Investigation into Pre-Bedtime Technology Use to Improve Adolescent Sleep

by

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Bachelor of Psychology (Honours)

Thesis submitted to Flinders University for the degree of Doctor of Philosophy (Clinical Psychology)

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24/01/2023

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SUMMARY

Many public health recommendations suggest that technology devices should not be used in the 1-hour before bed. However, it is no secret that the use of technology is ubiquitous in the lives of modern-day adolescents, where electronic media use is occurring not only before getting into bed, but also while in bed before attempting to sleep. Previous research has shown that curtailing evening technology use for even just 1-hour per school night, is difficult for adolescents to achieve - despite the positive effects that reducing technology use may have on their sleep. Therefore, this PhD sought to explore factors that could help adolescents reduce their pre-sleep technology use for just 1-hour on school nights.

In the first study, it was found that certain devices and apps were associated with positive or negative sleep outcomes. Specifically, phones, laptops, gaming consoles, and YouTube were associated with less sleep on school nights, while watching TV was associated with *more* sleep. In the second study, parent-set technology rules were found to be a protective factor for adolescent sleep, where even just having a rule was linked to earlier bedtimes. However, adolescents' compliance to their parent-set technology rules mattered when it came to obtaining more total sleep time (TST) on school nights. In addition, adolescents who experienced higher levels of Fear of Missing Out (FoMO) and/or Bedtime Procrastination (BtP) were more likely to report negative sleep outcomes compared to those who reported lower levels of these traits.

The final study involved a 1-week intervention where phone, YouTube, and TikTok use were instructed to be ceased 1-hour earlier on school nights. To assist adolescents with this, a face-to-face motivational session was delivered, where suggestions to students were made for both technology and non-technology activities to "switch" to during this 1-hour (based on the findings of Study 1). In addition, parents were asked to support their adolescents with the intervention (based on the findings of STUDY 2). Results indicated that this appeared to be a feasible intervention for adolescents, with adolescents reporting that they stopped using their phones ~58 minutes earlier during the intervention week. However, no significant changes in sleep outcomes were observed (increase of ~12 minutes of TST at post intervention approached significance p =.08). Despite these promising outcomes, it was observed that uptake and adherence remain to be barriers to adolescents completing technology restriction interventions. The results of this thesis present an intricate account of links between adolescent evening technology use and sleep, emphasising the major role parent-set technology rules play in protecting adolescent sleep, and provide additional evidence for the possible benefits of interventions that target evening technology use.

DECLARATION

I certify that this thesis:

1) does not incorporate without acknowledgement any material previously submitted for degree or diploma in any university
2) and the research within will not be submitted for any other future degree or diploma without the permission of Flinders University; and
3) 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.

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ACKNOWLEDGEMENTS

There are many people I would like to thank that have made finishing this PhD and the last 8-9 years of study enjoyable. Firstly, I would like to thank my long-term university partner of 9 years- Han aka the Hare. We have shared many moments together from travelling overseas, office chocolates and coffee, client/study debriefs, significant life events (the good and the bad), some occasional stress tears, but thankfully many more laughs. Thanks for helping the Turtle stay organised and on track towards graduation. This journey would not have been the same without your ongoing support, and I cannot imagine having done all these hours of study, research, and clinical training without you. I am truly grateful for our friendship that resulted from all this studying, and I am certain we'll be friends for a lifetime.

Secondly, to MG aka the Wise Owl- thank you x100 for all your support and guidance over these past 6-7 years. You have been the best mentor and teacher a Turtle could ever ask for. You have shown me that serious work can also be fun and played a huge role in making this PhD and clinical training journey enjoyable. You have taught me to dream big and work hard, but to never take yourself too seriously. Thanks for your ongoing generosity with your time spent sharing your knowledge and dedication to supporting all of us. Especially, your patience with me answering all my maths questions a thousand times. As we know, the Turtle always gets there eventually.

To Mika aka the Grasshopper- your presence and guidance here the last few years was truly a blessing. You somehow always made a hectic workload and wearing so many different hats look effortless. I cannot thank you enough for how much time you have spent helping me (and Han and everyone else) with data analyses, editing, clinical practice guidance, all the life chats, and just everything else! I will forever admire your enduring patience, strong work ethic, and holistic approach to everything you do, and hope that moving forwards I can one day approach everything in life as gracefully as you do.

To the broader CASC team- our ongoing weekly meetings and team banter is something I always enjoy and continue to learn from. Our supportive and fun team environment is truly wonderful. I hope our team continues to grow, learn, and kick goals for many years to come. Also, to my fellow Clin PhD students- it has been a pleasure learning alongside and supporting each other.

Special thanks to Tash, Re, and Iv for the study chats, debriefs, and helping me with my stats and IT struggles. I cannot wait to see where all our future careers take us.

A big thank you to my friends and family. To Dad, Mum, Tom, and Jack, thank you for your efforts occasionally trying to understand my PhD/uni studies. Thanks for supporting me over 9 years of studying post high school which allowed me to pursue my career goals. A special mention also goes to Eddie- thanks for all the walks, hugs, and always brightening my mood when I need it most. A big thank you to Corbyn, especially over these last few months. I appreciate your calmness, advice, and emotional support always, but even more so during this final stretch. To my friends, I appreciate the ongoing encouragement and attempts to try and understand my degree and its commitments.

Finally, I would like to thank the Australian Government Research Training Program Scholarship for the support financial assistance provided throughout my PhD, and all the adolescents and families who spent time participating in my research.

LIST OF MANUSCRIPTS, PUBLICATIONS, AND CONFERENCE PROCEEDINGS

Pillion, M., Gradisar, M., Bartel, K., Whittall, H., Mikulcic, J., Daniels, A., Rullo, B., & Kahn, M. (2022). Wi-Fi off, devices out: do parent-set technology rules play a role in adolescent sleep?. *Sleep medicine: X*, *4*, 100046.

Pillion, M., Gradisar, M., Bartel, K., Whittall, H., & Kahn, M. (2022). What's "app"-ning to adolescent sleep? Links between device, app use, and sleep outcomes. *Sleep Medicine* (in press).

Pillion, M., Whittall, H., Bartel K., Kahn, M., Gradisar, M. (2019). What apps?: Technology and (restricted) sleep in adolescents. *Sleep Medicine, 64:*S302.

CHAPTER 1

INTRODUCTION TO ADOLESCENT SLEEP AND TECHNOLOGY USE

Adolescence and sleep

Adolescence is a unique period of human development that represents the transition from childhood to adulthood (Jaworska & MacQueen, 2015). Typically, adolescence is thought to span from the age of 12 to 18 years, and marks a time of biological (i.e., hormonal and physical changes that accompany puberty), and social changes (e.g., spending more time with peers, increased autonomy from caregivers; Jaworska & MacQueen, 2015). During this time, many normal biological and social changes in sleep also occur (Colrain & Baker, 2011), leading to some researchers to conclude that the end of adolescence may be around 20 years of age (Roenneberg et al., 2004). The complex interplay between these biological and psychosocial factors often results in insufficient sleep during this developmental period (Crowley et al., 2018).

The National Sleep Foundation states that the recommended amount of sleep most adolescents need to function at their best is between 9-11 hours for 12- and 13-year-olds, and between 8-10 hours for 14- to 17-year-olds (Hirshkowitz et al., 2015). This is in line with laboratory studies that have found adolescents will often sleep for 9 or more hours a night when provided the opportunity to sleep as long as they need to (Carskadon et al., 1980). A more recent dose-response modelling study suggested the average sleep need for adolescents is approximately 9 hours and 18 minutes (Short et al., 2018). Yet, despite most adolescents requiring at least 9+ hours of sleep per night, an overwhelming number of adolescents worldwide regularly obtain less than 8 hours of sleep (Gariepy et al., 2020; Gradisar, Gardner, et al., 2011; Wheaton et al., 2018). In fact, one study suggests adolescent sleep has declined by 75 minutes per night on average over the last 103 years (Matricciani et al., 2012). This is concerning, given the significant consequences of sleep loss during this developmental period.

Consequences of adolescent sleep loss

The consequences of this sleep loss include, but are not limited to, impaired academic performance and compromised cognitive abilities (Perez-Lloret et al., 2013; Shochat et al., 2014; Spruyt, 2019), increased risk of motor vehicle accidents (Pizza et al., 2010), a compromised immune system (Orzech et al., 2014), negative mood states (e.g., depressed, angry, anxious; Booth et al., 2020;

Gangwisch et al., 2010; Gradisar et al., 2022; Short et al., 2020), and increased risk taking and sensation seeking across domains such as drug and alcohol use, smoking, violent/delinquent behaviour, sexual risk taking, and more (McKnight-Eily et al., 2011; Owens et al., 2017; Short & Weber, 2018). This is concerning for adolescents as many are studying at school, learning to drive, and undergoing many growth changes in their biological and social development (Owens & Adolescent Sleep Working Group, 2014). In fact, a number of adolescents have reported difficulty staying awake during the day (alarmingly this includes when driving a car), with some falling asleep at school, or even missing school due to oversleeping (Calamaro et al., 2009; National Sleep Foundation, 2006; Pizza et al., 2010). For some teenagers, combating daytime sleepiness has led to an increase in caffeine consumption (Calamaro et al., 2009), or sleeping-in on the weekends and school holidays to catch-up on lost sleep (Shochat et al., 2014). Given the highly adverse consequences of sleep deprivation, determining which factors are significantly contributing to this sleep loss is of utmost importance.

Why are adolescents not receiving enough sleep?

In recent years, it has been proposed that a combination of biological, psychosocial, and environmental factors interact over the course of this developmental stage, creating a “perfect storm” of insufficient sleep for adolescents (Carskadon, 2011; Crowley et al., 2018). This complex interaction of biological, psychosocial, and environmental factors is depicted in Figure 1 (Crowley et al., 2018). This review will now expand on some of these factors in more depth.

Figure 1: The updated "Perfect storm" model from Crowley et al. (2018); first developed by Carskadon (2011).

<This image has been removed due to copyright restriction. Available online from: Crowley, S. J., Wolfson, A.R., Tarokh, L., & Carskadon, M.A. (2018). An update on adolescent sleep: New evidence informing the perfect storm model. Journal of adolescence, 67, 55-65>

Biology of adolescent sleep

Sleep in humans is theorised to be regulated by two biological systems that undergo changes over the course of adolescence (Crowley et al., 2018). The two-process model of sleep regulation conceptualises sleep as consisting of a homeostatic sleep-wake pressure system (Process S), and a circadian timing system (Process C) that interact to determine sleep duration and timing (Borbély, 1982). The circadian timing system consists of many different approximate 24-hour daily rhythms (e.g., alertness, sleepiness, body temperatures, hunger) that are regulated by the suprachiasmatic nucleus inside the hypothalamus of the human brain (Czeisler et al., 1999; Gradisar & Lack, 2004). Melatonin, a hormone secreted from the pineal gland in the brain that responds to light and dark cues, is also an expression of the timing of the circadian system (Cajochen et al., 2003). Our circadian clocks send signals from our brains governing alertness and sleepiness levels across the 24-hour day, irrespective of prior sleep/wake duration (Crowley et al., 2007; Czeisler et al., 1999). On the other hand, the homeostatic sleep-wake pressure system (i.e., Process S) refers to a bi-directional relationship with sleep/wake duration, where sleep homeostatic pressure (i.e., desire to sleep) builds as wakefulness is extended over time, and wakefulness is desired following a period of adequate sleep (Borbély, 1982; Crowley et al., 2018; Taylor et al., 2005).

During adolescent development, many biological changes to sleep occur, including changes in sleep architecture, circadian timing, and sleep homeostasis (Becker et al., 2015; Crowley et al., 2018). Delays in circadian timing (Process C) are common during the teenage years, where the 24-hour sleep phase shifts towards later timing (Gradisar et al., 2022; Hagenauer et al., 2009). Research has corroborated that this delay can be attributed to intrinsic biological processes, as circadian phase delays have also been observed in juvenile non-human mammals (e.g., rats; Hagenauer et al., 2009; Melo et al., 2016; Nelson et al., 2013). For Process S, studies have demonstrated that sleep pressure in pubertal adolescents builds slower compared to pre-or early pubertal adolescents, giving older adolescents the ability to withstand increasing sleep pressure, leading to a delay in sleep onset (Jenni et al., 2005; Nelson et al., 2013; Taylor et al., 2005). However, evidence from other research suggests the rate at which sleep pressure dissipates does not change (Borbély, 1982; Crowley et al., 2018). Regardless, the combination of these bioregulatory processes explains why adolescents often shift towards an evening preference (Becker et al., 2015). This is typically observed as staying up and falling asleep later, which appears to be one of the key contributing factors to weekend phase delays (i.e., social jetlag), where many adolescents sleep-in on weekends to “catch-up” on sleep lost during the week (Becker et al., 2015). Optimal sleep is thought to occur when the circadian and homeostatic biological systems are synchronised, however this balance is often disturbed by some of the psychosocial and contextual factors that contribute to adolescent sleep (Becker et al., 2015).While biology is one aspect likely to be contributing to the “perfect storm” of insufficient sleep in this age group, sleep homeostasis and circadian timing will not be a focus of this thesis.

Psychosocial and societal factors associated with adolescent sleep

Beyond biology there are various other important factors that have been found to influence adolescent sleep patterns. These can include school start times, academic pressure, extracurricular commitments, part-time employment, family and peer relationships, bedtime autonomy, mental health, technology use, and also changes in health behaviours such as exploring substances and ‘coming of driving age’ (Becker et al., 2015; Crowley et al., 2018; de Zambotti et al., 2018; Zhou et al., 2021). For example, a meta-analysis that investigated both protective and risk factors for adolescent sleep concluded that good sleep hygiene appeared to be a protective factor for sleep, while a negative home environment and evening light exposure appeared to be risk factors (Bartel et al., 2015). This meta-analysis highlighted that parent-set bedtimes, physical activity, and delayed school start times were also possible protective factors, while technology, caffeine, tobacco, and alcohol should be treated with caution as they may be negatively related to sleep (Bartel et al., 2015). While all factors are arguably important, this review will now focus on some key modifiable environmental factors, such as school start times, bedtime autonomy, and technology use. Later, this review will focus further on the evening technology use of adolescents.

School start times

School start times are arguably a major contributor to this “perfect storm” forecasting sleep loss in adolescents (Crowley et al., 2018). Adolescents’ biology that tends to favour a later sleep onset and wake time is often incompatible with school commitments that tend to favour an early morning wakeup (e.g., 6:30 a.m. in many districts in the USA; Nahmod et al., 2019). In recent years, the American Academy of Sleep Medicine released a statement advising that middle or high school should start no earlier than 8:30 a.m. to accommodate for adolescents’ evening preference (Watson et al., 2017). This was informed by research that has compared varying school start times in the United States from 06:00-11:05 a.m., and found adolescents starting school at 08:30 a.m. or later, received more sleep compared to their peers with earlier school start times (Nahmod et al., 2019). In fact, a systematic review found that when school start times were delayed by 25-60 minutes, the number of minutes school was delayed by seemed to correspond with the number of minutes of additional sleep received per weeknight (i.e., 25-77 minutes of extra sleep; Minges & Redeker, 2016). Aside from receiving more sleep, later school start times have also been associated with less lateness and daytime sleepiness, improved safety and academic performance, and positive impacts on health, such as reduced caffeine use and improvements in mood (Minges & Redeker, 2016; Watson et al., 2017).

A recent study that investigated the effects of remote learning on sleep during COVID-19 found that adolescents reported a longer sleep duration of ~22 minutes, waking ~ 43 minutes later, less daytime sleepiness, and fewer anxiety symptoms, compared to their sleep during in-person learning (Stone et al., 2021). This is echoed by a similar study that found students reported waking up 2.0-2.9 hours later during school closures, averaging closer to their recommended sleep need on school nights (i.e., 7.9-8.7 hours of sleep; Weingart et al., 2021). However, it should be noted that unless under extreme circumstances (such as school closures during the COVID-19 pandemic; Weingart et al., 2021), many adolescents are still not quite receiving the minimum 8 hours of sleep per night (Hirshkowitz et al., 2015), even for those whose average school start time was 08:57 a.m. (Nahmod et al., 2019).

Despite the evidence that has demonstrated the benefits of delayed school start times, the move towards adopting this in schools worldwide has been met with much resistance (Fitzpatrick et al., 2021). Many school administrators and policy makers have had reservations about delaying school start times, citing several barriers such as school-based athletes missing more afternoon classes to attend or travel to games, difficulty co-ordinating the school bus transportation system, less after school time for athletic activities, and family members and/or teachers being resistant to change the schedule (Fitzpatrick et al., 2021). After many years of research and promotion for the "Start School Later" campaign, California finally introduced legislation that required public school districts to start school no earlier than 8:00 a.m. for middle schools, and 8:30 a.m. for high schools (Ziporyn et al., 2022). While this bill received attention both across the US and internationally around the world, policymakers in other US states and international countries are still yet to implement their own legislations protecting the sleep health of adolescents (Ziporyn et al., 2022). Although school start times are a significant contributor to the "perfect storm" of adolescent sleep loss, policy making will remain to be a factor outside of adolescents' control. As a result, other contributing factors should be the focus of interventions for adolescent sleep.

Technology use: devices and device content

Technology or device use has been identified as one prevalent pre-bedtime activity that could be an intervention target to improve adolescent sleep (Bartel et al., 2019). Compared to the last century, and even earlier in the 21st century, device development and internet accessibility has changed rapidly and often outpaced research capacity (Twenge et al., 2017). A review of the literature in 2010 on sleep and electronic media in school-aged children and adolescents, found that the use of electronic media appeared to have negative associations with sleep, such as delayed bedtimes and reduced sleep duration (Cain & Gradisar, 2010). The authors of this review developed a model proposing various mechanisms (i.e., media use displacing sleep, arousal, screen light and circadian rhythms, age, and parental involvement) by which media use was presumed to affect adolescent sleep (Figure 2; Cain & Gradisar, 2010). Since then, two meta-analyses and a systematic review have investigated the relationship between technology use and adolescent sleep (Bartel et al., 2015; Carter et al., 2016; Hale & Guan, 2015). Bartel et al. (2015) found technology (other than television) may be negatively related to sleep, and should thus be used cautiously. Hale and Guan (2015) included 67 studies between 1999-2014 and found screen time was adversely associated with sleep outcomes (i.e., shorter sleep duration and delayed sleep timing were indexed in 90% of studies). Carter et al. (2016) reviewed 20 studies between 2011 and 2015 and found a consistent association between bedtime media use and inadequate sleep duration, poor sleep quality, and excessive daytime sleepiness. Television, however, appeared to be the one technological device that was not associated with such outcomes (Bartel et al., 2015; Carter et al., 2016; Hale & Guan, 2015; Twenge et al., 2017). Longitudinal data have also suggested that electronic media might be contributing to shortened sleep duration (Mazzer et al., 2018; Twenge et al., 2017). Taken together, these studies have suggested computer use, video games, mobile devices, and "unspecified screen time" are most consistently related with adverse sleep outcomes (i.e., later bedtimes, reduced sleep duration, and increased daytime sleepiness; Bartel et al., 2015; Carter et al., 2016; Hale & Guan, 2015; Twenge et al., 2017).

While it is evident the relationship between sleep and device use has been studied enough to constitute meta-analyses and a systematic review (Bartel et al., 2015; Carter et al., 2016; Hale & Guan, 2015), less is known about the specific content and applications engaged with on these devices - or in other words the relationship between *how* devices are being used and adolescent sleep outcomes. In addition, while public recommendations exist to cease device use "1 hour before bed" (e.g., Breus, 2022b; raisingchildren.net.au, 2020b; Sleep Foundation, 2022b, 2022c; Sleep Health Foundation, 2016), one recent systematic review stated that there remains a lack of research measuring electronic media use at bedtime or during the night (Lund et al., 2021). The timing of device use and device content engaged in is arguably important to investigate (e.g., use in the hour before bed versus use in bed), as the increase in bedtime autonomy observed during adolescence, might lead to an increase in the use of electronic devices in bed, or even during the night (Lund et al., 2021). This thesis will address this gap in the literature by presenting evidence regarding the use of devices and device content (i.e., apps) at two distinct time points (i.e., use in the hour before bed and use in bed before sleep onset) in **CHAPTER 2**.

