used in Chapter 4.

Please indicate you have felt at home during the last two weeks.

	Always	Frequently	Sometimes	Rarely	Never
Our home is a good place to relax	❍	❍	❍	❍	❍
There is very little commotion in our home	❍	❍	❍	❍	❍
I often get drawn into other people's arguments at home	❍	❍	❍	❍	❍
There is often a fuss going on at our home	❍	❍	❍	❍	❍
The atmosphere in our home is calm	❍	❍	❍	❍	❍

Extracurricular Activities -Adapted from School Sleep Habits Survey

Think about the last two weeks.

During the last two weeks, did you work at a job for pay?
- ❍ Yes
- ❍ No

How many hours did you work at your paying job per week?

	Hours	Minutes
During the school week before school		
During the school week after school		
During the weekend in the morning		
During the weekend in the afternoon		

During the last two weeks, did you do any organized sports or a regularly scheduled physical activity?
- ❍ Yes
- ❍ No

What kind of sport or activity?

How many hours did you practice per week?

	Hours	Minutes
During the school week before school		
During the school week after school		
During the weekend in the morning		
During the weekend in the afternoon		

During the last two weeks, did you participate in organised extracurricular activities? [For example, committees, clubs, volunteer work, musical groups, religious groups, etc.]

❍ Yes
❍ No

How many hours did you participate per week?

	Hours	Minutes
During the school week before school		
During the school week after school		
During the weekend in the morning		
During the weekend in the afternoon		

During the last two weeks, did you study/do homework outside of school hours?

❍ Yes
❍ No

How many hours did you study per week?

	Hours	Minutes
During the school week before school		
During the school week after school		
During the weekend in the morning		
During the weekend in the afternoon		

Weekday Technology Use Questionnaire

On the average week night (Sunday – Thursday night) how much time do you spend on each of the following, after 6PM? (indicate response in hours and minutes). If you do not use a device, respond with "0."

	Hours	Minutes
Television		
Mobile phone (NOT including internet on mobile phone, includes checking text messages for short periods of time		
Computer (other than internet use)		
Internet (including internet use on desktop, laptop, tablet and mobile phone)		
Playing video games		
Wii or other electronic games involving movement		

Please indicate the time you start using each device on the average weeknight (Sunday-Thursday night).

	Hour												Minute												AM/PM		I do not use this device
	1	2	3	4	5	6	7	8	9	10	11	12	00	05	10	15	20	25	30	35	40	45	50	55	AM	PM	
Television	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Mobile phone	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Computer	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Internet	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Video games	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Wii / Kinect / PS Move	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Please indicate the time you stop using each device on the average weeknight (Sunday-Thursday night).

	Hour												Minute												AM/PM		I do not use this device
	1	2	3	4	5	6	7	8	9	10	11	12	00	05	10	15	20	25	30	35	40	45	50	55	AM	PM	
Television	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Mobile phone	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Computer	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Internet	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Video games	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Wii / Kinect / PS Move	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

On average, how many of the above activities do you do each week night, after 6PM?

❍ 0
❍ 1
❍ 2
❍ 3
❍ 4
❍ 5
❍ 6

On average, for weeknights, which of the above devices are you using at the same time, after 6PM? (please list).

Weekday Evening Room Lighting

Think about the room you spent the most time in after 6PM, over the last two weeks, during the week (i.e., Sunday night – Thursday night). What type of light do you use? (mark as many as applicable)

- ❑ Dim overhead light
- ❑ Bright, fluorescent light
- ❑ Bright desk lamp
- ❑ Dim lamp

Please indicate the time you start using each type of light on the average weeknight (Sunday-Thursday night).

	Hour												Minute												AM/PM		I do not use this light
	1	2	3	4	5	6	7	8	9	10	11	12	00	05	10	15	20	25	30	35	40	45	50	55	AM	PM	
Dim overhead light	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Bright, fluorescent light	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Bright desk lamp	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Dim lamp	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Please indicate the time you stop using each type of light on the average weeknight (Sunday-Thursday night).