Figure 2: Model by which electronic media use may affect sleep, first proposed by Cain and Gradisar (2010).

<This image has been removed due to copyright restriction. Available online from: Cain, N. & Gradisar, M. (2010). Electronic media use and sleep in school-aged children and adolescents: A review. Sleep medicine, 11(8), 735-742>

Testing the mechanisms by which technology use may affect sleep

In the modern day, technology use has expanded well beyond video gaming, television, and desktop computers. Adolescents today are engaging with a wide range of technology devices, such as mobile phones, laptops, and tablets/iPads. In 2017, a revision of the Cain and Gradisar (2010) model was proposed by Bartel and Gradisar (2017), updating some of the mechanisms linking technology and sleep (Figure 3). Some of these mechanisms and moderating factors are shared across both models, while an extra mechanism (i.e., sleep disrupted by technology presence/use) and moderating factors (i.e., habituation, flow, risk-taking) have been added (Bartel & Gradisar, 2017). Concluding with similar remarks to Cain and Gradisar (2010) and other research (Bartel et al., 2015; Carter et al., 2016; Hale & Guan, 2015; Lund et al., 2021), Bartel and Gradisar (2017) stated that there remains a need for experimental studies to determine cause and effects between the mechanisms by which technology use is proposed to affect adolescent sleep. They also concluded that future research should consider the protective factors of sleep, such as parental involvement and interventions to reduce technology use (Bartel & Gradisar, 2017). Consequently, this thesis will present a study on parent-set technology rules in **CHAPTER 3** and parental involvement supporting a technology restriction intervention in **CHAPTER 4**.

Figure 3: Updated model of mechanisms by which technology use may affect sleep by Bartel and Gradisar (2017), originally proposed by Cain and Gradisar (2010).

<This image has been removed due to copyright restriction. Available online from: Bartel, K., & Gradisar, M. (2017). New directions in the link between technology use and sleep in young people. Sleep disorders in children, 69-80>

Of the experimental research that has been conducted, the vast majority has focused on the effects of video gaming on adolescent sleep (Higuchi et al., 2005; Ivarsson et al., 2009, 2013; King et al., 2013; Reynolds et al., 2015; Smith, King, et al., 2017; Weaver et al., 2010). As gaming is arguably more of an active versus passive form of device use (i.e., frequently interacting by touching the screen or using a remote to interact with the screen versus passive observation where little input is required such as TV; Bartel & Gradisar, 2017; Gradisar et al., 2013; Weaver et al., 2010), many of these studies sought to test the mechanism of physiological arousal seen in Figure 3 (Higuchi et al., 2005; Ivarsson et al., 2009, 2013; King et al., 2013; Weaver et al., 2010). While three of these studies did find some evidence to support an increased heart rate and extension of sleep onset latency (SOL; Higuchi et al., 2005; Ivarsson et al., 2009, 2013), two did not (King et al., 2013; Weaver et al., 2010). It is also worth noting that even for those studies that found SOL extensions, these were not meaningful increases in SOL (e.g., 2.3 minute delay as measured by polysomnography; Bartel &

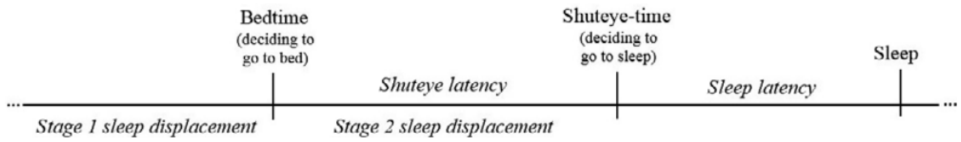
Gradisar, 2017). Consequently, it appears there is not consistent evidence to support that gaming leads to an increase in physiological arousal, and subsequently impacts on adolescents' ability to fall asleep.

The mechanisms of emotional and mental arousal have also been tested with video gaming. One study investigated the possible effects of game difficulty on cognitive arousal (i.e., a hard versus easy game difficulty), but found no significant differences between game condition and bedtime (Smith, King, et al., 2017). King et al. (2013) investigated gaming 'dose' by comparing a short versus long gaming condition (i.e., 50 mins vs 150 mins), and found prolonged gaming was linked to decreased sleep efficiency and less total sleep time compared to the short gaming condition. However, no differences were found between groups on physiological measures, suggesting that another mechanism might better explain these findings. Weaver et al. (2010) investigated the effects of an active versus passive activity (i.e., violent video game versus watching an animal documentary, respectively) to test the arousal hypothesis. They found cognitive alertness was higher in the video gaming group compared to the passive documentary group, however similar to King et al. (2013), no differences in physiological arousal (i.e., heart rate) were found between groups (Weaver et al., 2010). Taken together, this evidence supports the notion of cognitive arousal as a mechanism by which technology use may affect sleep. These two studies (King et al., 2013; Weaver et al., 2010) suggest that perhaps duration of technology use, or engaging in an active versus passive technology activity might also explain part of the link between adolescent sleep and technology use.

Another mechanism that has been tested with experimental research is bright light from screens and its capacity to delay circadian rhythms. Two experimental studies found bright screen light for 2-5 hours did show some effects on the secretion of melatonin (Cajochen et al., 2011; Wood et al., 2013). However, sleep was not measured in these studies (Cajochen et al., 2011; Wood et al., 2013). Since then, laboratory studies that have investigated the effects of screen light, and have found no effects on sleep (Duraccio et al., 2021; Heath et al., 2014; Higuchi et al., 2005; Van der Lely et al., 2015), despite evidence that it may attenuate the rise in melatonin (Cajochen et al., 2011; Van der Lely et al., 2015; Wood et al., 2013), or increase pre-sleep alertness (Cajochen et al., 2011; Heath et al., 2014; Van der Lely et al., 2015). One study (in counterbalanced design) did find a meaningful delay in circadian timing by 1.5 hours where participants either read a brightly lit e-book or printed book under dim light for 5 hours for 5 days (Chang et al., 2015). While they found a meaningful delay in circadian timing (~90 minute delay), and found melatonin was suppressed in the brightly lit e-book condition, the effects found on sleep were minimal (e.g., increase in SOL by 10 minutes; Chang et al., 2015). Taken together, while screen light may have some effects on melatonin or alertness, the evidence seems to suggest that this may not be the strongest mechanism influencing the relationship between technology use and adolescent sleep.

Finally, *sleep displacement,* first conceptualised by Van den Bulck (2010), is another mechanism suggested in the Cain and Gradisar (2010) model by which technology use is presumed to effect sleep. Sleep displacement describes the idea that technology use affects sleep whereby time spent using electronic media leads to later bedtimes and shorter sleep duration (Cain & Gradisar, 2010; Van den Bulck, 2010). More recently, sleep displacement has been theorised to be a two-step process, whereby bedtime (i.e., getting into bed) is separated and distinguished from "shut-eye" time (i.e., the time one attempts to sleep once in bed), depicted in Figure 4 (Exelmans & Van den Bulck, 2017). Exelmans and Van den Bulck (2017) found that participants in their study were mainly using technology before bedtime, and that after respondents went to bed, they spent a further ~39 minutes per night on devices before attempting sleep. This study highlighted that with the introduction of portable electronic media, bedtime and sleep are no longer synonymous, and that the bed and bedroom are now spaces for not just sleeping, but also to engage in other media driven activities (Exelmans & Van den Bulck, 2017). It also highlighted the need to ensure this modern-day sleep process is measured in future research, as arguably the intention to sleep should be directly asked, as the "sleep-attempt time" can no longer be assumed to be synonymous with bedtime or lights out time (Exelmans & Van den Bulck, 2017).

Figure 4: Process of two-step sleep displacement as proposed by Exelmans and Van den Bulck (2017).



Technology and sleep interventions

To test the mechanism of sleep displacement, there has been limited experimental research, most of which has instructed participants to cease device use at a certain time or earlier than usual to reduce the possible effects of sleep displacement (Bartel et al., 2019; Dunican et al., 2017; Harris et al., 2015; Perrault et al., 2019). An "electronic curfew" has been suggested as a possible intervention to improve adolescent sleep, as this mechanism proposes technology use could be directly competing with sleep time, especially when rise times are stable for school. Harris et al. (2015) randomised adolescent athletes into one of two groups, one with direct instructions to cease electronic media use from 10:00 p.m. each night, and the other group with no restrictions on their electronic media use. Contrary to expectations, they found no improvement in sleep habits for the electronic media restriction group (Harris et al., 2015). Another study compared two groups of judo athletes, one where electronic devices were removed for a period of 48 hours, and the other group with no technology restrictions (Dunican et al., 2017). Similarly, they observed no significant differences in sleep onset or sleep duration compared to the control group (Dunican et al., 2017). Both authors concluded that using a sample of athletes with arguably already acceptable sleep routines was a noticeable limitation that may have precluded significant effects to be seen in sleep between the two groups (Dunican et al., 2017; Harris et al., 2015). For example, the pre-intervention bedtimes of participants in Harris et al. (2015) were ~10:00 p.m. prior to the intervention, thus an electronic curfew of 10:00 p.m. may have been not early enough to capture any differences in sleep in this group.

In a similar study, Bartel et al. (2019) investigated the effects of an individualised 1-week pre-bedtime mobile phone restriction intervention on adolescent sleep outcomes. After one week of personalised mobile phone restriction, adolescents stopped using their phone on average 80 minutes earlier, turned out their lights approximately 17 minutes earlier, and gained on average 21 minutes more sleep each night (Bartel et al., 2019). These results indicate that one week of mobile phone restriction was enough to incite a meaningful extension of sleep (i.e., an extra 1 hour and 45 minutes across the week; Bartel et al., 2019). This 21-min increase in sleep per school night is promising when compared to the 48-min and 28-min increases from more intensive 8-week clinical interventions or 4-week school-based sleep interventions, respectively (Bonnar et al., 2015; Gradisar, Dohnt, et al., 2011).

While it might seem that this intervention would work well for adolescents who do not already have well established sleep routines like the athletes in Harris et al. (2015) and Dunican et al. (2017), there remains one prominent similarity that stands out in all three of these studies – adolescents consistently demonstrated low motivation to change technology use. In Harris et al. (2015), of the 45 participants in the intervention group, 10 dropped out, 27 deviated from the protocol at least once or up to 4 times, with only 7 fully adhering to the experiment protocol. Bartel et al. (2019) also experienced low compliance, and participant recruitment was even lower. Almost half of the participants (48%) had missing data during the intervention week, and of the 243 adolescents initially contacted, 98 gave consent, but only 63 made it to the final analyses (i.e., 26% completion; Bartel et al., 2019). Five participants in the device restriction group in Dunican et al. (2017) were excluded from the final analyses because they had obtained electronic devices during the 48-hour restriction period from the participants in the control group. What is interesting about the non-compliance in this group, is that participants were allowed to self-select which group they wanted to be part of in this study, perhaps indicating some intrinsic motivation to improve their sleep - yet perhaps parting with devices was too difficult (Dunican et al., 2017). This idea of device use being difficult to change is also echoed in Harris et al. (2015) and Bartel et al. (2019), where adolescents appeared unmotivated or unwilling to comply with an electronic curfew, even when the curfew might be almost the same as their current bedtime (Harris et al., 2015), or when only 1 device is restricted for just 60 minutes earlier than usual (Bartel et al., 2019)

Taken together, this evidence suggests that an electronic curfew, when adhered to, could improve sleep, but that future research might need to incorporate a motivational component to help adolescents adhere to the intervention to receive possible sleep benefits. To the best of the author's knowledge, only one study has investigated the effects of an electronic curfew paired with a 40-min educational workshop aimed at increasing motivation (Perrault et al., 2019). However, it is unclear exactly what this workshop included (Perrault et al., 2019). While improvements in sleep were found (i.e., advanced lights out times, sleep onset time, and increased sleep duration) for those who completed the intervention, this study also experienced significant drop out following the instruction of an electronic curfew from 9:00 p.m. (i.e., 569 participants at the workshop and who received the electronic curfew instructions, with only 183 completing; Perrault et al., 2019). It is also hard to know whether the workshop component worked, as this drop out could also potentially be explained by participant burden (i.e., 4 weeks of measures including actigraphy, sleep and activities diary, vigilance task and 5 saliva samples for melatonin; Perrault et al., 2019). While motivation is one factor, perhaps there are other intrinsic factors, such as individual characteristics, that are referred to in the Bartel and Gradisar (2017) model in Figure 3 (e.g., traits) that might moderate or mediate the relationship between technology use and adolescent sleep.

Individual traits that may moderate the association between technology use and sleep

Low motivation has been identified as a seemingly significant barrier to adolescents succeeding with a technology intervention such as restricting their phone use for 1-hour before bed. However, it is suggested that there may be certain adolescents who find it harder to make this behavioural change than others.

Flow and risk taking

Flow and risk taking are highlighted in the Bartel and Gradisar (2017) model in Figure 3 as possible moderating factors in the relationship linking technology and sleep. Flow and risk-taking have, again, been explored within the video gaming literature (Reynolds et al., 2015; Smith, Gradisar, et al., 2017). Flow in the gaming literature has been described as "game immersion", where research found adolescents high in “trait” flow (i.e., the likelihood of an individual to experience complete immersion when engaging in an activity) chose later bedtimes when playing a challenging game (Smith, King, et al., 2017). Higher flow states and increased accessibility predicted significantly longer gaming that led to later bedtimes (Smith, Gradisar, et al., 2017). Moreover, during adolescence, risk-taking and reward sensitivity tend to increase, which could also potentially explain adolescents' desire to continue using technology past recommended bedtimes (Reynolds et al., 2015). Reynolds et al. (2015) found that adolescents who perceived more consequences of risk-taking were more likely to stop video gaming and choose earlier bedtimes compared to those who perceived fewer consequences of risk-taking. While these traits are important moderating factors to be aware of in this area of research, the present thesis will focus on investigating some other individual traits.

Bedtime procrastination

Since 2017, other individual characteristics have emerged in the literature that are arguably relevant to device use, such as bedtime procrastination (BtP) and Fear of Missing Out (FoMO). Bedtime procrastination (BtP), defined as failing to go to bed at the intended time with no external circumstances preventing one from doing so, was first found to be associated with insufficient sleep-in adults (Kroese et al., 2014; Kroese et al., 2016). This finding was then replicated in Polish adolescents, with the addition that evening type adolescents also had a greater tendency to delay bedtimes (Kadzikowska-Wrzosek, 2020). More recently, it was found adults with higher BtP spent significantly more time engaging in media use 3 hours before bedtime (i.e., 61 minutes more time per day on their phone) compared to a low BtP group (Chung et al., 2020). When first coined, BtP was also found to be negatively associated with self-regulation (Kroese et al., 2014). This is supported by Exelmans and Van den Bulck (2021) who were the first to study the concepts of self-control, electronic media use (i.e., TV watching) and bedtime procrastination together. They found lower levels of trait self-control (i.e., those who struggle to resist short-term gratification over long-term goals) were associated with more bedtime procrastination, and more temptation to engage in television viewing in the evening (Exelmans & Van den Bulck, 2021). While this novel study provided the first insights into how these mechanisms may be linked, device use other than television, was not considered and sleep was not an outcome measure (Exelmans & Van den Bulck, 2021). Additionally, most of the research in the BtP literature thus far has focused on adults (Chung et al., 2020; Exelmans & Van den Bulck, 2021; Kroese et al., 2014; Kroese et al., 2016). Consequently, this thesis aims to address these gaps in the research by investigating the moderating role BtP might have on adolescent sleep outcomes given their age group's affinity to engage with multiple electronic devices (other than just television).

Fear of missing out

Fear of Missing Out (FoMO) is another individual characteristic emerging in the sleep and technology literature. FoMO can be defined as a general state of anxiety at missing out on rewarding experiences that often contributes to social media engagement (Przybylski et al., 2013). Scott and Woods (2018) propose that FoMO is a driving factor towards late night social media use that leads to delayed bedtime, but also that FoMO drives an increase in cognitive arousal, thus delaying sleep onset. The recent research in this area has found that in adolescents, night-time social media use has been found to be associated with later bedtimes, increased pre-sleep cognitive arousal, longer sleep onset latency, and less total sleep time (Scott & Woods, 2018). In addition, those with higher FoMO reported using social media for longer despite recognising they should be asleep, had shorter total sleep time, and poorer sleep quality (Scott et al., 2021). Adolescents reported in a qualitative systematic review that they recognised media use as a potential problem and barrier to adequate sleep (MacKenzie et al., 2022). They described habitual phone use (e.g., an urge to 'check' their phone) as a barrier to separating themselves from their phones at bedtime, and also feeling responsible for participating in social media communication (MacKenzie et al., 2022). It is possible that FoMO could be another moderating factor in the technology and sleep model (Figure 3). The author argues that these two individual factors (i.e., BtP and FoMO) and how they might link to sleep outcomes, is important to investigate given the increase in risk-taking and reward sensitivity in adolescence (Reynolds et al., 2015), combined with the expansive range of media options on offer to adolescents in a 24/7 connected world. Therefore, the present thesis also aims to add to the growing evidence-base for how BtP and FoMO relates to adolescent sleep (findings presented in **CHAPTER 3**).

Parent-set rules vs sleep and device autonomy

While intrinsic factors might make it more difficult for some adolescents to change their evening technology use, we should also consider the role of *extrinsic* motivators. Over the course of adolescence, autonomy is represented through the gradual freedom from childhood dependence on others and the development of self-regulation, and self-motivation towards becoming largely independent (Zimmer-Gembeck & Collins, 2008).While acknowledging this period represents a transition towards self-reliance, parents still have an important role to play. A recent meta-analysis supports this notion, and views parental involvement as a practical and promising approach to help adolescents achieve better sleep (Khor et al., 2020). Parents are a sensible suggestion as not only are they usually invested in the wellbeing of their adolescents, but their proximity to their adolescents places them in a key position to encourage, monitor and support their adolescent's adherence to healthy sleep behaviours (Khor et al., 2020). This notion appears to be endorsed by adolescents. In a recent qualitative study, adolescents expressed that parent support (e.g., warmth, engagement, and setting routines) was helpful for their own sleep (Jakobsson et al., 2022).

This review by Khor et al. (2020) showed that most of the research on parental involvement in sleep has focused on parent-set bedtimes. A solid evidence base has emerged over the last decade in support of parent-set bedtimes as a protective factor for adolescent sleep (Bartel et al., 2015; Khor et al., 2020). Parent-set bedtimes have been associated with earlier bedtimes, longer sleep duration, less daytime sleepiness/fatigue, some possible advancement of circadian timing, and overall better sleep quality (Bartel et al., 2015; Khor et al., 2020; Short et al., 2011). This evidence remained consistent during the COVID-19 pandemic where parent-set bedtimes were still found to be associated with earlier bedtimes and longer sleep duration during school closures (Weingart et al., 2021). There is even evidence that parent-set bedtimes may help to protect against depressive symptoms (Gangwisch et al., 2010; Peltz et al., 2019). However, much less is known about the effects of parent-set technology rules and sleep, where, as highlighted in a recent meta-analysis, there is not yet a "sound" evidence base (Khor et al., 2020)

In the modern family, parent-set technology rules have come to exist in households over the last decade alongside the rapid development of portable technology such as smart phones (Buxton et al., 2015). The limited evidence-base thus far suggests parent-set technology rules – where access to devices or the internet is restricted - could be protective for adolescent sleep. Such rules have been associated with less time spent on devices (Toh et al., 2019), earlier bedtimes, longer time in bed (Khor et al., 2020; Pieters et al., 2014), and increased total sleep time (Buxton et al., 2015; Charmaraman et al., 2021). There is also evidence to suggest that parental regulation can help to reduce time spent playing video games (Smith, Gradisar, et al., 2017). Despite this, there is also some contradictory evidence that found parental control of technology use or an evening rule regarding screen time did not predict improvements in adolescent sleep (Peltz et al., 2019; Richardson et al., 2021). However, these latter studies relied on the parents' report of rule-setting (Peltz et al., 2019; Richardson et al., 2021). Due to adolescents' reports that they may not always comply to their parent-set rules (Toh et al., 2019), and factors such as increased autonomy, possible socially desirable responding by parents, and circadian phase delay, adolescents might be awake later than their parents. Thus, parent reports may not be the most accurate source of rule-setting information (Short, Gradisar, Lack, Wright, & Chatburn, 2013). Arguably, adolescents' perception of whether they have rules set and enforced by their parents is likely to be more accurate (Short, Gradisar, Lack, Wright, & Chatburn, 2013). Currently, there is a scarcity of literature that has investigated parent-set technology rules and adolescents sleep outcomes. Furthermore, to the best of my knowledge, the relationship between adolescents' compliance to the rules compared to their peers without rules and their sleep outcomes has yet to be explored. This thesis will address this gap in CHAPTER 3 with a study on parent-set technology rules, compliance to these, and associated sleep outcomes (as reported by adolescents).