	Hour												Minute												AM/PM		I do not use this light
	1	2	3	4	5	6	7	8	9	10	11	12	00	05	10	15	20	25	30	35	40	45	50	55	AM	PM	
Dim overhead light	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Bright, fluorescent light	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Bright desk lamp	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Dim lamp	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

School Attendance

How many days in the past 2 weeks did you attend school?

❍ 1
❍ 2
❍ 3
❍ 4
❍ 5
❍ 6
❍ 7
❍ 8
❍ 9
❍ 10

Perseverative Thinking Questionnaire – Child Version

Please rate how often the following have happened for you over the past week while trying to fall asleep at night.

	Never	Almost Never	Sometimes	Often	Almost Always
The same thoughts keep going through my mind again and again	❍	❍	❍	❍	❍
My thoughts come on and I can't do anything against it	❍	❍	❍	❍	❍
I can't stop thinking about it	❍	❍	❍	❍	❍
I think about many problems without solving any one of them	❍	❍	❍	❍	❍
I can't do anything else while thinking about my problems	❍	❍	❍	❍	❍
The same thoughts return into my mind	❍	❍	❍	❍	❍
Thoughts come into my mind without me wanting them to	❍	❍	❍	❍	❍
When I am thinking about certain things, I get stuck and	❍	❍	❍	❍	❍

find it difficult to stop these thoughts					
I keep asking myself questions without finding an answer	❍	❍	❍	❍	❍
My thoughts prevent me from focusing my attention on other things	❍	❍	❍	❍	❍
I keep thinking about the same things all the time	❍	❍	❍	❍	❍
Thoughts just pop into my mind	❍	❍	❍	❍	❍
I feel as if I must keep thinking about the same things	❍	❍	❍	❍	❍
My thoughts are not much help to me	❍	❍	❍	❍	❍
My thoughts take up all my attention	❍	❍	❍	❍	❍

Evaluation of Brief Self-help Interventions Used in Chapter 6. Brief School-Based Interventions to Assist Adolescent Sleep: Comparing Mindfulness and Constructive Worry versus Controls