Aims and outline of thesis

While the use of an electronic curfew as an intervention for adolescent sleep appears promising, there is a need for further research to investigate certain moderating factors (e.g., intrinsic and extrinsic motivators) in the Bartel and Gradisar (2017) model (Figure 3) that may support adolescents to achieve these positive sleep outcomes. To date, limited evidence has investigated the *content* and *timing* of device use despite many pre-existing public health recommendations. That is, specifically what adolescents are using devices for, and whether certain apps/activities and the timing of use (i.e., in the hour before bed and use in bed before sleep onset) might be more or less associated with unfavourable sleep outcomes. Given the pervasiveness of technology in the modern adolescent's life, and the difficulty observed parting with these even for just 1 hour before bed (rather than a blanket rule of electronic device restriction), the findings of this research may help to assist with the development of an electronic intervention that could help to minimise the possible negative effects of technology use to (e.g., use in the hour before bed may be more favourable for sleep than using devices/apps in bed before attempting sleep/or a certain app may be associated with unfavourable sleep outcomes compared to others). The findings of STUDY 1 were intended to be used as part of a later study to assist adolescents with compliance to an electronic curfew intervention. Evidence from STUDY 1 investigating the relationship between devices and app use at two time points (i.e., hour before bed and in bed before sleep onset) and sleep outcomes is presented in **CHAPTER 2**.

Next, this thesis aimed to target parent-set technology rules as a potential moderating factor of the link between adolescents' evening technology use and sleep. As previously stated, in the literature thus far, most of the research on parental involvement and sleep has focused on parent-set bedtimes. To the best of our knowledge, there remains a limited evidence base that has investigated the effects of parent-set technology rules on adolescent sleep (e.g., devices removed from bedroom overnight), and even less on the role compliance to the rules may play in this relationship. Due to the proximity of parents to their adolescents, we suggest that engaging parents may be a practical way to help adolescents achieve better sleep. We were also interested in determining whether certain individual traits of the adolescent (i.e., FoMO or BtP) moderate the relationship between parent-set technology rules, compliance to rules, and adolescent sleep. The findings of this study were also intended to be used to inform a later study to test whether parental rule setting could assist adolescents to comply with an electronic curfew intervention. Evidence from STUDY 2 investigating the relationship between parent-set technology rules and sleep outcomes, with the consideration of some individual trait moderators (i.e., FoMO and BtP) are presented in **CHAPTER 3**.

Combining what was found in **CHAPTERS 2** and **3**, the final study of this thesis aimed to replicate and extend on Bartel and colleagues' (2019) 1-week phone restriction intervention. The extension of the Bartel and colleagues' study was to add parental support and face-to-face school session using a motivational framework. To the best of my knowledge, no study to date has investigated the combination of parental support and a motivational school session within a technology restriction intervention with the aim to improve adolescent sleep. Findings from **CHAPTER 2** helped to inform components of the intervention (i.e., devices/apps to avoid during the 1-hour technology restriction). The preliminary efficacy of an intervention where phone use is reduced before sleep were assessed. The findings of this study are presented in **CHAPTER 4.** This thesis concludes with a final discussion section including suggestions for ongoing future research in **CHAPTER 5.**

CHAPTER 2

WHAT'S "APP"-NING TO ADOLESCENT SLEEP? LINKS BETWEEN DEVICE, APP USE, AND SLEEP OUTCOMES

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MP led study conceptualisation, design, recruitment, data collection, data management and analysis, results interpretation, and manuscript preparation. MG contributed to study conceptualisation, design, results interpretation, and manuscript preparation. KB assisted with conceptualisation and manuscript preparation. HW assisted with data collection and manuscript preparation. MK contributed to data management and analysis, results interpretation, and manuscript preparation.

Pillion, M., Gradisar, M., Bartel, K., Whittall, H., & Kahn, M. (2022). What's "app"-ning to adolescent sleep? Links between device, app use, and sleep outcomes. *Sleep Medicine* (in press).

Abstract

This study investigated the associations between adolescent evening use of technology devices and apps, night-time sleep, and daytime sleepiness. Participants were 711 adolescents aged 12-18 years old (46% Female, M_{age} = 15.1, *SD* = 1.2). Time spent using technology devices and apps in the hour before bed, and in bed before sleep onset, was self-reported. Participants additionally completed a questionnaire about their sleep on school nights and next day sleepiness. In the hour before bed, 30 minutes of phone use was associated with a 9-minute delay in bedtimes. Thirty minutes spent using laptops, gaming consoles, and watching YouTube was associated with later lights out times of 9 minutes, ~ 16 minutes and ~ 11 minutes respectively, while watching TV was associated with a 9 minute *earlier* lights out times. Using gaming consoles and watching YouTube were associated with greater odds of receiving insufficient sleep (≤ 7 hours TST). In bed before sleep onset, 30 minutes spent using laptops, phones, iPad/tablets, and watching YouTube were linked with later lights out times of ~ 7 minutes for phones and laptops, 9 minutes for iPad/tablets, and ~13 minutes for YouTube. Watching Netflix was associated with greater daytime sleepiness. YouTube at this time point was associated with increased odds of sleeping ≤ 7 hours on school nights. Adolescents are engaging with a wide range of technology devices and apps in the evenings. However, certain devices and apps (e.g., phones, laptops, gaming, and YouTube) might lead to more negative sleep outcomes for adolescents on school nights compared to others.

Introduction

Sleep plays a crucial role in adolescent development and is vital for both physical and mental wellbeing. The National Sleep Foundation recommends that adolescents aged 14-17 years sleep between 8-10 hours per night (Hirshkowitz et al., 2015). This is consistent with research that has found adolescents will often sleep for over 9 hours a night when provided the opportunity (Short et al., 2018). Yet, despite this 9+ hours sleep need, many adolescents worldwide regularly obtain much less sleep on school nights (i.e., between 7-9 hours; Gariepy et al., 2020; Gradisar, Gardner, et al., 2011). Consequences of sleep deprivation relevant to adolescents include increased risk of impaired cognitive abilities associated with poorer school performance (Perez-Lloret et al., 2013), compromised immune system (Orzech et al., 2014), negative mood states (Booth et al., 2020), and increased risk taking across domains such as drug and alcohol use, smoking, transport/road safety, and violent/delinquent behaviour (McKnight-Eily et al., 2011; Short & Weber, 2018). Given these highly adverse consequences, determining what factors contribute to sleep loss is of utmost importance.

One major difference which separates modern day adolescents from those in the last century and even those earlier in the 21st century, is the sharp increase in the portability and accessibility of electronic devices (Twenge et al., 2017). A meta-analysis found bedtime device use to be associated with increased odds of short sleep duration, poor sleep quality and excessive daytime sleepiness (Carter et al., 2016). Portable electronic devices have received most attention in recent research (Bartel et al., 2015; Carter et al., 2016; Hale & Guan, 2015), where some research has found time spent using portable devices had a stronger association with reduced sleep duration compared to non-portable devices (Twenge et al., 2019). Furthermore, a longitudinal study found time spent using technology predicted shorter sleep duration and vice versa (Mazzer et al., 2018), suggesting technology may be displacing adolescents' time otherwise dedicated to sleep. Alternately they suggested adolescents who are experiencing sleep difficulties might use technology to pass time lying awake (Mazzer et al., 2018). Most research to date has focused solely on technology collectively (Mazzer et al., 2018), or on device type and their associations with sleep (e.g., portable vs. non-portable, mobile phone vs. TV; Bartel et al., 2015; Carter et al., 2016; Hale & Guan, 2015; Twenge et al., 2019). While device type is important (i.e., which devices might be more harmful to sleep outcomes compared to others), fewer studies have investigated the links between sleep and the content or apps adolescents are engaging in on these devices (Galland et al., 2020; Harbard et al., 2016; Hisler et al., 2020; Smith et al., 2020; Tavernier et al., 2017).

Two studies measured evening activities within the hour before bed on school nights (Galland et al., 2020; Harbard et al., 2016). One found online social media was a risk factor for shorter and poorer sleep, but only during vacation periods (Harbard et al., 2016), while the other found all screen-based activities - except texting - were associated with reduced sleep duration (Galland et al., 2020). In contrast to this, Tavernier et al. (2017) assessed adolescents' evening use of eight technology-based activities and found that more time spent texting friends was associated with less sleep, whereas more time spent talking on the phone to friends was associated with more sleep. Hisler et al. (2020) found social media and internet use were more strongly associated with reduced sleep duration than watching TV or gaming. Other studies agreed that, collectively, social media use was a common pre-bedtime activity in adolescents associated with negative sleep outcomes (Galland et al., 2020; Harbard et al., 2016; Scott et al., 2019; Smith et al., 2020). Taken together it appears there is conflicting findings regarding some activities (e.g., texting; Galland et al., 2020; Tavernier et al., 2017), while the evidence seems to agree that social media collectively is associated with negative sleep outcomes (Galland et al., 2020; Hisler et al., 2020; Scott et al., 2019; Smith et al., 2020). However, many of these studies measured daily use instead of just evening use (Hisler et al., 2020; Scott et al., 2019; Tavernier et al., 2017), did not measure *where* the technology use took place (e.g., in or out of bed; Galland et al., 2020; Hisler et al., 2020; Tavernier et al., 2017), or measurement of "evening technology use" was categorical (e.g., 0= never engage in this behaviour, to 3= engage in this behaviour most nights; Galland et al., 2020; Harbard et al., 2016; Tavernier et al., 2017).

Recent findings suggest that technology device restriction in the evening can lead to improved sleep outcomes in adolescents, including earlier lights out times, earlier sleep onset times and increased sleep duration (Bartel et al., 2019; Perrault et al., 2019). However, adolescents' motivation to comply with technology restriction is low, with ~32% of the original sample completing the full technology restriction intervention in Perrault et al. (2019), and only 26% providing data in Bartel et al. (2019). This low uptake suggests perhaps an approach that encourages more appropriate technology use rather than pure technology restriction might be the most feasible for adolescents to adopt to try and improve their sleep.

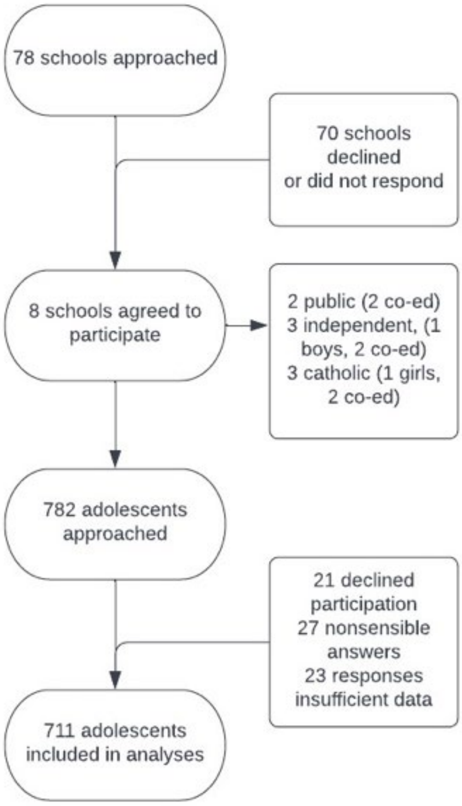
Before developing more suitable approaches for evening technology use, more detailed investigation of device content – and especially apps - is warranted to explore which might be associated with negative sleep outcomes in adolescents. We propose to extend on previous research by investigating specifically which apps (e.g., rather than social media collectively, Snapchat vs Instagram) might be associated with negative sleep outcomes and daytime sleepiness compared to others. This is important to investigate as many apps are inherently designed to try and compete with sleep (e.g., Netflix and YouTube; Lukoff et al., 2021) and might be negatively associated with sleep outcomes, while some apps could be neutral or perhaps even favourable for sleep. Additionally, this study aimed to assess device and app use at two distinct time points–use in the hour before bed and use in bed– to investigate whether screen-sleep links may differ when screens are used before bedtime or closer to sleep onset. As it is unlikely technology will disappear from adolescents' evenings anytime soon, it is important to investigate how use of devices/apps closer to sleep onset and/or use in the sleep environment (i.e., in bed) is related to sleep outcomes and daytime sleepiness.

Method

Participants

A total of 78 secondary schools around metropolitan Adelaide, South Australia were approached for participant recruitment. Of those approached, 8 schools agreed to participate and provided a sample of students from grades 7-12 from June to September 2019 (Figure 5). A total of 711 responses were included in the final analyses (46% female, M_{age} = 15.1, *SD* = 1.2, range = 12-18 years old). Socioeconomic status (SES) of the sample according to the Socioeconomic Indexes for Areas Score (Australian Bureau of Statistics, 2016) indicated that adolescents were mostly of moderate socioeconomic backgrounds (*M* = 7.22, *SD* = 2.49, range: 1 = SES disadvantage – 10 = SES advantage). Ethics approval for this study was granted by the Social and Behavioural Ethics Committee at Flinders University, the Department of Education South Australia, and Catholic Schools Ethics South Australia.

Figure 5: Participant flow chart.



Procedure

Potential secondary schools were invited to have their students participate in the online ‘Adolescent Sleep and Technology Survey’ via Qualtrics (see Materials). An opt-out consent procedure was used, whereby information sheets were sent home to parents in the weeks prior to the survey to ensure parents were informed of the research and had time to decide if they did not want their adolescent to participate. Students also read the information sheet prior to the study and provided their consent or chose to opt-out on the day if they did not wish to participate. The survey took approximately 35 mins to complete. Each participating school was given a sleep education presentation for their students at the end of the study to thank them for their contribution.

Materials

Sleep

Sleep items for the survey were taken from the School Sleep Habits Survey (SSHS; Wolfson et al., 2003). The SSHS is a valid self-report measure of sleep pattern estimates in adolescents that has been validated against sleep diaries (school nights: for TST α = 0.61, for bedtime/sleep onset α = 0.76, for sleep offset α = 0.71) and actigraphy (school nights: for TST α = 0.53, for bedtime/sleep onset α = 0.70, sleep offset α = 0.77; Wolfson et al., 2003). Participants were asked to describe their sleep over the past week on school nights. School nights were chosen as the focus due to the importance of sleep for school days and possible next day functioning consequences (Perez-Lloret et al., 2013; Spruyt, 2019). The sleep variables included were bedtime, lights out time, sleep onset latency (SOL), and total sleep time (TST). Lights out time was added as a variable (not in the SSHS).

Technology use

Technology questions focused on device and app use at two different time points. “In the hour before bed” referred to use within the 60 min before getting into bed. “In bed before sleep onset” referred to any technology or app use that occurred in bed prior to attempting sleep. Participants were asked to estimate a time in minutes that best described the average duration through which they had used each device and app at each of those time points over the last week. Participants could choose to provide responses for multiple devices/apps at each time point. Technology devices listed were: phone, iPad/tablet, laptop, desktop, TV, iPod/mp3, gaming console or ‘other’. Activity/apps listed were: text messaging, phone calls, Instagram, Facebook, Snapchat, Twitter, YouTube, Reddit, Tumblr, Spotify (or other music streaming app), Netflix (or other streaming channel) Viber/WhatsApp, Gaming apps, audio books, or ‘other’.

Daytime Sleepiness

The Pediatric Daytime Sleepiness Scale (PDSS) is an 8-item scale used to measure daytime sleepiness in adolescent populations (Drake et al., 2003). This measure was used to obtain adolescents’ own subjective rating of their daytime sleepiness. Participants were asked to respond based on the last week using a 5-point scale ranging from 0 (Never) to 4 (Always/Very often). Higher total scores are indicative of higher daytime sleepiness (score range 0-32). Internal consistency for the 8 items was good (α = 0.79).

Sleep hygiene

Sleep hygiene questions about light exposure, naps, and caffeine were included as these factors are known to be associated with sleep outcomes (Bartel et al., 2015) and should be controlled in analyses of technology use and sleep (Gradisar et al., 2013). Participants were asked how often they sleep with lights on in their bedroom overnight, how many caffeinated beverages they drink per day, how many times they nap per week, when they nap (e.g., school days and/or weekends and what time), and how long they nap.

Demographics

Demographic information collected included student sex, age, year level, school name, and postcode. Home postcodes were collected to calculate a socioeconomic status (SES) rating as school night sleep timing has previously been found to be associated with SES (Marco et al., 2012).

Statistical Analyses

Data were analysed using IBM SPSS Statistics v.25. Bivariate correlations were run to assess the relationship between sleep variables and device/app use (see Supplementary Tables 1 and 2) and to assess any carry over effects from using devices/apps before bed and in bed before sleep onset (see Supplementary Table 3). Stepwise regressions were used to assess the unique contribution of the amount of time spent using certain devices or apps in explaining sleep variables while controlling for significant covariates. Correlations for each sleep variable were run against a number of potential covariates related to sleep (i.e., age, gender, SES, caffeine, lights on in bedroom overnight, naps) to determine which variables should be entered into Step 1 and 2. Age, gender and where appropriate, SES, were entered into Step 1. The remainder significant covariates per outcome variable were entered into Step 2. The main predictor variables (i.e., device/app use per time point) were entered into Step 3. The main predictor variables were type of device and type of app used at two different time points: (i) minutes of use in the hour before bed or (ii) minutes of use in bed before sleep onset. Devices and apps endorsed by ~20% or more of participants at both time points were included in the analyses to ensure the most common devices and apps were represented. Other devices and apps were excluded due to the low cell count (e.g., $<5\%$ of sample; Greenland et al., 2016). Additionally, to evaluate the odds ratios of insufficient sleep, binary logistic regressions were run for the devices and apps that yielded significant results for TST. TST was converted to a binary variable where insufficient sleep was TST $\leq$ 7 hours and sufficient sleep was $>$ 7 hours on school nights to correspond with the lowest recommended sleep time for adolescents as per the Sleep Health Foundation guidelines (Hirshkowitz et al., 2015). Significant covariates were also controlled in these adjusted models (i.e., age, gender, caffeine). Finally, alpha was adjusted to p =.006 by dividing 0.05 by the number of outcome variables (i.e., 9 outcome variables each for both device and app regressions). This adjustment was made to control for Type 1 error in multiple comparisons.

Results

Sleep and daytime sleepiness

Descriptive statistics for sleep variables by age are displayed in Table 1. The average reported TST across the sample was 7.7hrs, which is less than the lower end of the recommended range for adolescents (M = 7.7 hours, SD = 1.2; Hirshkowitz et al., 2015). In our sample, 46.1% of adolescents obtained 8 or more hours of sleep on school nights. However, only 11.6% reported they obtain the optimal 9 or more hours on school nights (Short et al., 2018). Moreover, 29% of the sample reported that their SOL was >30 minutes, which can be considered the clinical cut-off for long SOL (Gradisar, Gardner, et al., 2011). For daytime sleepiness, the sample scored across the full range (0-32) with the average adolescent reporting daytime sleepiness scores close to the cut-off score of 15 that may predict a self-reported sleep problem (M = 14.5, SD = 6.2; Short, Gradisar, Lack, Wright, & Dohnt, 2013). Fifty percent of the sample scored on or above the cut-off score indicating half of the sample had elevated levels of daytime sleepiness (notably in the 16-18 year old age range; Short, Gradisar, Lack, Wright, & Dohnt, 2013).