Click to write the question text

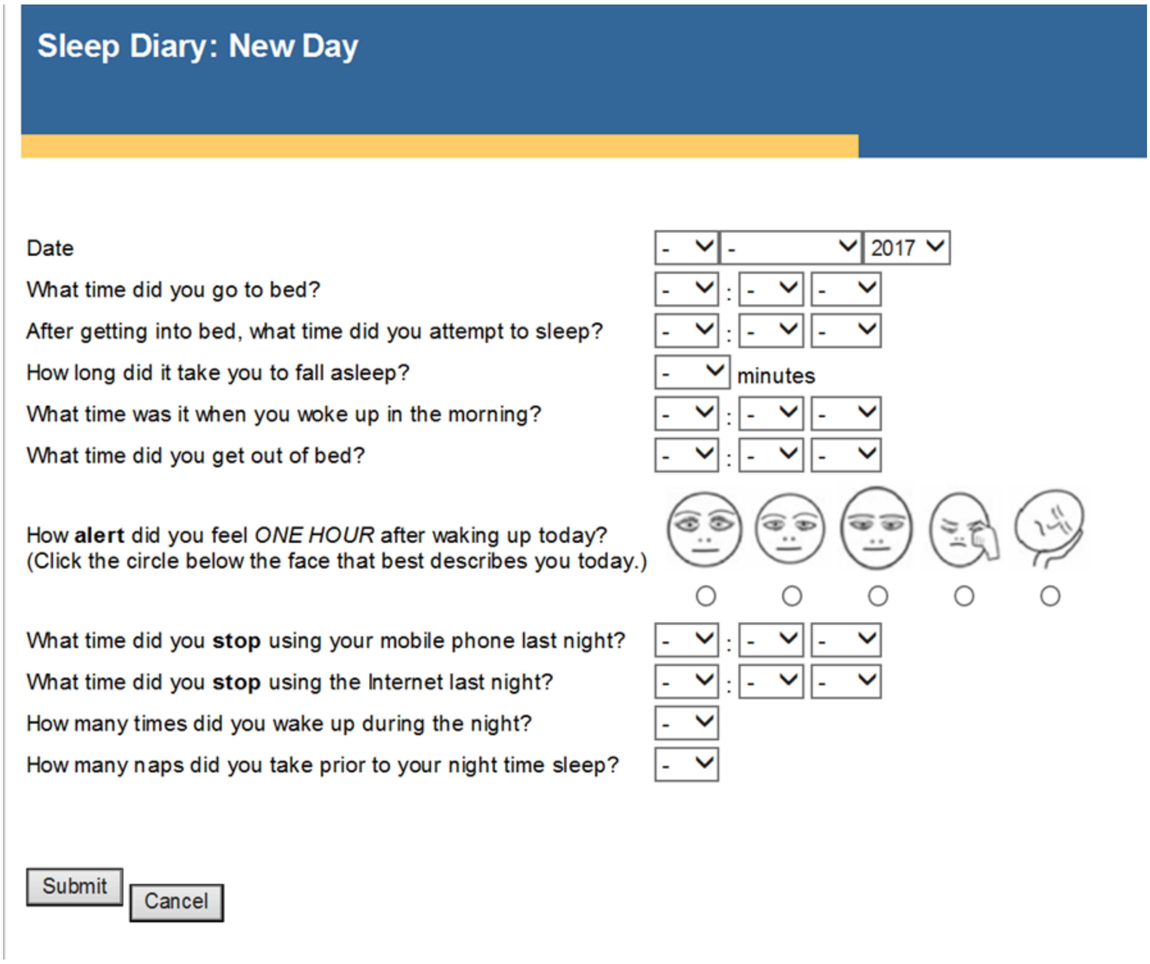
After doing the self-help evaluation my problems falling asleep have..
- ❍ Improved a Lot
- ❍ Improved a Bit
- ❍ Stayed the Same
- ❍ Got Worse

My overall impression of the self-help intervention is that it was..
- ❍ Highly Effective
- ❍ Somewhat Effective
- ❍ Neither Effective nor Ineffective
- ❍ Ineffective

Based on your experiences doing this intervention, what are your suggestions for improving this intervention?

On how many nights did you do the intervention during the past week?
- ❍ 0
- ❍ 1
- ❍ 2
- ❍ 3
- ❍ 4
- ❍ 5
- ❍ 6
- ❍ 7

Screen Shot of Sleep Dairy Used in Chapter 5. Altering Adolescents' Pre-bedtime Phone Use to Achieve Better Sleep Health



Sleep Diary: New Day

Date	- / - / 2017
What time did you go to bed?	- : - -
After getting into bed, what time did you attempt to sleep?	- : - -
How long did it take you to fall asleep?	- minutes
What time was it when you woke up in the morning?	- : - -
What time did you get out of bed?	- : - -
How **alert** did you feel *ONE HOUR* after waking up today? (Click the circle below the face that best describes you today.)	○ ○ ○ ○ ○
What time did you **stop** using your mobile phone last night?	- : - -
What time did you **stop** using the Internet last night?	- : - -
How many times did you wake up during the night?	-
How many naps did you take prior to your night time sleep?	-

Submit Cancel

Appendix C

Supplementary Tables from Chapter 4. Protective and Risk Factors Associated with Adolescent Sleep: Findings from Australia, Canada and The Netherlands

Table S4.1. Correlation Matrix Between Sleep Variables and Protective and Risk Factors for Australian Adolescents