Table 1

Frequencies and Means (standard deviations) of demographics, self-reported sleep variables on school nights and daytime sleepiness by age (12-18 years)

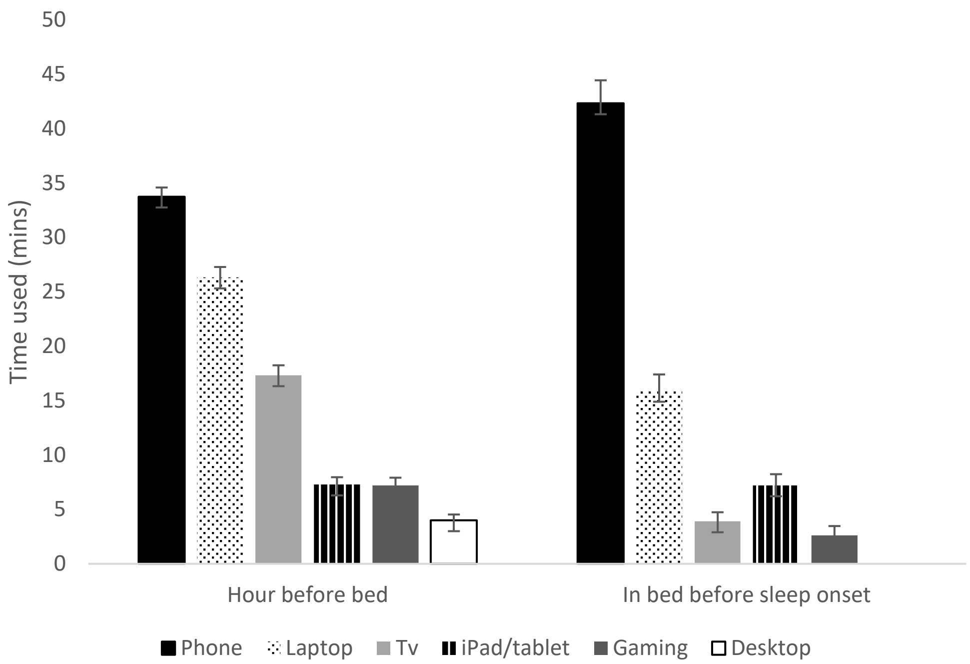
	Age (years)					
	12-13 N = 99	14 N = 85	15 N = 251	16 N = 220	17-18 N = 56	Total sample N = 711
Bedtime (hh:mm)	21:18 (0:48)	21:54 (0:54)	22:06 (0:48)	22:12 (0:48)	22:24 (1:06)	22:00 (0:54)
Lights out (hh:mm)	21:48 (1:00)	22:30 (1:06)	22:42 (1:00)	22:54 (1:00)	23:12 (1:12)	22:36 (1:06)
SOL (mins)	41.2 (38.8)	39.6 (36.7)	30.3 (32.0)	32.0 (34.0)	32.4 (31.1)	33.6 (34.2)
TST (hrs:mins)	8:06 (1:24)	7:42 (1:18)	7:42 (1:06)	7:36 (1:12)	7:30 (1:18)	7:42 (1:12)
PDSS score	12.1 (6.1)	14.0 (6.4)	14.6 (6.1)	15.3 (6.1)	16.3 (6.0)	14.5 (6.2)
Sex (N = 698)	M = 52.7%	F = 47.3%				
SES (N = 662)	7.2 (2.5)					

Note: SES = socioeconomic status (score range 1- 10), SOL = sleep onset latency; TST = total sleep time; PDSS = Pediatric Daytime Sleepiness Scale (score range 0-32).

Frequency of device and app use

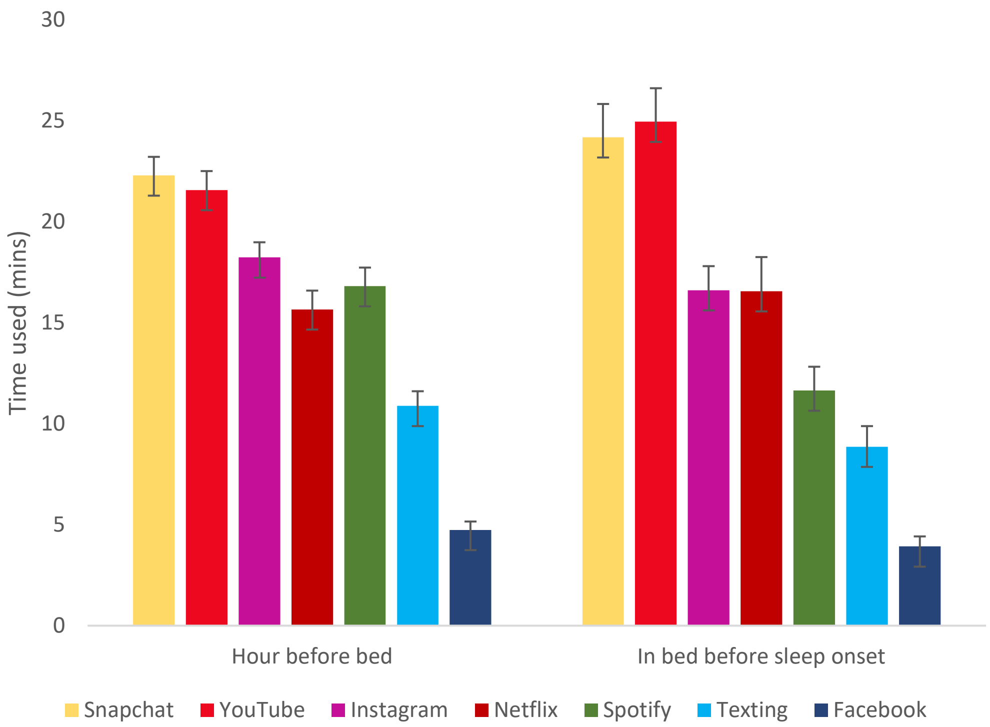
In our sample, 97.6% of adolescents reported using devices in the hour before bed, and 76.3% reported using devices in bed before attempting sleep. The most common devices used were a phone (98.8%) and a laptop (90.2%), followed by TV (67.5%), gaming consoles (51.9%), iPad or tablet (47.3%) and desktop computer (22.2%). In the free text response box, Virtual Reality (0.3%) and Apple Watch (0.1%) were also listed. The phone was the most popular technology device - and on average - the device used for the longest duration both in the hour before bed (*M* = 34.0, SD = 21.2 mins) and in bed before sleep onset (*M* = 42.3, SD = 53.6 mins). Average duration of use of each device at each time point is presented in Figure 2.

Figure 6: Means and standard error of device use in minutes at both evening time points: hour before bed and in bed before sleep onset. Note: Desktop = 0 at in bed before sleep onset.



The most popular apps used by adolescents were Instagram (61.8%), Snapchat (58.7%), YouTube (52.2%), Texting (36.6%), Spotify (35.6%), Netflix (30.9%) and Facebook (26%). Other activities/apps endorsed were phone calls (18.4%), Gaming apps (15.1%), and Twitter (6%). Reddit, Tumblr, Viber, WhatsApp, WeChat, TikTok, Audiobooks, Discord, Meditation/Reading apps were each endorsed by $< 5\%$ of the sample. The apps used for the longest duration at both time points were Snapchat in the hour before bed ($M = 22.3$, SD = 23.0 mins) and in bed before sleep onset ($M = 24.1$, SD = 41.2 mins), and YouTube in the hour before bed ($M = 21.6$, SD = 23.3 mins), and in bed before sleep onset ($M = 24.9$ mins, SD = 41.4; Figure 3).

Figure 7: Means and standard error of app use in minutes at both evening time points: hour before bed and in bed before sleep onset.



Associations between Device and App Use, Sleep, and Daytime Sleepiness

Duration of use in the hour before bed

Zero order correlations between device and app use in the hour before bed and adolescent sleep and sleepiness are presented in Supplementary Table 1. Significant correlations (p <.001) were found between bedtime and phone and Snapchat use; between LOT and phone, laptop, gaming, Snapchat, Facebook, and YouTube use; between SOL and iPad/tablet only; between TST and iPad/tablet, gaming, Snapchat, and YouTube; and between sleepiness and Snapchat and Netflix.

Table 2 provides the coefficients for the adjusted regression models for each device and sleep variable in the hour before bed. Duration of laptop use in the hour before bed was associated with later lights out times (p = .004), where every 30 minutes spent using a laptop was associated a delay in lights out time of 9 minutes. Time spent using a phone in the hour before bed was associated with later bedtimes (p = .003), while time spent watching TV was associated with *earlier* lights out times (p = .006). For every 30 minutes of phone use, bedtimes were delayed by ~ 9 minutes, while every 30 minutes spent watching TV was associated with ~9 minutes earlier lights out time. Duration of gaming in the hour before bed was associated with later lights out times (p <.001) and less TST (p = .002), where every 30 minutes spent gaming was associated with ~16 minutes later lights out time and ~14 minutes less TST. Duration of device use in the hour before bed did not explain any additional variance in SOL or daytime sleepiness scores.

Models assessing the links between app use in the hour before bed and sleep revealed that duration of time spent watching YouTube was associated with later lights out times (p = .003) and less TST (p = .001; see Table 3 for coefficients for each app and sleep variable in the hour before bed). For every 30 minutes spent watching YouTube, this was associated with ~13 minutes later lights out time and ~11 minutes less TST. Duration of app use in the hour before bed did not explain any additional variance in bedtimes, SOL, or daytime sleepiness scores.

Table 2

Adjusted linear regression models for device use in the hour before bed (in minutes)

		Bedtime (hours)			Lights out time (hours)			SOL (hours)			TST (hours)			PDSS (score)		
Model	Factors	b (SE)	ß	*p*	b (SE)	ß	*p*	b (SE)	ß	*p*	b (SE)	ß	*p*	b (SE)	ß	*p*
3	Phone	.005 (.002)	.12	**.003***	.005 (.002)	.095	.015	-.001 (.001)	-.020	.63	-.002 (.002)	-.039	.34	-.004 (.012)	-.015	.71
	iPad/tablet	.000 (.002)	-.004	.93	.001 (.002)	.019	.64	.003 (.001)	.101	.013	-.007 (.003)	-.102	.012	.017 (.014)	.049	.22
	Laptop	.003 (.001)	.076	.047	.005 (.002)	.11	**.004***	.001 (.001)	.041	.32	-.005 (.002)	-.103	.011	.012 (.010)	.051	.20
	Desktop	.005 (.002)	.080	.037	.007 (.003)	.086	.025	.000 (.002)	.000	.99	-.005 (.003)	-.065	.10	-.011 (.018)	-.025	.54
	TV	-.003 (.001)	-.079	.037	-.005 (.002)	-.106	**.006***	.000 (.001)	.017	.67	.002 (.002)	.035	.38	.005 (.010)	.018	.66
	Gaming	.000 (.02)	-.009	.81	.009 (.002)	.151	**.000***	.000 (.001)	-.009	.82	-.008 (.003)	-.127	**.002***	.025 (.014)	.073	.08
		R^2_{change} = .029, F_{change} (6, 610) = 3.47, *p = .002*			R^2_{change} = .061, F_{change} (6, 577) = 7.14, *p <.001*			*p = .30*			R^2_{change} = .045, F_{change} (6, 579) = 4.93, *p <.001*			*p* = .29		

Key: b = unstandardised coefficient; ß = standardised coefficient; SOL = sleep onset latency; TST = total sleep time; PDSS= Pediatric Daytime Sleepiness Scale; ***p* = .006***. *Note:* 30 minutes of phone usage is associated with 0.15 hour (30*0.005) or a 9-minute delay in bedtime.
Step 1: Age, gender, SES. Step 2: sleep hygiene covariates (e.g., lights on in bedroom overnight, daily caffeinated beverages, naps).

Table 3

Adjusted linear regression models for app use in the hour before bed (in minutes)

		Bedtime (hours)			Lights out time (hours)			SOL (hrs)			TST (hours)			PDSS (score)		
Model	Factors	b (SE)	ß	*p*	b (SE)	ß	*p*	b (SE)	ß	*p*	b (SE)	ß	*p*	b (SE)	ß	*p*
3	Texting	-.001 (.002)	-.14	.74	.002 (.002)	.044	.30	.002 (.001)	.054	.22	-.001 (.003)	-.011	.81	.014 (.014)	.044	.32
	Instagram	-.002 (.002)	-.045	.33	-.003 (.003)	-.048	.31	-.001 (.001)	-.019	.70	-.002 (.003)	-.037	.45	-.013 (.015)	-.041	.39
	Facebook	-.001 (.004)	-.006	.89	.001 (.004)	.011	.81	-.002 (.002)	-.033	.47	.006 (.005)	.056	.22	-.024 (.025)	-.042	.35
	Snapchat	.003 (.002)	.080	.09	.005 (.002)	.12	.021	0.00 (.001)	.012	.81	-.003 (.003)	-.055	.26	.021 (.012)	.082	.35
	YouTube	.003 (.002)	.073	.07	.006 (.002)	.12	**.003***	.002 (.001)	.076	.07	-.007 (.002)	-.147	**.001***	-.004 (.011)	-.015	.71
	Spotify	.000 (.002)	.034	.47	.003 (.002)	.057	.19	.001 (.001)	.024	.59	.000 (.002)	-.008	.86	.003 (.011)	.011	.81
	Netflix	.000 (.002)	.001	.98	-.001 (.002)	-.029	.50	.001 (.001)	.025	.59	-.002 (.002)	-.040	.37	.016 (.011)	.063	.15
		p = .30			R^2_{change} = .036, F_{change} (7, 552) = 3.31, *p* =.002			*p = .41*			R^2_{change} = .035, F_{change} (7, 554) = 3.09, *p* =.003			*p = .37*		

Key: b = unstandardised coefficient; ß = standardised coefficient; SOL = sleep onset latency; TST = total sleep time; PDSS= Pediatric Daytime Sleepiness Scale; ***p* = .003**. *Note*: 30 minutes of watching YouTube is associated with 0.18 hour (30*0.006) or a ~11-minute delay in lights out time.
Step 1: Age, gender, SES. Step 2: sleep hygiene covariates (e.g., lights on in bedroom overnight, daily caffeinated beverages, naps).

Duration of use in bed before sleep onset

Zero order correlations between device and app use in bed before sleep onset and adolescent sleep and sleepiness are presented in Supplementary Table 2. Significant correlations ($p<.001$) were found between lights out time and all devices/apps; between TST and phones, laptops, texting, Instagram, Snapchat, YouTube, and Netflix; and between sleepiness and phones, Snapchat, YouTube and Netflix. No significant correlations ($p<.001$) found between SOL and device/app use.

Adjusted models revealed that time spent using laptops ($p<.001$), phones ($p<.001$), and iPad/tablets ($p = .002$) in bed before sleep onset was associated with later lights out times on school nights (see Table 4 for coefficients for device use in bed before sleep onset by sleep variable)[1]. For every 30 minutes spent using a phone or a laptop, this was associated with ~ 7 minutes delay in lights out time. For iPads/tables, 30 minutes of use was associated with a 9-minute delay in lights out times.

For apps, time spent watching YouTube in bed before sleep onset was associated with later lights out times ($p<.001$) and less TST ($p<.001$) on school nights. For every 30 minutes spent watching YouTube, this was associated with ~ 13-minute delay in lights out times, and ~ 11 minutes less TST. Time spent watching Netflix in bed before sleep onset was associated with increased daytime sleepiness ($p = .002$), where more time spent watching Netflix was associated with an increase in daytime sleepiness scores.

[1] For the duration of device and app use in bed before sleep onset, bedtime was excluded as theoretically bedtime (i.e., getting into bed) occurred before the time that using devices/apps in bed began.

Table 4

Adjusted linear regression models for device use in bed before sleep onset (in minutes)

		Lights out time (hours)			SOL (hours)			TST (hours)			PDSS (score)		
Model	Factors	b (SE)	ß	*p*	b (SE)	ß	*p*	b (SE)	ß	*p*	b (SE)	ß	*p*
3	Phone	.004 (.001)	.19	**.000***	.001 (.000)	.060	.16	-.002 (.001)	-.11	.007	.001 (.005)	.092	.027
	iPad/tablet	.005 (.002)	.12	**.002***	.001 (.001)	.049	.22	-.003 (.002)	-.064	.11	.017 (.005)	.077	.05
	Laptop	.004 (.001)	.15	**.000***	.001 (.001)	.088	.033	-.003 (.001)	-.11	.007	.010 (.006)	.062	.13
	TV	.002 (.002)	.041	.35	-.002 (.001)	-.069	.14	-.001 (.002)	-.024	.62	-.011 (.013)	-.038	.41
	Gaming	.001 (.002)	.024	.60	.002 (.001)	.069	.15	-.003 (.002)	-.056	.24	.000 (.013)	.000	.99
		R^2_{change} = .090, F_{change} (5, 575) = 13.13, p <.001			R^2_{change} = .021, F_{change} (5, 592) = 2.86, p = .02			R^2_{change} = .043, F_{change} (5, 578) = 5.51, p <.001			R^2_{change} = .021, F_{change} (5, 579) = 2.81, p = .016		

Key: b = unstandardised coefficient; ß = standardised coefficient; SOL = sleep onset latency; TST = total sleep time; PDSS= Pediatric Daytime Sleepiness Scale; ***p* = .002.** *Note:* 30 minutes of phone use is associated with 0.12 hour (30*0.004) or a ~7-minute delay in lights out time.

Step 1: Age, gender, SES. Step 2: sleep hygiene covariates (i.e., lights on in bedroom overnight, daily caffeinated beverages, naps).

Table 5

Adjusted linear regression models for app use in bed before sleep onset (in minutes)

		Lights out time (hours)			SOL (hours)			TST (hours)			PDSS (score)		
Model	Factors	b (SE)	ß	*p*	b (SE)	ß	*p*	b (SE)	ß	*p*	b (SE)	ß	*p*
3	Texting	.003 (.002)	.068	.12	.001 (.001)	.060	.57	-.001 (.002)	-.017	.69	.006 (.010)	.026	.57
	Instagram	-.002 (.002)	-.054	.23	.000 (.001)	.049	.77	-.002 (.002)	-.053	.28	-.014 (.010)	-.067	.18
	Facebook	.004 (.003)	.050	.23	.002 (.002)	.088	.23	.002 (.004)	.020	.65	-.025 (.021)	-.054	.23
	Snapchat	.002 (.001)	.089	.044	.000 (.001)	-.069	.84	.000 (.001)	-.016	.74	.007 (.007)	.050	.28
	YouTube	.007 (.001)	.28	**.000***	.001 (.001)	.069	.020	-.006 (.001)	-.24	**.000***	.014 (.006)	.098	.026
	Spotify	.003 (.001)	.075	.07	.001 (.001)	.029	.53	-.003 (.002)	-.086	.05	.006 (.009)	.029	.51
	Netflix	.001 (.001)	.030	.48	-.001 (.001)	-.058	.20	.000 (.001)	.000	.99	.020 (.006)	.14	**.002***
		R^2_{change} = .129, F_{change} (7, 552) = 13.34, *p* <.001			*p = .17*			R^2_{change} = .085, F_{change} (7, 555) = 7.80, *p* <.001			R^2_{change} = .037, F_{change} (7, 555) = 3.45, *p* <.001		

Key: b = unstandardised coefficient; ß = standardised coefficient; SOL = sleep onset latency; TST = total sleep time; PDSS= Pediatric Daytime Sleepiness Scale; ***p* = .002***. *Note:* 30 minutes of watching YouTube is associated with 0.21 hour (30*0.007) or a ~13-minute delay in lights out time.
Step 1: Age, gender, SES. Step 2: sleep hygiene covariates (i.e., lights on in bedroom overnight, daily caffeinated beverages, naps).

Technology device/app use and risk of insufficient sleep

Binary regressions were used to investigate the odds ratios (i.e., Exp (B)) of obtaining insufficient sleep (i.e., < 7 hours) on school nights for devices and apps which were found to be associated with TST. In the hour before bed, every additional 15 minutes spent gaming was associated with a 24% greater chance of insufficient sleep on school nights, Exp(B)= .98, C.I. 95% = [.97, .99], p =.002. Watching YouTube for 15 minutes in the hour before bed was also associated with a 24% greater chance of having insufficient sleep on school nights, Exp(B)= .98 C.I. 95% = [.98, .99], p <.001. For every 15 minutes then spent watching YouTube in bed before sleep onset, the odds of insufficient sleep on school nights increased by 18% Exp(B)= .99, C.I. 95% = [.98, .99], p <.001.