	BT	SOL	TST	Age	Gender	Mobile	Internet	Cog. arousal	Caffeine	Home	Sports	Functioning	Tobacco	Alcohol	Parent-set BT
BT		(.03)	(<.01)	(<.01)	(.57)	(<.01)	(<.01)	(<.01)	(<.01)	(<.01)	(<.01)	(<.01)	(<.01)	(<.01)	(<.01)
		321	316	322	323	122	172	322	323	294	272	244	323	323	299
SOL	.12*		(<.01)	(.14)	(.63)	(.93)	(<.01)	(<.01)	(.11)	(<.01)	(.89)	(<.01)	(.97)	(.60)	(.56)
			316	322	323	123	173	322	323	294	272	244	323	323	299
TST	-.59*	-.18*		(<.01)	(.048)	(<.01)	(<.01)	(<.01)	(<.01)	(<.01)	(<.01)	(<.01)	(<.01)	(.17)	(<.01)
				317	318	120	171	317	318	290	269	241	318	318	294
Age	.27*	-.08	-.18*		(.95)	(<.01)	(<.01)	(.97)	(.95)	(.32)	(.05)	(.12)	(.07)	(<.01)	(<.01)
					324	123	174	323	324	295	273	245	324	324	300
Gender	.03	.03	-.11*	.003		(.11)	(.32)	(<.01)	(.80)	(.01)	(.14)	(<.01)	(.90)	(.35)	(.66)
						123	174	324	325	296	274	246	325	325	301
Mobile	.47*	.01	-.29*	.29*	-.15		(<.01)	(.16)	(.23)	(.34)	(.84)	(.12)	(.36)	(.04)	(.30)
							118	123	123	123	122	107	123	123	123
Internet	.69*	.22*	-.53*	.32*	.08	.40*		(<.01)	(.08)	(<.01)	(.12)	(<.01)	(.09)	(.03)	(<.01)
								174	174	174	174	149	174	174	174
Cog. arousal	-.23*	-.32*	.33*	.002	-.31*	-.13	-.24*		(<.01)	(<.01)	(.59)	(<.01)	(<.01)	(<.01)	(.67)
									324	296	273	245	324	324	300

Caffeine	.16*	.09	-.18*	.004	-.01	.11	.13	-.19*		(.28)	(.81)	(<.01)	(.01)	(<.01)	(.32)
										296	274	246	325	325	301
Home	.22*	.24*	-.20*	.06	.143*	.09	.22*	-.41*	.06		(.13)	(<.01)	(<.01)	(<.01)	(.08)
											273	243	296	296	293
Sport	-.25*	.01	.25*	-.12	-.09	-.02	-.12	.03	-.01	-.09		(<.01)	(.03)	(.22)	(.38)
												236	274	274	272
Functioning	.41*	.29*	-.42*	.10	.28*	.15	.33*	-.51*	.22*	.35*	-.24*		(.03)	(.51)	(.21)
													246	246	243
Tobacco	.26*	-.002	-.22*	.10	-.01	.08	.13	-.15*	.15*	.26*	-.13*	.14*		(<.01)	(.01)
														325	301
Alcohol	.22*	.03	-.08	.27*	-.05	.19*	.17*	-.15*	.25*	.27*	-.08	.04	.41*		(<.01)
															301
Parent-set BT	-.23*	-.03	.22*	-.37*	-.03	-.09	-.27*	.02	-.06	-.10	.05	-.08	-.15*	-.19*	

Note. Alcohol= alcohol use after 6pm where 1=no, 2=yes BT = weekday bedtime, Caffeine = caffeine use after 6pm, Cog. arousal = pre-sleep cognitive emotional arousal as measured by the Adolescents Sleep Hygiene Scale- Revised, Functioning = daytime functioning as measured by the Sleep Reduction Screening Questionnaire, Gender: male =1 female =2, Home = home environment as measured by the Confusion Hubbub and Order Scale; Internet = weekday internet stop time, Mobile = weekday mobile phone stop time, SOL = weekday sleep onset latency, sports = duration of sports activities after school, tobacco = tobacco use after 6pm where 1=no, 2=yes, TST= weekday total sleep time. *Indicates significance at $p<.01$

Bottom left of table represents r values. Top right of table represents (p) and N

Table S4.2. Correlation Matrix Between Sleep Variables and Protective and Risk Factors for Canadian Adolescents