Discussion

The aim of this study was to examine the associations between sleep and evening device and app use at two time points – the hour before bed, and in bed before sleep onset. Our findings indicate that adolescents are engaging with a wide range of technology devices and apps at both of these time points on school nights. Use of three specific devices (i.e., phone, laptop, gaming) and one particular screen activity (i.e., watching YouTube) were the most consistent factors associated with negative sleep outcomes and daytime sleepiness. The findings of this study provide insights into the role apps and the timing of technology use might play in the relationship between adolescent sleep and technology use.

Mobile phones were the device used for the longest duration at each time point. The phone and laptop emerged as the devices most associated with negative sleep outcomes across both time points, while gaming was associated with later lights out time and less TST only in the hour before bed. However, gaming consoles were the only device associated with increased odds of insufficient sleep on school nights. Conversely, TV was associated with earlier lights out times. This is consistent with previous research that has found portable or more interactive devices were more likely to be associated with adverse sleep outcomes, as opposed to watching TV (Bartel et al., 2015; Carter et al., 2016; Hale & Guan, 2015; Twenge et al., 2019).

YouTube was the only app consistently and negatively related to sleep outcomes. Time spent on YouTube was associated with increased odds of insufficient sleep on school nights, where every 15 minutes spent watching YouTube in the hour before bed was associated with a 24% greater chance of receiving ≤ 7 hrs of TST, and every 15 minutes spent watching YouTube in bed before sleep onset was associated with an 18% greater chance. Watching Netflix in bed before sleep onset was found to be associated with more daytime sleepiness, yet no other app was found to be associated with negative sleep outcomes. This is in contrast with previous research which found online social media use (albeit collectively) was a risk factor for shorter and poorer sleep (Harbard et al., 2016; Hisler et al., 2020; Scott et al., 2019). This is also in contrast to Tavernier et al. (2017) who found texting was associated with less TST, and Galland et al. (2020) that found that all screen-based activities in the hour before bed except texting were associated with reduced sleep duration.

Our findings seem peculiar in that theoretically, watching YouTube, Netflix and TV appear to be a similar activity (i.e., passive observation), yet our data suggest that while TV is associated with earlier lights out times, YouTube was associated with later lights out times and less TST, and yet Netflix was linked with increased daytime sleepiness. One explanation could be the structured vs unstructured nature of these media activities. Structured media use can be defined as goal-directed behaviour to satisfy information needs where media is used in a purposeful, selective way (Kubey, 1986); while unstructured media use can be thought of as habitual or frequent media use with few to no external boundaries or goal-directed involvement, that are often engaged in alone (e.g., no time limits; Kubey, 1986; Rubin, 1984). Traditional TV is arguably a structured media, where the content and time schedule are predetermined by an external source (e.g., TV programme). YouTube is almost entirely the opposite - an unstructured media type where content is endless and personalised to the individual viewer by an algorithm that has learned what they like to watch (Lukoff et al., 2021). It is perhaps unsurprising that an app like YouTube that can be accessed on a portable device in bed - displaying endless personalised content - is associated with unfavourable sleep outcomes compared to a static device that displays content with a pre-determined beginning and end (e.g., episode or TV show that will end at 10pm or runs for 45 min). The latter argument can also be applied to Netflix.

Like YouTube, Netflix also recommends content to viewers, and can be watched on portable devices (or TV). However, like traditional TV, there is a clear beginning and end point to the content watched.

The role of self-control might also provide an explanation for these findings (Exelmans & Van den Bulck, 2021; Lukoff et al., 2021). In today's "attention economy", apps like YouTube are designed to interfere with their users' sense of agency (Lukoff et al., 2021), where it is almost impossible to use this platform in a structured way. For example, even if an individual has a specific goal-directed intention (e.g., making a recipe or learning a skill) internal features of the app such as "autoplay" and recommendations are automated to promote the unstructured flow of content. Data suggests 70% of YouTube's watch time comes from algorithmic recommendations, and that video recommendations become progressively longer in minutes the longer a user remains engaged on the platform (Lukoff et al., 2021). This is where the role of self-control and its flow on effects for sleep become particularly important. For instance, participants in a YouTube study described finding it difficult to resist engaging in "just one more video" which could then become a couple hours of watching (Lukoff et al., 2021). This demonstrates the platform's potential to undermine users' sense of agency to displace bedtimes, lights out times, and/or "shut-eye" time (Exelmans & Van den Bulck, 2017). Those participants described this as unplanned and regretful use, where videos from the algorithm are too engaging and lead to getting stuck in a "rabbit hole" of videos (Lukoff et al., 2021). This phenomenon, often described as "binge viewing", is a term also used to describe watching TV or Netflix in large doses (Exelmans & Van den Bulck, 2021). Higher binge viewing frequency has been found to be associated with poorer sleep quality, more fatigue, and symptoms of insomnia, but regular TV viewing was not (Exelmans & Van den Bulck, 2021). Our data and the findings of Lukoff et al. (2021) suggest binge viewing might also be occurring on YouTube, associated with later lights out times and less TST. For some people, binge watching could also be occurring on Netflix, explaining its association with daytime sleepiness. Alternately, it is possible this daytime sleepiness could be explained by other factors such as sleep disordered breathing or sleep quality which was not measured in our study.

The role of self-control can also be applied to our findings for gaming. Video games are often designed to keep individuals in a balanced state between challenge and engagement (Smith, King, et al., 2017). While we did not find an association between gaming and bedtimes as seen in previous research (Hale & Guan, 2015), our findings support the idea that gaming might be "displacing" the sleep process by delaying lights out times and, consequently, sleep onset times which could explain the increased odds of less TST on school nights. Time distortion can occur in a state of "flow" where adolescents might lose track of time spent playing a video game, potentially leading to a delay in the sleep process (Exelmans & Van den Bulck, 2017; Rau et al., 2006; Wood & Griffiths, 2007). "Flow" is a term used to describe a psychological state where an individual flows from one moment to the next, immersed in typically an enjoyable activity where there becomes little distinction between self and environment (e.g., fully immersed in a game and then realising the time; Smith, King, et al., 2017).

Our findings provide some support for Exelmans and Van den Bulck (2017)'s two-step displacement theory - that evening technology or app use could be displacing bedtimes, as time spent on these passes, leading to a delayed bedtime. Sleep-onset time could then be displaced through devices and apps being taken to bed to use (e.g., phones, watching YouTube), therefore delaying the sleep-onset attempt (i.e., shut-eye latency; Exelmans & Van den Bulck, 2017). However, it must be acknowledged that there were many null findings or small effects. These findings might indicate that most apps or devices *individually* might not be related or strongly related to negative sleep outcomes. Measuring use at two particular time points increased the sensitivity of the data that could possibly lead to small effects. However, while beyond the scope of this study, this is not to say that multitasking or switching between devices/apps frequently might find different results. Our study found no associations between app/device use and SOL. Previous research has found cognitive pre-sleep arousal mediated the relationship between binge viewing and negative sleep outcomes (Exelmans & Van den Bulck, 2021), however our findings do not support the pre-sleep arousal hypothesis. Rather, our findings are consistent with Bartel et al. (2015) who found no association between device use and an index of arousal – sleep onset latency. Although it could be argued SOL was not objectively measured in our study, previous research investigating the impact of prolonged violent video-gaming on adolescent sleep found that adolescents' subjective reports of SOL were longer and more conservative than the polysomnography measures of SOL (King et al., 2013).

Therefore, self-reported SOLs in our study should have been conservative enough to capture effects. The duration of device and app use by the adolescents in our sample, on average, was not long enough for any potential effects of screen light to disturb melatonin or sleep onset (>1.5- 2 hours needed for negative effects to be seen; Bartel & Gradisar, 2017).

Limitations and future directions

Limitations of the current study include its cross-sectional design that precludes causal conclusions to be drawn and the use of self-reports to measure sleep and technology use. Further longitudinal and experimental research is required to understand directionality and causality regarding the links identified in our study. Due to the elevated levels of daytime sleepiness experienced in 50% of the adolescents in our sample, it cannot be ruled out that technology use might be occurring due to sleep difficulties (Bartel & Gradisar, 2017), with recent evidence to suggest a bi-directional relationship between sleep and technology likely exists (Mazzer et al., 2018; Richardson et al., 2021). Despite this clear limitation, we argue that controlling for several covariates known to affect sleep onset (e.g., caffeine, lights, age, etc.) is a strength. Moreover, as with most research in the technology field, device and app development often outpaces research capabilities. Specific to this study, TikTok became an international phenomenon shortly after we collected our data, which is an app that operates in a similar manner to YouTube (e.g., algorithms, autoplay etc). While our discussion has highlighted the role some individual factors could play, the present study did not account for individual factors that may impact technology use and/or sleep. Emerging research has found individual traits such as self-control (Exelmans & Van den Bulck, 2021), "risk-taking" (Reynolds et al., 2015), fear of missing out (FOMO; Scott & Woods, 2018) and "flow" have moderated the links between technology and sleep outcomes (Smith, King, et al., 2017). Future research should continue to investigate the role these individual factors might play in the relationship between sleep and technology use. Finally, it was beyond the scope of our study to measure multi-tasking, but we are aware our data suggests this may be happening. Future research investigating switching between devices/apps and multitasking would be valuable to further explore how adolescents might be using technology in the evening/before sleeping.

Conclusion

The present research provides further insights to the relationship between devices and more importantly apps and adolescent sleep. While a night-time digital detox could be a powerful remedy for adolescent sleep, motivation to part with devices in the evenings appears to be low (Bartel et al., 2019; Perrault et al., 2019). Therefore, an approach aimed at minimising possible negative effects of technology such as reducing or trying to remove specific devices or apps (e.g., phones, laptops, gaming, and YouTube) might be more feasible, as it is likely technology will remain an integral part of adolescents' evenings. Moreover, there remains a need for future experimental research to test the devices, apps, and mechanisms (e.g., individual differences, multitasking) to further investigate the relationship between evening technology and use and sleep in adolescence.

CHAPTER 3

WI-FI OFF, DEVICES OUT: DO PARENT-SET TECHNOLOGY RULES PLAY A ROLE IN ADOLESCENT SLEEP?

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MP led study conceptualisation, design, recruitment, data collection, data management and analysis, results interpretation, and manuscript preparation. MG contributed to study conceptualisation, design, results interpretation, and manuscript preparation. KB assisted with conceptualisation and manuscript preparation. HW assisted with data collection and manuscript preparation. JM, AD, and BN assisted with data collection and manuscript preparation. MK contributed to data management and analysis, results interpretation, and manuscript preparation.

Pillion, M., Gradisar, M., Bartel, K., Whittall, H., Mikulcic, J., Daniels, A., Rullo, B., & Kahn, M. (2022). Wi-Fi off, devices out: do parent-set technology rules play a role in adolescent sleep?. *Sleep medicine: X*, *4*, 100046.

Abstract

There is limited evidence surrounding the relationship between parent-set technology rules and adolescent sleep. This study had two aims: 1) to investigate the relationship between presence of and compliance to parent-set technology rules and adolescent sleep outcomes and daytime sleepiness; 2) to investigate if compliance, non-compliance, or the absence of rules could moderate the relationship between Fear of Missing Out (FoMO) and Bedtime Procrastination (BtP) on sleep outcomes and daytime sleepiness. A total of 711 adolescents aged 12-18 years old (46% Female, M_{age} = 15.1, *SD* = 1.2) were recruited through secondary schools in South Australia. Participants completed a survey containing self-report measures about their sleep, daytime sleepiness, FoMO, BtP, the presence/absence of technology rules in their house, and their compliance to these rules. The study design was cross sectional. Results indicated that the presence of a parent-set technology rule was associated with earlier bedtimes regardless of compliance. Earlier lights out times and increased sleep duration were observed in adolescents who always complied to their rules compared to those who did not comply or did not have parent-set technology rules. BtP and FoMO were associated with later bedtimes, later lights out times, longer sleep onset latency, shorter sleep duration, and more daytime sleepiness. However, parent-set rules did not moderate the links between BtP/FoMO and adolescent sleep. Whilst longitudinal investigations are warranted to examine the directionality of these relationships, the present study suggests that parent-set technology rules may play an important role in protecting adolescent sleep.

Introduction

Adolescence is a period of many biological, psychological, and social changes, including, but not limited to, sleep, identity, independence, and relationships with caregivers and peers (Colrain & Baker, 2011). Sleep and wake timing during adolescence tends to drift later, due to the maturation of the two bioregulatory processes of sleep: reduced sleep homeostatic pressure and delayed circadian timing (Crowley et al., 2018). The average sleep duration recommended for adolescents is approximately 9.35 hours a night for optimal cognitive functioning (Short et al., 2018). However, many adolescents in their home environments are not meeting this nightly sleep need, receiving ~7-8 hours per night (Gariepy et al., 2020; Gradisar, Gardner, et al., 2011). This discrepancy between sleep need assessed in the laboratory and sleep in the home environment highlights that psychosocial factors, such as school start times, socialising, device use, and bedtime autonomy, are likely to be contributing to sleep loss (Crowley et al., 2018).

In a recent systematic review and meta-analysis, parent-set rules have been suggested as a practical and promising intervention to improve adolescent sleep (Khor et al., 2020). Not only are parents usually motivated and invested in the wellbeing of their children, but parents' proximity to their adolescents means that they are also in prime position to monitor and support them in achieving their sleep goals (Khor et al., 2020). Thus far, most of the evidence on parent-set rules in the context of sleep has investigated the effects of parent-set bedtimes (Khor et al., 2020). Parent-set bedtimes have been associated with earlier bedtimes and longer sleep duration (Bartel et al., 2015; Short et al., 2011), with some evidence to suggest they might also have protective effects against adolescent depression and suicidal ideation (Gangwisch et al., 2010). However, the consensus is that there is not yet a "sound" evidence base for other parent-set rules, such as those surrounding evening technology use, on sleep outcomes (Khor et al., 2020).

Parent-set rules regarding evening technology use have emerged in households over the last decade along with the development of portable technology (Buxton et al., 2015). Having a parent-set rule which limits device use (e.g., technology is removed from the bedroom overnight) has been associated with earlier bedtimes, longer time in bed (Khor et al., 2020; Pieters et al., 2014), and increase of 36-54 minutes of total sleep time (Buxton et al., 2015). Similarly, having a rule that restricts access to the internet in the evening (i.e., a Wi-Fi rule) has the potential to limit the amount of activities available to use on mobile devices and time spent on them (Toh et al., 2019). Importantly, when parent-set rules around media use were absent, electronic media was more likely to be used for longer durations and used in the hour before sleep (Pieters et al., 2014).

However, this poses a question- what if adolescents do not comply to their rules? Frequent instances of non-compliance to parent-set device rules were reported by many parents and adolescents in a qualitative study (Toh et al., 2019). While some adolescents did comply with their rules and reported that these were helpful in preventing excessive mobile device use, many other adolescents reported difficulty with self-control when it came to using mobile devices (Toh et al., 2019). Furthermore, parents often express frustration and difficulty with implementing device rules and then monitoring their adolescent's compliance to them (Toh et al., 2019). One study found that adolescents whose parents enforced rules about how late they could use cell phones slept for longer durations than adolescents who 'sometimes' had rules, and those who did not have rules (Buxton et al., 2015). However, another study found parents' enforcement of screen time usage did not predict TST (Peltz et al., 2019). The evidence base for parent-set technology rules and their relationship with sleep outcomes is still emerging (Khor et al., 2020) and therefore warrants further work. Furthermore, how parent-set technology rules relate to daytime functioning, to the best of our knowledge, is yet to be understood (Khor et al., 2020). Consequently, the present study aimed to investigate the relationship between compliance to parent-set technology rules, and sleep outcomes, including daytime sleepiness.

It is possible that individual traits might play a role in compliance, where some adolescents are more likely to comply with parents' or researchers' rules, while others might not be (Bartel et al., 2019; Toh et al., 2019). Fear of Missing Out (FoMO) and Bedtime Procrastination (BtP) may each impact on adolescents' likelihood of complying with parent set rules. FoMO is defined as a general state of anxiety at missing out on rewarding experiences others may be having that often pushes social media engagement as a means to satisfy a psychological need (Beyens et al., 2016; Przybylski et al., 2013). BtP is defined as going to bed later than intended, despite the absence of external barriers preventing one from doing so (Kroese et al., 2014). Other research has found FoMO and social media use to be associated with later bedtimes, increased pre-sleep cognitive arousal, longer SOL, and less

TST (Scott & Woods, 2018). In one study, those with higher FoMO scores used social media for longer and were more likely to experience negative sleep outcomes (e.g., less TST, poorer sleep quality; Scott et al., 2021). For those who experience FoMO it appears there may be choice to trade sleep for remaining engaged on social media for the reward of continuing to connect with peer groups (Adams et al., 2017). For BtP, research has found higher scores were associated with insufficient sleep in adolescents (Kadzikowska-Wrzosek, 2020), and in young adults BtP was associated with later bedtimes, later rise times, and more eveningness tendencies (Chung et al., 2020). Additionally, those higher in BtP spent signficantly more time using their mobile phones before bed (Chung et al., 2020). Here it is possible that those who are bedtime procrastinators might have good intentions for healthy sleep habits, but experience this form of self-regulatory failure where a short-term gain is prioritised over the negative consequence of adequate sleep (Exelmans & Van den Bulck, 2021).

Taken together, it could be that adolescents who experience FoMO and/or bedtime procrastination may benefit from parent-set technology rules to assist them with regulating their evening media use to achieve better sleep. However, it is also possible that the level of compliance to these rules could moderate the relationship between these individual differences and sleep/daytime sleepiness outcomes. Therefore, the final aim of the present study will be to investigate whether compliance, non-compliance, or the absence of parent-set technology rules could moderate the relationship between the individual traits of FoMO/BtP and sleep/daytime sleepiness.

Method

Participants

A total of 78 secondary schools around metropolitan Adelaide, South Australia were approached for participant recruitment. Of those approached, 8 schools participated and provided a sample of students from grades 7-12 from June to September 2019. A total of 711 responses were collected (52.7% male, M_{age} = 15.1, *SD* = 1.2, range = 12-18 years old). Socioeconomic status (SES) of the sample according to the Socioeconomic Indexes for Areas Score (SEIFA; Australian Bureau of Statistics, 2016) was *M* = 7.48, *SD* = 2.41, range from 1 = SES disadvantage – 10 = SES advantage, indicating that the sample was mostly representative of adolescents in middle-upper socioeconomic status in Australia. Ethics approval for this study was granted by the Social and Behavioural Ethics Committee at Flinders University, the Department of Education South Australia, and Catholic Schools Ethics South Australia.

Procedure

Interested schools were invited to participate in an online survey on adolescent sleep and technology use (see Materials). Informed consent was obtained from both adolescents and parents using an opt-out procedure. Students read the information sheet and provided their consent to participate on the day of data collection. At least one researcher was present at each school on the day the survey was distributed, to ensure students could ask the researcher any questions regarding their participation or the survey itself. The survey was part of a larger study on adolescent sleep and technology use and took ~35 min to complete. Participating schools were provided with a sleep education presentation for their students after data collection was complete.

Materials

Parent set rules

Participants were asked whether their parents implemented one of three different parent-set technology use rules at home on school nights to which they answered *Yes* or *No* (*1) Do you have a rule in your house where your phone is put in a certain place overnight (i.e., out of your bedroom?); 2) Do you have a rule or time in your house when devices/electronics are to be put away?; 3) Do you have a rule or time in your house when the WiFi/Internet is turned off for the night?).* Participants who answered "*Yes*" to at least one parent-set technology rule were also asked whether they *always* complied with their rule(s) (i.e., *Do you always comply with these rules?*) by indicating *Yes* or *No*. Following this, participants were categorised into one of three technology rule groups: (1) those with a parent-set rule(s) and comply, (2) those with a parent-set rule(s) and do not comply, and (3) those with no parent-set technology rules.