	BT	SOL	TST	Age	Gender	Mobile	Internet	Cog. arousal	Caffeine	Home	Sports	Functioning	Tobacco	Alcohol	Parent-set BT
BT		(.01)	(<.01)	(<.01)	(.01)	(<.01)	(<.01)	(<.01)	(.01)	(.03)	(.83)	(<.01)	(.01)	(.07)	(<.01)
		191	188	192	192	93	125	191	192	168	164	171	192	192	173
SOL	.18*		(<.01)	(.18)	(.09)	(.68)	(.09)	(<.01)	(.02)	(.34)	(.84)	(<.01)	(.22)	(.95)	(.15)
			188	192	192	93	125	191	192	168	164	171	192	192	173
TST	-.62*	-.31*		(<.01)	(.01	(.15)	(<.01)	(<.01)	(.27)	(<.01)	(.56)	(<.01)	(.12)	(.28	(.13)
				189	189	92	124	188	189	166	162	169	189	189	171
Age	.21*	-.10	-.25*		(.03)	(.08)	(.35)	(.93)	(.07)	(.61)	(.64)	(.02)	(.09)	(<.01)	(<.01)
					193	93	125	192	193	169	165	172	193	193	174
Gender	.18*	.12	-.18*	.16*		(.80)	(.25)	(<01)	(.72)	(.01	(.77)	(<01)	(.93)	(.33)	(.08)
						93	125	192	193	169	165	172	193	193	174
Mobile	-.35*	-.04	.15	.18	-.03		(<.01)	(.73)	(.18)	(.80)	(.80)	(.68)	(.85)	(.57)	(.94)
							89	92	93	93	91	93	93	93	93
Internet	.54*	.15	-.31*	.08	.10	-.44*		(.12)	(.08)	(.06)	(.74)	(.03)	(.58)	(.20)	(.06)
								124	125	125	123	125	125	125	125
Cog. arousal	-.36*	-.36*	.41*	-.01	-.29*	-.04	-.14		(<.01)	(<.01)	(.64)	(<.01)	(.19)	(.61	(.20)
									192	168	165	171	192	192	173

Caffeine	.18*	.17*	-.08	-.13	-.03	-.14	.16	-.36*		(.11)	(.96)	(.09)	(<.01)	(.71)	(.98)
										169	165	172	193	193	174
Home	.17*	.07	-.23*	.04	.19*	.03	.17	-.31*	.12		(.18)	(<.01)	(.98)	(.20)	(.21)
											165	169	169	169	169
Sport	-.02	-.02	.05	-.04	-.02	.03	-.03	-.04	.004	-.11		(.05)	(.78)	(.14)	(.85)
												165	165	165	165
Functioning	.35*	.30*	-.44*	.18*	.32*	-.04	.19*	-.41*	.13	.35*	-.15*		(.89)	(.07)	(.01)
													172	172	172
Tobacco	.19*	.09	-.11	.12	-.01	-.02	.05	-.09	.25*	.002	-.02	.01		(<.01)	(.19)
														193	174
Alcohol	.13	.004	-.08	.27*	.07	-.06	.12	-.04	.03	.10	.11	.14	.32*		(.04)
															174
Parent-set BT	-.26*	.11	.12	-.35*	-.13	-.01	-.17	.10	.00	-.10	.02	-.20*	.10	-.16*	

Note. Alcohol= alcohol use after 6pm where 1=no, 2=yes BT = weekday bedtime, Caffeine = caffeine use after 6pm, Cog. arousal = pre-sleep cognitive emotional arousal as measured by the Adolescents Sleep Hygiene Scale- Revised, Functioning = daytime functioning as measured by the Sleep Reduction Screening Questionnaire, Gender: male =1 female =2, Home = home environment as measured by the Confusion Hubbub and Order Scale; Internet = weekday internet stop time, Mobile = weekday mobile phone stop time, SOL = weekday sleep onset latency, sports = duration of sports activities after school, tobacco = tobacco use after 6pm where 1=no, 2=yes, TST= weekday total sleep time. *Indicates significance at $p<.01$.

Bottom left of table represents r values. Top right of table represents (p) and N

Table S4.3. Correlation Matrix Between Sleep Variables and Protective and Risk Factors for Dutch Adolescents

	BT	**SOL**	**TST**	**Age**	**Gender**	**Mobile**	**Internet**	**Cog. arousal**	**Caffeine**	**Home**	**Sports**	**Functioning**	**Tobacco**	**Alcohol**	**Parent-set BT**
BT		(.03)	(<.01)	(<.01)	(.26)	(<.01)	(<.01)	(.92)	(.84)	(.86)	(.06)	(<.01)	(.23)	(<.01)	(<.01)
		148	149	149	150	99	100	148	150	141	139	141	150	150	143
SOL	-.17*		(.08)	(.29)	(.63)	(.15)	(.97)	(<.01)	(.14)	(.03)	(.11)	(.03)	(.12)	(.82)	(.06)
			147	147	148	98	99	146	148	139	137	139	148	148	141
TST	-.70*	-.14		(<.01)	.48)	(<.01)	(<.01)	(.33)	(.91)	(.89)	(.30)	(<.01)	(.98)	(.10)	(.01)
				148	149	98	99	147	149	140	138	140	149	149	142
Age	.61*	-.09	-.46*		(.33)	(<.01	(<.01)	(.45	(.16)	(.72)	(.61)	(.01)	(.32)	(<.01)	(<.01)
					149	99	100	147	149	140	138	140	149	149	142
Gender	-.09	-.04	.06	.08		(.34)	(.048)	(.01)	(.14)	(.07)	(.70)	(.95)	(.71)	(.55)	(.07)
						99	100	148	150	141	139	141	150	150	143
Mobile	.60*	.15	-.49*	.39*	-.10		(<.01)	(.09)	(.91)	(.23)	(.33)	(<.01)	(.07)	(<.01)	(.01)
							93	98	99	99	99	99	99	99	99
Internet	.58*	.004	-.41*	.31*	-.20*	.55*		(.75)	(.08)	(.55)	(.25)	(<.01)	(.62)	(.10)	(.14)
								99	100	100	100	100	100	100	100
Cog. arousal	.01	-.27*	.08	-.06	-.21*	-.17	.03		(.24)	(<.01)	(.58)	(<.01)	(.93)	(.30)	(.35)
									148	139	137	139	148	148	141
Caffeine	-.02	.12	-.01	-.12	-.12	-.01	.18	-.10		(.70)	(.58)	(.62)	(.61)	(.12)	(.55)

										141	139	141	150	150	143
Home	-.02	.19*	.01	-.03	.15	.12	.06	-.32*	.03		(.40)	(<.01)	(.29)	(.84)	(.17)
											139	141	141	141	141
Sport	.16	-.14	-.09	.04	.03	.10	.12	-.05	-.05	-.07		(.55)	(.01)	(.23)	(.47)
												139	139	139	139
Functioning	.29*	.18*	-.31*	.23*	.01	.37*	.35*	-.31*	.04	.27*	-.05		(.47)	(.04)	(.93)
													141	141	141
Tobacco	.01	.13	.002	.08	-.03	.19	.05	-.01	.04	.09	-.23*	.06		(.01)	(.86)
														150	143
Alcohol	.29*	-.02	-.14	.34*	-.05	.35*	.17	-.09	.13	.02	.10	.17*	.22*		(.15)
															143
Parent-set BT	-.37*	.16	.23*	-.41*	-.15	-.27*	-.15	.08	.05	.12	-.06	.01	.01	-.12	

Note. Alcohol= alcohol use after 6pm where 1=no, 2=yes BT = weekday bedtime, Caffeine = caffeine use after 6pm, Cog. arousal = pre-sleep cognitive emotional arousal as measured by the Adolescents Sleep Hygiene Scale- Revised, Functioning = daytime functioning as measured by the Sleep Reduction Screening Questionnaire, Gender: male =1 female =2, Home = home environment as measured by the Confusion Hubbub and Order Scale; Internet = weekday internet stop time, Mobile = weekday mobile phone stop time, SOL = weekday sleep onset latency, sports = duration of sports activities after school, tobacco = tobacco use after 6pm where 1=no, 2=yes, TST= weekday total sleep time. *Indicates significance at $p<.01$