Sleep

Sleep items were derived from the School Sleep Habits Survey (SSHS; Wolfson et al., 2003). Each participant was asked to indicate the time they got into bed (bedtime), the time they turned out the lights (lights-out time), the number of minutes they estimate it took for them to fall asleep (sleep onset latency; SOL), and the time they wake up (sleep offset) on weekdays/nights. Using these variables, total sleep time (TST) could be calculated. The present study focused only on school nights, as previous research has found parent-set rules are often not enforced on weekend nights (e.g., 91% of a sample of 1,926 adolescents reported having no rules for their cell phone on weekends; Pieters et al., 2014). The SSHS is a valid self-report measure of sleep pattern estimates in adolescents that has been validated against sleep diaries (school nights: for TST $\alpha = 0.61$, for bedtime/sleep onset $\alpha = 0.76$, for sleep offset $\alpha = 0.71$) and actigraphy (school nights: for TST $\alpha = 0.53$, for bedtime/sleep onset $\alpha = 0.70$, sleep offset $\alpha = 0.77$; Wolfson et al., 2003).

Daytime Sleepiness

The Pediatric Daytime Sleepiness Scale (PDSS) is an 8-item scale used to measure daytime sleepiness in adolescent populations (Drake et al., 2003). Each adolescent was asked to respond to a series of questions regarding their daytime functioning over the last week using a 5-point scale ranging from 0 = *Never* to 4 = *Always*, with higher scores indicating more daytime sleepiness (score range from 0 - 32). This measure was used to determine whether the presence or absence of parent-set rules for adolescents could impact daytime functioning in adolescents. Internal consistency for the 8 items in our sample was acceptable (Cronbach's alpha = 0.79).

Sleep hygiene and demographics

Known sleep hygiene and demographic covariates were measured to ensure these could be controlled for in analyses. Each participant indicated the number of caffeinated beverages they would drink per school day on average, as this has been associated with negative sleep outcomes (Bartel et al., 2015). Light exposure was also measured as this has been identified as a risk factor to adolescent sleep (Bartel et al., 2015). Participants were asked to indicate on a 4-point scale how often they sleep with lights on in their bedroom overnight (0 = Never – 4 = Every night) as measured in the National Sleep Foundation's *2011 Sleep in America Poll* (Gradisar et al., 2013). Questions regarding the frequency, clock time, and duration of naps during the week on school days were also asked as napping has been known to delay sleep onset (Gradisar et al., 2008) and decrease sleep duration (Jakubowski et al., 2017). Participants were asked to indicate frequency (once a week- everyday), what time they nap (e.g., 4pm) and the duration of that nap in hours and minutes.

Demographic information collected included gender, age, year level, and postcode. Home postcodes were collected to calculate socioeconomic status (SES), as SES has been found to be associated with sleep (Marco et al., 2012).

Fear of Missing Out (FoMO)

The iNOD *(Index of Nighttime Offline Distress)* is a 10-item self-report measure of difficulty disengaging from social media at night time (London et al., 2020; Scott et al., 2021). The questionnaire has two subscales that measure concerns about "staying connected" to peers via social media at night time to avoid missing out, and "following etiquette" regarding perceptions of either the self or others' social expectations of night time interactions (Scott et al., 2021). Each item (e.g., *"I would feel left out from my friends if I could not use social media at night"*) is measured on a 5-point scale from 0 = *not at all true of me* to 4 = *extremely true of me*, with higher scores indicating higher levels of difficulty disengaging from social media (score range 0 to 40). The iNOD has been validated for use with adolescents aged 10-18 years old (Scott et al., 2021). Internal consistency for the 10 items was good (Cronbach's alpha = 0.87).

Bedtime procrastination (BtP) scale

The Bedtime Procrastination Scale is a 9-item self-report measure of self-regulation and procrastination around bedtime (Kroese et al., 2014). Each adolescent was asked to respond to a series of questions regarding their tendency to procrastinate going to bed and self-regulation to cease evening activities (e.g., "*I easily get distracted by things when I would actually like to go to bed"*) on a 5-point scale ranging from 1= *(almost) never* to 5 = *(almost) always*, with higher scores indicating higher levels of bedtime procrastination (score range 9 to 45). The scale had good internal reliability, as demonstrated by a Cronbach's alpha of 0.72.

Statistical Analyses

Data were analysed using IBM SPSS Statistics v.27 and macro PROCESS v.3.5 (Model 1; Hayes, 2017). Univariate general linear models (GLMs) were used to assess the links between parent-set rule groups and each of the sleep and sleepiness variables. GLMs were also used to assess the main effects of BtP and FoMO on sleep outcome variables/daytimes sleepiness. Least Significant Difference (LSD) adjusted pairwise post-hoc analyses allowed for comparisons between the three groups on each outcome variable. PROCESS was used to test for an interaction between BtP/FoMO and parent-set technology rule group on the sleep outcome variables/daytime sleepiness. Age and gender were controlled for in each model. Other covariates (e.g., caffeine, SES) were controlled for if they were significantly correlated to the outcome variable. Supplementary Table 4 presents zero order correlations between sleep variables, FoMO/BtP, daytime sleepiness, and covariates.

Results

Sample characteristics

Approximately half of the sample had at least one of the three parent-set technology rules in their household (49.0%, N= 337). A total of 235 (33.1%) participants had a rule where their phone is taken out of their bedroom overnight. Also, 235 (33.1%) of participants had a rule where all electronic devices are put away overnight, and 66 (9.3%) had a rule where the WiFi is turned off. A total of 176 (25.6%) participants reported having one of the parent-set technology rules, 127 (18.5%) participants had two of the rules, and 34 (4.9%) had all three rules. The probability of having at least one parent-set technology rule significantly decreased with age, $r = -.160$, $p < .001$. For those who had a parent-set technology rule, 131 (51.8%) indicated that they always complied to these rules, while 123 (48.2%) indicated they do not always comply to their rules. There was significant difference between rule group and age, $F(2, 697) = 8.9$, $p < .001$, where those who had no rules were older in age compared to those who had rules and complied ($p < .001$), and those who had no rules and did not comply ($p = .002$). There was no significant difference in age between those who had rules and complied, and those who had rules and did not always comply, $p = .79$ (Figure 8). Descriptive statistics are presented in Figure 9. Descriptive statistics as well as main effects for rule groups on sleep variables, daytime sleepiness, FoMO, and BtP can be seen in Table 6. While gender was not a focus of this paper, FoMO, BtP, sleepiness and all sleep variables except lights out significantly differed between gender (Supplementary Table 5).

Figure 8: Presence and compliance of parent-set rules by age

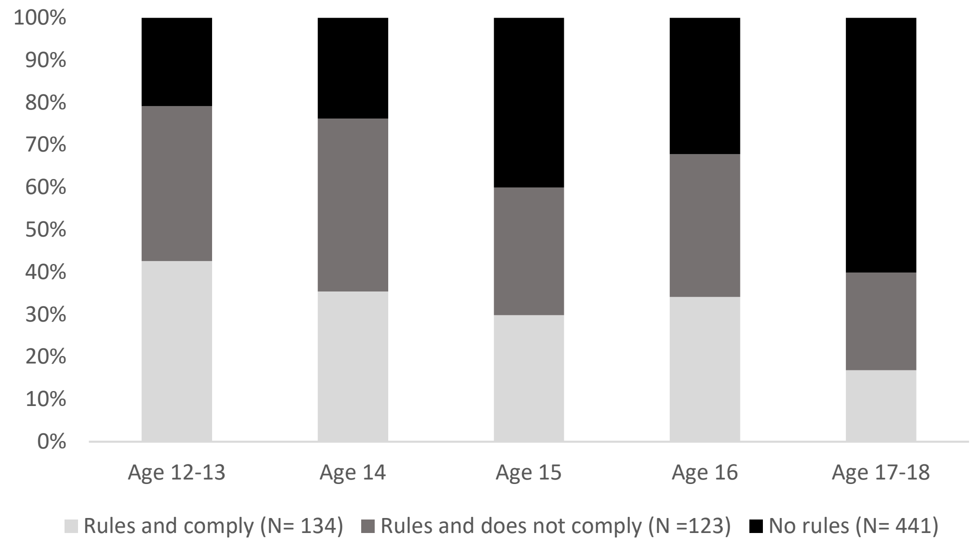


Table 6

Estimated marginal means (standard error) of self-reported sleep variables on school nights, daytime sleepiness, FoMO and BtP scores for those who had parent-set technology rules and either do or do not always comply to their rules, and those without parent rules.[23]

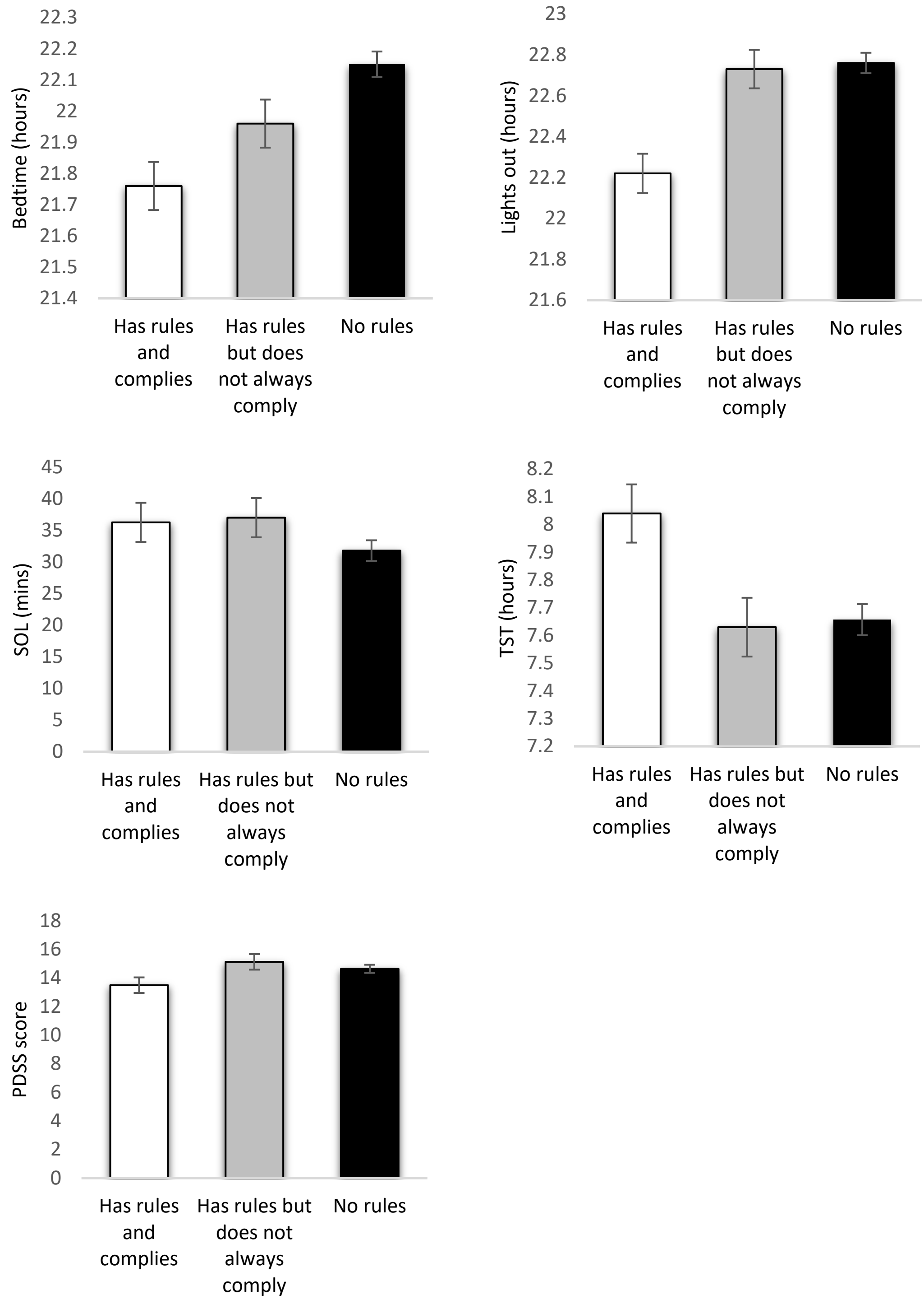
	Has rules and complies N = 131	Has rules and does NOT comply N = 123	No rules N = 441	
Bedtime (hrs)[b,c]	21.7 (0.8)	21.9 (0.8)	22.2 (0.4)	$F(2, 648) = 9.20, p < .001$
Lights out (hrs)[a,b]	22.3 (0.9)	22.7 (0.9)	22.8 (0.5)	$F(2, 648) = 11.29, p < .001$
SOL (mins)	36.5 (3.1)	37.1 (3.1)	31.8 (1.6)	$F(2, 650) = 1.66, p = .19$
TST (hrs)[a,b]	8.0 (0.1)	7.6 (0.1)	7.7 (0.6)	$F(2, 614) = 5.09, p = .006$
PDSS score	13.5 (0.5)	15.1 (0.5)	14.6 (0.3)	$F(2, 634) = 2.49, p = .084$
iNOD score	7.6 (0.5)	9.5 (0.6)	9.2 (0.3)	$F(2, 692) = 2.99, p = .051$
BtP score[a,b]	24.3 (0.5)	28.9 (0.5)	29.0 (0.2)	$F(2, 690) = 32.2, p < .001$

Note: SOL = sleep onset latency; TST = total sleep time; PDSS = Pediatric Daytime Sleepiness Scale (score range 0-32); iNOD = Index of Nighttime Offline Distress (score range 0 to 40); BtP = Bedtime Procrastination Scale (score range 9 to 45).

[1] Adjusted for covariates: age, gender, naps, caffeine, evening light.

[2] [a]Sig. difference between Comply and Non Comply group; [b]Sig difference between Comply and No Rules group; [c]Sig. difference between Non-Comply and No Rules group

Figure 9: Estimated marginal means and standard error for rule group and sleep outcome measures



Are parent-set technology use rules associated with adolescent sleep and sleepiness?

A series of univariate general linear models were run to assess the impact parent-set technology rules (presence of parent-set rule and/or compliance to rule) had on bedtimes, lights out times, SOL, TST and daytime sleepiness (PDSS scores) on school nights. The main effect of parent-set technology rules on bedtimes was significant ($p < .001$). Post-hoc analyses revealed that those who had no rules went to bed 22.1 minutes later than those who had a rule and complied to it ($p <.001$, $d = 0.62$), and 11.3 minutes later than those who had a rule and did not always comply to it ($p = .033$, $d = 0.33$). However, there was no difference in bedtimes between the two groups that had technology rules, regardless of whether they complied or not ($p = .10$).

The main effect of the parent-set technology rules on lights out times was also significant ($p < .001$). Those who had a parent-set rule and complied to it turned their lights-out 34.5 minutes earlier compared to those with no rules ($p < .001$, $d = 0.70$), and 32.2 minutes earlier than those who had rules but did not comply to them ($p < .001$, $d = 0.63$). However, there was no significant difference in lights out times between those who did not comply to their parent-set rule(s) and those with no rules ($p = .72$).

The main effect of the parent-set rule variable on TST was also significant ($p = .006$). As with lights out times, those who had a rule and complied to it obtained 22 more minutes of TST on school nights compared to those with no rules ($p = .004$, $d = 0.43$) and 25.1 more minutes of TST compared to those who did not comply to their parent-set rule(s) ($p = .008$, $d = 0.35$). There was also no significant difference in TST on school nights between those who did not comply to their parent-set rule(s) and those with no rules ($p = .68$). Finally, there was no significant main effect of parent-set technology rules for SOL ($p = .33$) or daytime sleepiness ($p = .09$). All sleep and sleepiness measures changed significantly with age (Supplementary Table 4); however, the parent-set rule effects on sleep did not change with age (no significant age by group interaction, all $p >.005$).

Do parent-set technology use rules moderate the link between FoMO/bedtime procrastination and adolescent sleep/daytime sleepiness?

Analyses yielded main effects of FoMO on bedtimes, lights out time, SOL, TST, and daytime sleepiness. FoMO was associated with later bedtimes, b = .76, SE = .33, p =.018, 95% CI [.13, 1.4], later lights out times, b = 1.41, SE = .27, p <.001, 95% CI [.88, 1.9], longer SOL, b = .020, SE = .009, p =.021, 95% CI [.003, .037], less TST, b = -1.23, SE = .25, p <.001, 95% CI [-1.7, -.74], and more daytime sleepiness, b = .201, SE = .049, p <.001, 95% CI [.11, .30]. When the parent-set technology rule variable was added as a moderator, moderation analyses revealed there was no significant interaction between parent-set rule group and FoMO on any of the sleep outcome variables or daytime sleepiness.

For bedtime procrastination (BtP), there was a main effect of BtP on bedtimes, lights out time, SOL, TST, and daytime sleepiness. BtP was associated with later bedtimes, b = 2.36, SE = .26, p <.001, 95% CI [1.8, 2.8], later lights out times, b = 3.09, SE = .20, p <.001, 95% CI [2.7, 3.5], longer SOL, b = .036, SE = .007, p <.001, 95% CI [.022, .051], less TST, b = -2.67, SE = .19, p <.001, 95% CI [-3.1, -2.3], and higher daytime sleepiness scores, b = .46, SE = .039, p <.001, 95% CI [.39, .54]. When the parent-set technology rule variable was added as a moderator, analysis revealed no significant interaction between parent-set technology rule group and bedtime procrastination (BtP) scores on any of the sleep outcome variables. However, there was a significant interaction between BtP and parent-set technology rule group on daytime sleepiness scores, R^2 *change* = 0.07, F (2, 588) = 3.28, p = .03. Post-hoc pairwise comparisons revealed that higher bedtime procrastination scores were associated with higher daytime sleepiness scores (PDSS) for all three groups. However the effect was greater for those with no parent-set rules, b = 0.48, SE = 0.04, p <.001, 95% CI [0.40, 0.57] compared to those with parent-set rules (rule and comply: b = 5.48, SE = 2.72, p =.044, 95% CI [0.15, 10.81]; and those with a rule but *not* always complying: b = 6.06, SE = 2.78, p =.029, 95% CI [0.59, 11.52]). For those who had parent-set technology rules, there was no significant difference in PDSS scores (p = .76) between those who indicated they do always comply and those who indicated they do not.

Discussion

The aim of this study was to investigate the relationship between parent-set technology rules and how compliance to these rules might relate to sleep and daytime sleepiness in adolescents. Additionally, we aimed to investigate the links between sleep and BtP as well as FoMO, and whether parent-set technology rules might moderate these links. Our findings suggest that parent-set technology rules may play a protective role in adolescent sleep, but also that adolescents' compliance to these rules may be important for achieving earlier lights out times and more TST on school nights. The findings also suggest that parent-set rules may not be potent enough to weaken the relationship between the adolescent's levels of FoMO or BtP and sleep outcomes. This study adds to the emerging evidence base regarding parent-set technology rules and their relationship with sleep outcomes (Khor et al., 2020).

Consistent with previous research, we found that the presence of having at least one parent-set technology rule was associated with earlier bedtimes on school nights (Buxton et al., 2015; Khor et al., 2020; Pieters et al., 2014). This was compared to the group of adolescents who did not have any rules. Interestingly, compliance did not appear to matter in the case of bedtimes, where no significant difference was found between those adolescents who always complied to their parent-set technology rules and those who had rules but did not always comply. This finding suggests that simply setting a parent-set technology rule could be protective of bedtimes for adolescents regardless of their compliance to it. However, when it came to lights out times and TST, compliance to the rules did matter. Adolescents who had at least one parent-set technology rule and indicated that they always complied to their rule(s), turned their lights out 34 minutes earlier and obtained 22 more minutes of TST on school nights compared to their peers who did not have rules. They also turned their lights out 32.2 minutes earlier and obtained 25.1 minutes more TST on school nights compared to their peers who had parent-set technology rules but did not always comply to them. It should be noted there was no significant difference in lights out times and TST for those who had rules yet did not always comply and those who had no rules. The improvement in TST in our study is similar to that found in a one-week mobile phone restriction study (i.e., 19 minute increase in TST; Bartel et al., 2019) and the 27 minute increase in TST found in a school-based motivational sleep education program that involved parents (Bonnar et al., 2015). This is meaningful, as it appears parents setting a rule and monitoring compliance could help adolescents receive possible benefits of earlier lights out times and longer TST on school nights that are comparable to a one-week researcher led mobile phone restriction intervention and a school-based motivational intervention.