Bottom left of table represents r values. Top right of table represents (p) and N

Appendix D

Information Sheet Used in CHAPTER 5. Altering Adolescents' Pre-bedtime Phone Use to Achieve Better Sleep Health

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INFORMATION SHEET

Title: 'Switching off before bed: Pre-bed mobile phone use among adolescents'

Investigators:
Mrs Kate Bartel
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Supervisor(s):
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Description of the study:
This study is part of the project entitled '*Switching off before bed: Pre-bed mobile phone use among adolescents'.* This project will investigate mobile phone use on adolescent sleep. This project is supported by Flinders University School of Psychology.

Purpose of the study:
This project aims to find out how much mobile phones use in the evenings affects adolescents' sleep.

What will participants be asked to do?
Participants will be asked to complete questionnaires and a sleep diary, for two weeks. Each morning, participants will need to complete information about their sleep. This will be done online, and should take no more than 5 minutes each morning. Sleep information may be entered in the afternoon if necessary, however, the morning is preferred, as that is when memory of when you slept is most accurate. If allowed by the school, it may be completed during homegroup.

In the second week, we will ask participants to use their mobile phone differently from usual. If a participant does not have a mobile phone at home, they will be asked to complete the week as usual, and still complete the sleep diary. They will still be able to attend an information session about sleep, after all data has been collected.

For participants with smart phones, they will be asked to download a free application (e.g., Screen On/Off Logger Lite for Android) that records when the phone screen was turned on. Each morning, the participant will be asked to take a screen shot of the application page, and email it to the researcher. These images will be deleted immediately by the researcher, after they have recorded the compliance of the participant. No personal phone activity information will be stored. The app only shows the duration of any screen "on" time, and does not show any other activity. Participants may delete the app from their phone, after data collection, if they wish. Participants with a 'non-smart' mobile phone will still be able to participate, without taking a screen shot.

Participants will also be asked to complete some additional questionnaires, on 2 occasions. This should take no more than 10 minutes at any one time. Participants will be offered a $20 gift voucher at the end of their participation for their time.

What benefit will I gain from being involved in this study?
As adequate sleep is essential for daily functioning, improving adolescents' sleep would beneficial for them.

The project will also be a learning experience for the students, into how research can be conducted. This will assist in their year 11/12 research project.

Will I be identifiable by being involved in this study?
Classmates and teachers may be aware who within the class is participating, however, no information collected will be linked directly to you. All data will be stored on a password protected computer, and only the researchers will have access. No participants will be identified in any resulting publications/thesis.

Are there any risks or discomforts if I am involved?
There are no foreseeable risks associated with participation in this study. Although not anticipated, if you feel your sleep has worsened, you can contact the Child and Adolescent Sleep Clinic via email casc.enquiries@flinders.edu.au or by phone 8201 7587. An information session will be held after data has been collected, which will include tips for sleeping well. Participants are within their right to withdraw from the study at any stage, if they experience any unexpected negative effects.

How do I agree to participate?
A consent form accompanies this information sheet. If the student DOES NOT wish to participate, please ensure that you return this form to the class teacher. If you do not return this form, you are implying consent for your child to participate. Alternatively, you may email/phone the class teacher, researcher, if you decline for your child to participate. In additionally, students will be asked to complete a consent form on the first day of the study, if they DO want to participate.

Participation is voluntary. Participants may answer refuse to answer any questions and are free to withdraw from the study at any time without effect or consequences.

How will I receive feedback?
Information about the study will be given to students in a classroom setting, after the study has ended.

Thank you for taking the time to read this information sheet and we hope that you will accept our invitation to be involved.

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project number 6793). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by email human.researchethics@flinders.edu.au