Moreover, our findings support those of Buxton et al. (2015) who found in a survey of parents of children aged 6-17 years, that adolescents whose parents always enforced rules about how late they could use cell phones slept more than adolescents whose parents only sometimes enforced these rules, or had no rule at all. However, our findings contrast those of Peltz et al. (2019), who found that parental enforcement of a rule regarding evening screen time did not significantly predict adolescents' self-reported sleep duration, and also Richardson et al. (2021) who found parental control over technology use did not predict improvements in adolescent sleep. We propose that the difference in these findings could be explained by the populations surveyed: in our study we collected data from students, whereas Peltz et al. (2019) and Richardson et al. (2021) surveyed parents. Arguably, whether adolescents perceive they have a parent-set rule for technology and their report on compliance is likely to be more valuable than asking parents. There is a possibility parents may respond in a socially desirable way for both sleep patterns and parent-set rules (Short, Gradisar, Lack, Wright, & Chatburn, 2013). Only 50% of adolescents reported having at least one parent-set technology rule compared to Peltz et al. (2019) where 70% of parents reported having pre-bedtime screen rules. Richardson et al. (2021) asked parents to report their control over their adolescent's technology use, however in our study 48.2% of adolescents reported that they do not always comply to their rules. It is possible a parent may perceive they have control, and their adolescent is following the rules, but this may not always be the case. Parents may not be the most accurate source of this information due to the many biopsychosocial factors in adolescence (e.g., increased autonomy, circadian phase delay, academic/social commitments, desire to use devices and compliance to rules; Short, Gradisar, Lack, Wright, & Chatburn, 2013). For sleep, previous evidence suggests that parents of adolescents may overestimate the amount of sleep their child obtains on both school nights and weekends (i.e., for sleep duration parents reported 35-45 minutes more on school nights and 40-90 minutes more on weekends compared to adolescent reports; Short, Gradisar, Lack, Wright, & Chatburn, 2013).

For SOL and daytime sleepiness, our findings indicated parent-set technology rules were not related to the time it took adolescents to fall asleep on school nights or next-day daytime functioning. This is in line with a previous meta-analysis that found no association between technology use and SOL (Bartel et al., 2015). Alternately, a long SOL (and perception of daytime sleepiness) could be explained by a mismatch between circadian timing and the sleep attempt (Crowley et al., 2018), rather than technology use or the presence or absence of a technology rule.

Our study additionally aimed to investigate the role of FoMO and BtP in this context. In line with previous research, FoMO was associated with later bedtimes, later lights out times, longer SOL, less TST (Scott et al., 2021; Scott & Woods, 2018), and more daytime sleepiness. However, we did not find interaction effects between FoMO and parent-set technology rules, perhaps indicating that parent-set technology rules do not attenuate the relationship between FoMO and sleep outcomes in adolescents. This highlights the need to develop alternate intervention strategies to address the cognitive and behavioural factors of FoMO on sleep outcomes (Scott & Woods, 2018) as parent-set technology rules may not be potent enough to address the potential impact FoMO may have on sleep.

Also in line with previous research, BtP was associated with less TST (Kadzikowska-Wrzosek, 2020) and also later bedtimes, later lights out times, longer SOL, and more daytime sleepiness. Between our rules groups it was found that those who did not always comply to their rules and those who had no rules self-reported a higher tendency for bedtime procrastination compared to those who had parent-set technology rules and indicated they always complied to them. For the moderation, although we did not find an interaction between BtP and parent-set technology rules on any of the sleep outcome variables, we did find a significant interaction for daytime sleepiness scores. Here, a stronger association was found between BtP and sleepiness for adolescents who did not have any parent-set technology rules, compared to those who did. Therefore, it is possible that parent-set technology rules may act as a buffer to the potential negative impacts of bedtime procrastination on next-day daytime functioning. Taken together however, it appears that the association between adolescents' individual tendencies (i.e., FoMO and BtP) and sleep outcomes (i.e., bedtimes, lights out times, SOL, and TST) do not substantially change as a function of parent-set technology rules. For

BtP this also highlights the need to develop an alternate strategy to mitigate the potential that bedtime procrastination has to displace the sleep process (Exelmans & Van den Bulck, 2021).

It is possible parental *monitoring* of compliance could explain some of the findings in this study, especially between those who had rules and always complied, and those who had rules but did not always comply. Previous research has indicated that parental monitoring has been associated with better sleep quality and longer sleep opportunity, but also that inconsistency (e.g., to enforce rules) has been associated with poorer sleep quality (Khor et al., 2020). Therefore, it could be posed that adolescents that indicated they always complied to their rules, were more likely to have parents who/that were monitoring their compliance to the rules they had set, which may have been a crucial factor associated with the sleep benefits received in this group. Arguably, other parenting factors may have contributed to these findings. Currently, there is an insufficient evidence base in the area of parenting factors that have investigated autonomy granting, permissiveness, and non-specific household rule-setting, and only an emerging evidence base for monitoring and inconsistency, and their associations with sleep in adolescents (Khor et al., 2020).

Limitations and Future Directions

Whilst the present study addressed the dearth of scientific investigation into the influence of parental rules on adolescents' sleep, we did not ask about parental monitoring of rules and compliance to them. Therefore, we are unable to determine if parents were monitoring the rules in the group of adolescents who complied to their rules, or whether there might be another reason to explain compliance (e.g., avoiding punishment, agree with the rules). Additionally, we are unable to determine what percentage of time our "did not always comply" group complied vs did not comply with their parent-set rules (e.g., does the group consist of adolescents who complied 85% of the time or only 5% of the time?). On the contrary, we also did not ask adolescents about the level of independence given to them by their parents. Independence or autonomy compared to parental monitoring/rule-setting could be a factor of interest. One strength of our study that should be noted is controlling for a number of significant covariates known to affect adolescent sleep (i.e., caffeine, naps, gender, age, light, SES). By doing so, we can be more confident of the unique relationships between parent-set rules and sleep. However, for SES it should be noted that most of our sample came from similar, more affluent SES backgrounds. It would of value for future research to investigate some of the racial, ethnic, and social disparities that could influence sleep and/or parental rule setting (Williams et al., 2015). Other variables to be considered in future research is the role of mental health (e.g., depression, anxiety, stress), age and gender on sleep and parent-set rules. Although the current study's cross-sectional design precludes causal conclusions to be drawn, it provides justification for future experimental research to test whether parent-set technology rules could be a promising intervention to improve adolescent sleep.

Conclusion

The presence of at least one parent-set technology rule is associated with adolescents achieving an earlier bedtime on school nights compared to their peers who do not have rules (regardless of compliance). However, the presence of a parent-set technology rule was not associated with earlier lights out times and increase TST on school nights. Here, compliance mattered, where earlier lights out times and more TST on school nights was only associated with compliance to parent-set technology rules. While getting into bed is an important step for beginning the sleep process, the moments in which adolescents turn their lights out and attempt sleep is arguably the most important intervention point. Consequently, compliance to parent-set technology rules may need to be monitored by parents to ensure adolescents receive any potential benefits from parent-set technology rules. This study further highlights the negative relationship between BtP and FoMO on sleep outcomes. As BtP and FoMO did not change as a function of parent rules, it appears having parent-set rules could be beneficial for adolescents regardless of their level of BtP/FoMO. Future research is needed to continue investigating the external (e.g., parent-set technology rules) and internal mechanisms (e.g., BtP/FoMO) to improve adolescent sleep.

CHAPTER 4

TEENAGE SLEEP DILEMMA: EVALUATION OF A MOTIVATIONAL TECHNOLOGY REDUCTION INTERVENTION FOR ADOLESCENT SLEEP

Abstract

There is limited research that has investigated the effect of technology restriction interventions on adolescent sleep. The aim of this study was to investigate whether a technology restriction intervention with a motivational interviewing (MI) framework + parental support could improve adolescent sleep. Specifically, the 1-hour per school night phone restriction intervention used by Bartel and colleagues' (2019) was replicated and extended by requesting that adolescents also restrict the use of YouTube and TikTok on all other devices during this 1-hour. Motivation, adherence, and parent support were measured to test whether these factors moderated sleep outcomes between baseline and post intervention. A total of 78 adolescents (52.6% female, M = 15.0, SD = 0.27, age range 15-16 years) were recruited from a high school in South Australia. Participants completed a baseline survey containing self-report measures of sleep and technology use 1-week prior to the intervention. During the school session, the intervention instructions were delivered, and motivation was measured at this time. The post intervention survey regarding self-reported sleep, technology use, adherence, and parent support was collected 1-week following the intervention. Results indicated that adolescents stopped using their phones ~58 minutes earlier during the intervention week. However, no significant changes in sleep outcomes were observed (increase of ~12 minutes of TST at post intervention approached significance p =.08). A significant increase in TST of ~22 minutes was observed for those who adhered to the intervention 0-2 nights, but not for those who reported high adherence (possibly already "good sleepers"). Parent support and motivation did not moderate the relationship between sleep and phone stop times between baseline and post intervention. No other significant interactions were found for adherence and any other sleep variables/phone stop times. These findings indicate that a technology restriction intervention with an MI component + parental support is a feasible and acceptable intervention. Despite these promising outcomes, it appears that uptake and adherence remain to be barriers for adolescents succeeding with technology restriction interventions.

Introduction

Pre-sleep technology use has been identified as a psychosocial factor that is likely to be contributing to sleep loss in adolescents (Crowley et al., 2018). This is due to consistent cross-sectional evidence that has found a relationship between electronic media use and insufficient sleep in adolescents (Carter et al., 2016; Hale & Guan, 2015; Lund et al., 2021). More specifically, it is thought that interactive forms of media (e.g., mobile phones) may have a greater impact on sleep compared to passive forms of media in this age group (e.g., television; Lund et al., 2021). Despite this consistent evidence, the current research base is saturated with cross-sectional studies, and many reviews have advocated for experimental or intervention studies to confirm the suspected relationship between electronic media and sleep in adolescents (Bartel & Gradisar, 2017; Carter et al., 2016; Hale & Guan, 2015; Lund et al., 2021).

To the best of my knowledge, there has been very limited research on technology interventions with adolescents, specifically those involving restricting evening device use (e.g., phones) and the subsequent effects on adolescent sleep outcomes. The first study to do so, by Harris et al. (2015), implemented an electronic curfew for devices and found no improvement in the sleep outcomes of adolescent athletes compared to a control group. The authors attributed this finding to implementing a uniform electronic media restriction time of 10:00 p.m., which was approximately the same as the participants' pre-intervention bedtimes (Harris et al., 2015). Another study of adolescent athletes allowed self-selection to participate in either a 48-hour technology restriction intervention or control group of no technology restrictions (Dunican et al., 2017). This study also found no significant differences in sleep onset or sleep duration in the electronic device restriction group compared to no restrictions group (Dunican et al., 2017). Based on this research, developing a uniform approach to manipulating all technology use at either a certain time or for a certain duration may not be appropriate, given the different sleep needs and sleep timing across adolescents.

Instead of a uniform technology restriction time, or restricting *all* technology, Bartel et al. (2019) aimed to test the effects of a 1-week mobile phone restriction intervention individualised to each adolescent. Participants were asked to stop using their mobile phones 1-hour earlier on school nights than usual for 1 week, with no instruction to stop using other technology (e.g., TV, computers;

Bartel et al., 2019). After 1 week, adolescents reported that they stopped using their phone ~ 80 minutes earlier, turned out their lights ~ 17 minutes earlier, and gained an average of 21 minutes more total sleep time (TST) each school night - a meaningful extension of sleep equating to ~1 hour and 45 minutes extra TST across the school week (Bartel et al., 2019). This 21-min increase in sleep per school night incited from a low intensity, single instruction intervention is promising when compared to the 48-min and 28-min increases from a more intensive 8-week clinical intervention and 4-week school-based sleep intervention respectively (Bonnar et al., 2015; Gradisar, Dohnt, et al., 2011). However, while the Bartel et al. (2019) findings appear promising, challenges with participant recruitment and compliance were faced in each of these technology restriction studies.

In the most recently published study, Perrault et al. (2019) investigated the effects of an electronic curfew paired with a 40-minute educational workshop (Perrault et al., 2019). It appears Perrault et al. (2019) may have included a sleep education workshop to educate adolescents on sleep and to potentially appeal to them to try the intervention. In line with Bartel et al. (2019), participants who completed this electronic curfew received various sleep benefits, including earlier lights out times, earlier sleep onset, and more TST (Perrault et al., 2019). However, also in line with the previous intervention studies (Bartel et al., 2019; Dunican et al., 2017; Harris et al., 2015), there was significant attrition after the electronic curfew instruction was introduced. Specifically, of 569 participants who attended the workshop (and thus received intervention instructions), only 32% completed the intervention (Perrault et al., 2019). Similarly, Bartel et al. (2019) reported a ~26% completion rate, Harris et al. (2015) found only 7 adolescents of 45 fully adhered to the experiment protocol (15%), and Dunican et al. (2017) excluded 5 out of 14 participants who self-selected to be in the electronic restriction group for obtaining electronics from the control group participants. Taken together, this suggests interventions where pre-sleep electronic device use is restricted could improve adolescent sleep outcomes *when adhered to*. However, it appears adolescents have low motivation to either engage with or adhere to an intervention where their evening device use is altered.

This indicates that adolescents' motivation to change and factors that may influence this would be an important target for technology-and-sleep intervention studies. To address low intrinsic motivation, previous school education programs that have aimed to improve sleep habits in adolescents (e.g., regulating delayed sleep timing), have adapted a motivational interviewing (MI) framework to increase motivation to make behavioural change in sleep habits (Bonnar et al., 2015; Cain et al., 2011). MI is a goal-directed counselling technique that aims to improve intrinsic motivation by education of problem behaviours, exploring ambivalence to change, and delicately turning determination into behavioural change (Miller & Rollnick, 2002). With reference to the transtheoretical model of change (i.e., Stage 1: pre-contemplation- not considering change; Stage 2: contemplation- ambivalent about changing; Stage 3: determination- determined to change; Stage 4: action- changing behaviour; Stage 5: maintenance- maintaining behavioural change; Prochaska & DiClemente, 1983), it is suggested that many of the adolescents in previous electronic device curfew studies would be in either the Stage 1 "pre-contemplation" or Stage 2 "contemplation stage" of change. This is suggested as many adolescents are declining to attempt these interventions. Further, while some adolescents initially consent, many seem unable to adhere. Previous inclusion of MI within a school education program improved not only sleep knowledge, but also motivation to adhere to a bright light protocol, resulting in improved sleep outcomes and mood relative to a control group (Bonnar et al., 2015). However, without the inclusion of MI, it appears promotion programs can improve adolescents' sleep knowledge, but that this increased knowledge may not successfully translate to sleep-related behavioural change or long-term improvements in sleep (Cassoff et al., 2013). Consequently, we suggest a single MI session could assist adolescents to engage with a 1-hour technology restriction intervention. To the best of our knowledge, this has not yet been investigated, and thus it is an aim of the present study.

While increasing internal motivation is one factor to target, external motivators that could increase adherence should also be considered. Parental engagement, warmth, and support, including routines and rule setting, have been identified by adolescents and previous research as important for improving sleep outcomes (Jakobsson et al., 2022; Khor et al., 2020; Pillion et al., 2022). While acknowledging that adolescence represents a transition towards self-reliance, parents still have an important role to play in this period and may help support adolescents to overcome barriers to behavioural change and thus achieve better sleep outcomes (Khor et al., 2020). Specifically with technology, it was found in **CHAPTER 3** that the presence of at least one parent-set technology rule (e.g., phone out of the bedroom overnight) was associated with earlier bedtimes for adolescents compared to their peers who did not have one of these parent-set rules. In addition, those adolescents who always complied with rules achieved earlier lights out times and more TST on school nights (**CHAPTER 3**). This evidence suggests parents could play a key role in supporting their adolescent with an intervention involving behavioural change aimed at improving sleep on school nights (e.g., enforcing the rule/supporting their adolescent to comply to a 1-week phone restriction intervention). To the best of our knowledge, the inclusion of parents in a technology restriction intervention for adolescents has not yet been investigated, and thus it is also an aim of the present study.

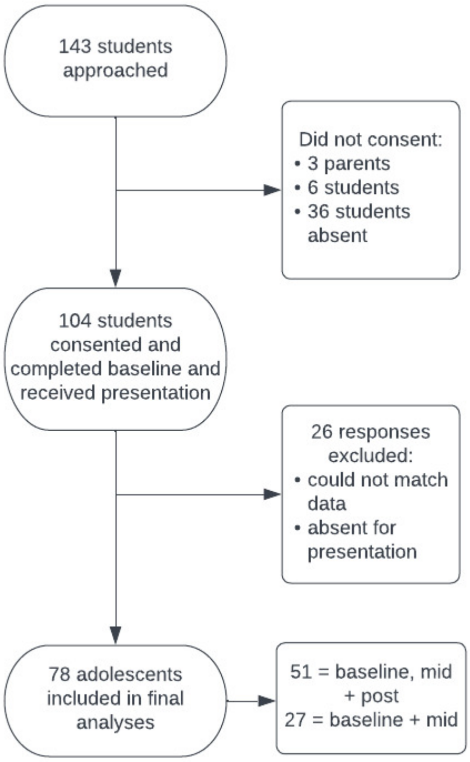
Overall, the present study aimed to investigate whether a technology restriction intervention with a MI framework + parental support could improve adolescent sleep. This study sought to replicate the 1-hour mobile phone restriction intervention on school nights used in Bartel et al. (2019), and extend on this by also requesting that adolescents restrict the use of two specific apps (i.e., YouTube and TikTok) on all other devices during this 1-hour. It was decided to alter the intervention instructions to include these two apps on all other devices based on the findings regarding devices and apps in **CHAPTER 2**. In addition, this study included a MI session and parental involvement to investigate whether these two factors might help to improve intrinsic motivation and reduce barriers to change, and in turn increase adherence to the intervention to improve sleep. It was predicted that motivation, adherence, and parent support might moderate the relationship between sleep at baseline and post intervention.

Method

Participants

A total of 140 adolescents were approached from an independent secondary school in Adelaide, South Australia. Of these, 104 adolescents initially consented to participating in the study and completed the baseline questionnaires. The final sample consisted of 78 adolescents (52.6% female, *M* = 15.0, SD = 0.27, age range 15-16 years). Participants who completed either all three assessment points or the baseline and mid-questionnaires were included in the final analyses (Figure 10 presents a participant flow chart). Participants who did not have mid-data were excluded as it could not be determined whether they attended the school education session There was no other specific inclusion or exclusion criteria as we did not want to restrict the generalisability of the findings. Socioeconomic status (SES) of the sample was $M = 9.6$, SD = 1.1 (range from 1 = SES disadvantage – 10 = SES advantage; Australian Bureau of Statistics, 2016). Ethics approval for this study was obtained from the Human Research Ethics Committee, Flinders University.

Figure 10: Intervention study participant flow chart



Procedure

Participating adolescents were recruited from a high school in South Australia. An on-site school researcher co-ordinated the distribution of information sheets, consent forms and communicated information to parents/caregivers. Informed consent was obtained from adolescents and their parents using an opt-out procedure. Parents were provided with the information sheet at the start of the school term that detailed the study outline and time commitment from their adolescent (baseline questionnaires, 1x face-to-face MI session + mid questionnaire, follow up questionnaire 1-week later). Parents were also informed that there would be a brief 3-minute online video made accessible to them after the school education session, summarising what their adolescent learned during the 45-minute education session and tips to support them (Appendix C). Adolescents read the information sheet and provided their consent to participate on the day of baseline questionnaires administration. Adolescents who did not consent at this time also did not complete the follow up questionnaires but were still able to attend the MI session if they chose to. Adolescents whose parents did not give consent to participate did not attend the MI session. The on-site school researcher co-ordinated teachers' and classroom resources for students to complete the baseline questionnaires via Qualtrics (completion time ~ 12 min). One week later, the PhD candidate (MP) provided a 45-minute face-to-face MI session aimed to motivate adolescents to comply to a 60-min per day mobile phone + app restriction over the coming school week. At the conclusion of this session, adolescents completed the mid-questionnaire (completion time ~2 min). After 1-week, the on-site school researcher co-ordinated teachers and classroom resources for students to complete the follow-up questionnaire via Qualtrics (completion time ~ 8min).

Materials

Demographics

Personal and demographic information collected in the baseline questionnaire included first name, last name, date of birth (D.O.B), gender (i.e., male, female, non-binary, prefer not to say), age, year level, and postcode. Names and D.O.B were collected in all three questionnaires (baseline, mid, and post intervention questionnaires) to match up data across time points. Once responses were matched, responses were de-identified using an individual ID code to maintain anonymity, and the document containing and identifying information was deleted. Home postcodes were collected to calculate socioeconomic status (SES) using the SEIFA index of economic advantage and disadvantage which is an area level measure of relative socioeconomic position constructed from Australian Census data (Australian Bureau of Statistics, 2016).

Sleep

Sleep was measured during baseline and post intervention questionnaires. Sleep items were based on the School Sleep Habits Survey (SSHS; Wolfson et al., 2003). The SSHS is a validated self-report measure of school week sleep pattern estimates in adolescents that has been validated against sleep diaries (Wolfson et al., 2003). The SSHS measures bedtime, sleep onset latency (SOL) and sleep offset (i.e., morning wake up time) over the past week (Wolfson et al., 2003). Given the portability of technology in the bedroom, and that now 'bedtime' does not necessarily signify the sleep attempt (Exelmans & van den Bulck, 2017), extra sleep questions were asked in addition to the SSHS questions. These included their usual lights out time and their usual "sleep attempt" time (Exelmans & Van den Bulck, 2017). Using a combination of these sleep variables, total sleep time (TST) could be calculated ([sleep attempt time + SOL] – wake up time = TST). The present study focused only on school nights in line with Bartel et al. (2019), and also due to the vast differences between weekday and weekend sleep in adolescents (i.e., less sleep reported on school nights; Crowley et al., 2014).

Phone stop time, YouTube and TikTok restriction

Phone stop time was measured using a single item during baseline and follow up questionnaires. Before the intervention, adolescents were asked what time they usually stop using their mobile phone at night (clock time response). After the intervention, adolescents were asked over the past week, what time they stopped using their mobile phone on school nights (clock time response). The comparison between these two time points was used to measure compliance to the intervention (i.e., change in mobile phone stop times). Based on the findings of **CHAPTER 2**, we also requested that adolescents did not use YouTube or TikTok on any other device during this 1-hour of phone restriction. Adherence to the intervention was asked directly, with participants indicating the number of school nights they followed the intervention's instructions (0 = 'did not adhere to the experiment' to 5 = 'adhered every school night').

MI session

The aim of the motivational session was to deliver educational content about adolescent sleep and technology use and to motivate adolescents to comply to the 1-week school night mobile phone, YouTube, and TikTok restriction. The MI session was approximately 45 minutes in length and delivered via PowerPoint to adolescents at their school. Education on sleep needs and the "perfect storm" model of adolescent sleep was described (Crowley et al., 2018), followed by a classroom abridged excerpt of the Netflix documentary *The Social Dilemma.* This sleep psychoeducation was used to educate teenagers on how much sleep they should be getting (i.e., ~9 hours a night) and an abridged video of *the Social Dilemma* was used to explain to adolescents why it could be hard for them to achieve this, as the aim of big technology companies is to keep individuals engaged on their devices for as long as possible, which could be impinging on valuable sleep time. *The Social Dilemma* classroom abridged version was free to access and show to students once the PhD candidate registered the school presentation on *the Social Dilemma's* website (www.thesocialdilemma.com). The entire classroom version was not shown (excluded the political dilemma and no themes shown of self-harm and suicide). The intervention instructions were delivered towards the end of the MI session. The term "phone restriction" was rephrased to *phone switch time* to change the negative connotation associated with "restriction". Following this, we provided adolescents with suggestions of less "harmful" screen and non-screen activities as ideas to "switch" to during the 1-hour intervention (Appendix C).

Motivation

Immediately following the MI session, a single measure of motivation (the mid questionnaire) was distributed to students to complete. Three individual 'motivational rulers' were used: 1) *How important is it to you to try this experiment;* 2) *How confident are you that you can do the 1-week experiment;* 3) *How much do you want to do the 1-week experiment.* Reponses ranged from 0 to 10, with 0 indicating 'not important', 'not confident' 'do not want to', respectively, and 10 indicating 'very important' 'very confident' or 'very much want to'. Each scale's score was considered individually (i.e., not combined to a total score). Previous literature that has found adolescents' readiness to comply with therapy instructions and their intention to make behavioural change related to sleep can be assessed by their desire, ability, reason and need to change (i.e., DARN; Micic et al., 2019). These three questions were drawn from this literature to assess desire, ability and need to change their device use, respectively, by complying to the intervention's instructions.

Parent video/parent support

The link to a single YouTube video (2-min 24-sec runtime) was distributed to parents by the school researcher that contained a summary of the MI session, and the intervention instructions that were provided to students. The parent video aimed to encourage parents to support their adolescents with the 1-week intervention. Specifically, it contained a short clip provided by *the Social Dilemma* available on their website (www.thesocialdilemma.com) interlaced with a video commentary and slides by one of the researchers (MG). This link was made accessible to parents immediately following the school education/motivation session and remained available for the duration of the 1-week intervention. From YouTube, we were able to ascertain the number of unique viewers (i.e., parents) that watched the video over the course of the week, a method used to measure parental involvement in a previous study (Bonnar et al., 2015).

Adolescents' perceptions of whether their parents supported them during the intervention week was also measured to support the parent video measure. A single question was asked (i.e., *"Did you parent/guardian support you to complete the 1-week experiment?")* to which adolescents responded either "Yes" or "No".

Statistical Analyses

Data were analysed using IBM SPSS Statistics v.27. Distributions of the data were assessed visually using stem and leaf plots and histograms. Any significant outliers (e.g., sleep attempt time = 3:00 a.m.) were adjusted to the next value lower/higher within the plot. Generalised estimating equations (GEEs) were used to assess the effect of the intervention on sleep variables and phone stop times from pre- to post-intervention. GEEs were also used to test for moderation effects of motivation, adherence, and parent support variables. Adjusted pairwise post-hoc analyses allowed for time comparisons on each outcome variable. For continuous predictor variables (i.e., adherence and motivation), a median split was used to allow for pairwise comparisons on significant outcome variables. GEEs were chosen due to their ability to cope with missing data and unequal sample sizes.

Results

Following the MI session, adolescents rated (out of 10) their perceived *importance* to try the intervention as M= 4.2, SD= 2.9; how *confident* they were that they could complete the intervention as M= 6.7, SD = 3.3; and how much they *wanted* to do the intervention as M= 3.6, SD = 2.9. For the intervention, a main effect was found for phone stop time, where adolescents reported that they stopped using their phones ~58 minutes earlier at post intervention compared to baseline (see Table

7). For sleep variables, there was an increase of ~12 min in TST from baseline to post-intervention, however this change only approached statistical significance (p = .08). There were no significant changes observed for any of the other sleep variables between baseline and post intervention (i.e., bedtime, lights out times, sleep attempt times).

Table 7: Estimated marginal means (standard errors) for sleep variables and phone stop time for baseline and post-intervention.

	Baseline M(SE)	Post M(SE)	Wald chi square	*p*
Phone stop time (hh:mm)	22:14 (0:07)	21:12 (0:07)	126.335	.000*
Bedtime (hh:mm)	22:00 (0:06)	21:56 (0:06)	.967	.32
Lights out (hh:mm)	22:25 (0:07)	22:19 (0:07)	2.511	.11
Sleep attempt time (hh:mm)	22:36 (0:07)	22:30 (0:07)	1.740	.19
TST (hours:mins)	7:45 (0:9)	7:57 (0:9)	3.004	.08

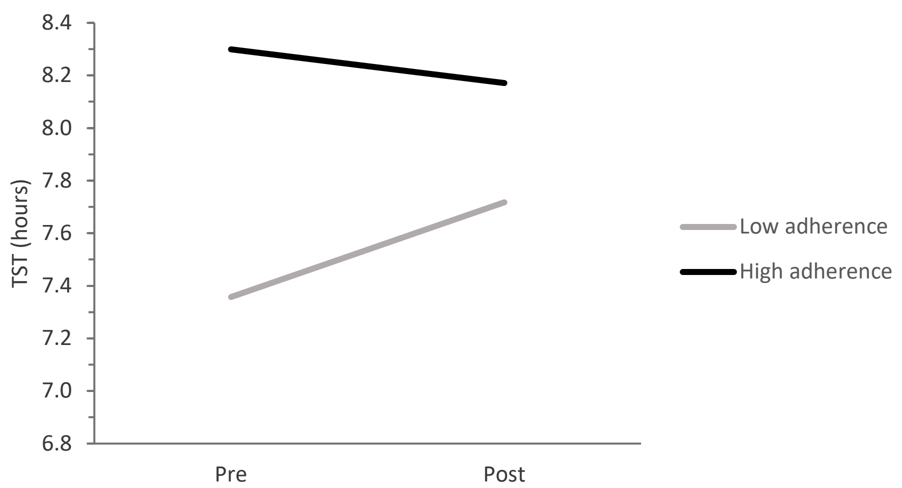
During the intervention week, the *main* activity adolescents reported choosing to "switch to" during the 1-hour of phone, YouTube, and TikTok restriction were (in order from most-to least popular): Watch Netflix or other streaming service (20.5%), homework on laptop (11.5%), watch free to air TV (3.8%), read a book (2.6%), gaming (2.6%), listen to music on another device, exercise, talk to other household members, sleep (all 1.3%). For adherence to the intervention, 16.3% of adolescents stated that they adhered to the experiment protocol every school night (i.e., 5 nights), 10.2% stated they adhered 4 school nights, 18.4% adhered 3 school nights, 22.4% adhered 2 school nights, 6.1% adhered for one night, and 26.5% stated they did not adhere to the experiment protocol.

Regarding parent support, there were 37 unique viewers that watched the parent video on YouTube throughout the week of the intervention (out of ~ 78 adolescents). This is consistent with adolescents' reports of parent support, with 47.4% adolescents indicating that their parent supported them across the week with the intervention (52.6% reported their parent did not assist them).

Moderators

A series of GEEs were run to assess the impact of adherence, motivation (i.e., confidence, want, importance), and parent support on sleep outcomes and phone stop time. For adherence, there was a significant interaction observed between time and adherence on TST, Wald = 6.66, *p* = .010 (Figure 11). Post-hoc comparisons revealed that for those in the high adherence group, there were no significant changes reported in TST from baseline to post intervention (*p* =.55). For those in the low compliance group, there was a significant increase in TST observed of ~22 minutes from baseline to post intervention (*p* =.005). There were no other interaction effects observed between time and adherence on any other sleep outcomes or phone stop times. No interaction effects were found between time or any of the other moderators (i.e., motivation or parent support) on sleep outcomes or phone stop times.

Figure 11: TST at baseline and post-intervention for low and high adherence groups



Discussion

The aim of the present study was to investigate whether a technology restriction intervention with an MI framework + parental support could improve adolescent sleep. Specifically, we aimed to replicate and extend on Bartel and colleagues' (2019) 1-hour phone restriction intervention by also restricting the use of two apps (i.e., YouTube and TikTok) and the addition of a motivational session and parent involvement. The purpose of measuring motivation and parental involvement was to investigate whether these two factors might help to improve intrinsic motivation and reduce barriers to change, and in turn increase adherence to the intervention to improve sleep. Overall, the findings suggest this technology restriction intervention was feasible for adolescents, as significantly earlier phone stop times were reported in line with the intervention protocol. However, this did not appear to translate to statistically significant improvements in sleep (although a promising finding of increased TST by ~12 minutes from baseline to post intervention was observed).

In line with Bartel et al. (2019), adolescents reported that they stopped using their mobile phones significantly earlier (in our study ~58 min earlier) during the intervention week. However, in contrast to Bartel et al. (2019) and Perrault et al. (2019), the present study did not find any significant improvements in sleep variables during the 1-week intervention. While not statistically significant, it could be argued that an increase in ~12 minutes of TST is clinically meaningful, given that an additional ~12 minutes each night can equate to 1 extra hour of sleep across the school week for sleep deprived teenagers. In addition, by using an opt-out consent procedure, it is argued that this study observed an increase (albeit not statistically significant) in TST among a real-world sample of teenagers (e.g., likely capturing various levels of technology use and motivation) compared to previous opt-in samples, where some adolescents have willingly chosen to reduce their technology use (Bartel et al., 2019; Perrault et al., 2019). However, even with an opt-out sample, intervention uptake and adherence was low in the present study (~36% provided data at all three time points, with only 16.3% adhering to the protocol every school night). This low uptake and adherence is also in line with previous studies that have attempted technology restriction interventions (Bartel et al., 2019; Dunican et al., 2017; Harris et al., 2015; Perrault et al., 2019). Overall, while it appears this intervention was acceptable to adolescents given the change in phone stop times during the intervention week, it cannot be ruled out that socially desirable reporting occurred. If socially desirable reporting did account for the main effect of time, and adolescents did not change their technology use (or perhaps not to this magnitude) this could possibly explain the absence of changes in sleep outcomes during the intervention week.

For the moderators, we found that motivation (i.e., importance, confidence, and want to change) and parent support did not moderate the relationship between time and sleep outcomes/phone stop times. There was a significant interaction observed between adherence and TST, but adherence did not significantly moderate the relationship between time and any of the other sleep variables or phone stop times. Contrary to predicted, in the high adherence group, there was no significant change in TST. It should be noted that this group at baseline appeared to already be receiving close to adequate sleep (i.e., 8.3 hours of the recommended ~9 hours per school night; Hirshkowitz et al., 2015). Since participants in the high adherence group were already receiving more TST at baseline than their low adherence peers, perhaps this group of "good sleepers" consisted of adolescents who already use less evening technology, or these are the adolescents who already have established parent-set rules that restrict evening technology use. This could possibly explain why their sleep did not significantly change. For those in the low adherence group, perhaps even just 1 or 2 nights of attempting the intervention was enough change in their usual technology use to observe a significant increase in TST of ~22 minutes. It should be noted that these adolescents were receiving significantly less sleep to their peers in the high adherence group at baseline (~1 hour less and well below the recommended amount of sleep for adolescents; Hirshkowitz et al., 2015). It could be that these adolescents were the ones who "needed" the intervention, those who were big technology users, or might experience a sleep problem, where making even just some change (albeit not consistently for the whole week) was enough to increase the amount of TST received on school nights.

Despite the inclusion of a motivational session, uptake and adherence appear to remain as barriers to adolescents succeeding with a technology restriction intervention. The motivational session in this study attempted to employ the "come alongside" technique where adolescents, teachers, parents, researchers, and presenters in *the Social Dilemma* come together to make behavioural change to "take back our time" from the common enemy - the Big Tech companies. Results from the motivational rulers indicate that perhaps the motivational session did not fulfil the intended aim of motivating adolescents to try "taking an hour of their time back" by stopping their phone, YouTube and TikTok use 1 hour earlier. The average adolescent rated *importance* to try the intervention as low, and also rated their *want* to do the intervention as low, which were lower than those reported by adolescents embarking on bright light therapy for their sleep disorder (Micic et al., 2019). It might be that the motivational school education session was targeting a stage of change (i.e., contemplative/ambivalent) that adolescents in this sample may not have been ready for. It appears the average adolescent in this sample was likely in the pre-contemplative stage of change (i.e., not ready to consider change) given the ratings of low importance and perceived low need to try the intervention. These low ratings of importance and perceived need to try the intervention could also be explained by our opt-out sample. While opt-out consent may have increased our initial uptake and arguably serves to increase the real-world validity of our sample, it is suggested that this MI session might be more suited to adolescents who opt-in to a technology intervention or those who are further along the process of considering change (e.g., ambivalent).

Regarding parents, we had predicted that parents would likely be invested in wanting to support their child with a 1-week technology intervention. However, our prediction may have overestimated parents' intrinsic motivation to help their teenager reduce their technology use, with only 37 out of 78 (47.4%) parents watching the parent video, and less than half of adolescents reporting their parent supported them with the intervention during the week. This finding could be explained by the low-intensity, non-invasive method of attempting to involve parents (i.e., a ~3 min video). It might also be explained by parents missing the communication provided to them by the school regarding their involvement in the study, as we cannot definitively conclude that all parents checked their emails or even received this information. While this method of parental involvement has been used in a previous study (Bonnar et al., 2015), future research may need to include parents in a more active approach (e.g., face-to-face education session) to motivate *them* to support their adolescent to adhere to a technology restriction intervention.

Limitations and future directions

The absence of a control group presents as the major limitation of the current study. The present study intended to have three groups, comparing the above findings with a control group, and the motivational session alone (i.e., no parental involvement). Unfortunately, due to the ongoing COVID-19 pandemic, local restrictions, recruitment challenges, and time constraints, this resulted in the data collection of only one arm of the proposed experimental study: school motivation session + parental support. While the use of self-report measures for sleep and technology use has positives such as reducing participant burden, without objective measurements, we cannot rule out that adolescents may have responded in a socially desirable way (i.e., reporting earlier phone stop times) to match the experiment's instructions. In addition, we did not include a YouTube or TikTok stop time to directly measure whether this was ceased. Further to measures, as our study only measured motivation once, we could not determine whether any change in motivation occurred (i.e., whether motivation increased following our motivational session). Although our measure of parent support may not be able to inform us exactly how many parents watched the video (i.e., two parents of the same child may have watched on different devices), the view count does align approximately to the adolescents' report of perceived support. Future research should consider assessing motivation and parental support at multiple time points to explore whether these factors change as the result of a motivational session aimed at facilitating behavioural change in technology use. It appears this may be relevant for not only adolescents but parents too. Researchers may need to consider the active involvement of parents to motivate and support their adolescent with challenging behavioural changes regarding evening device use. While it could also be considered a strength of the current study, its homogenous sample was in the high-socio economic range. Future research should consider the use of more diverse samples of adolescents (and parents). Additionally, emerging research has found individual traits such as fear of missing out (FoMO; Scott & Woods, 2018), self-control (Exelmans & Van den Bulck, 2021), risk-taking (Reynolds et al., 2015) and "flow" (Smith, King, et al., 2017) might play a role in the relationship between technology and sleep outcomes. Future research should continue to investigate the links between individual factors and their relationship between sleep and technology use in adolescents.

Conclusion

These findings indicate that a technology restriction intervention with an MI component + parental support is a feasible and acceptable intervention for adolescents due to the significant reduction observed in mobile phone stop times. In addition, some meaningful increases in overall TST were observed for a real-world sample, and for those who were already receiving below the recommended amount of sleep per night for adolescents, adhering for just 1-2 nights might have been enough to see significant increases in TST. Despite these promising outcomes, it appears that uptake and adherence remain to be barriers for adolescents succeeding with technology restriction interventions.

CHAPTER 5

GENERAL DISCUSSION

Summary of Findings

Overall, this thesis sought to provide further evidence to explore the relationship between pre-sleep technology use and adolescents sleep outcomes. Specifically, this thesis (1) investigated the content (i.e., apps) and devices adolescents are engaging in at two distinct time points (i.e., the hour before bed and in bed before sleep onset); (2) the role parent-set technology rules, adolescents' compliance to these rules, and factors that might impact on compliance to these rules (i.e., FoMO and BtP) may play in adolescent sleep outcomes; and finally, (3) whether a 1-hour phone, YouTube, and TikTok restriction for the duration of 1 school week could improve the sleep outcomes in adolescents.

As previous research had suggested that complete technology restriction (i.e., all devices removed in the evening) was too challenging for adolescents to adhere to (Dunican et al., 2017; Harris et al., 2015; Perrault et al., 2019), **CHAPTER 2** sought to investigate whether certain devices or apps used at two specific time points might be associated with negative sleep outcomes in adolescents. The findings of **CHAPTER 2** helped to inform a more suitable approach for altering technology use in **CHAPTER 4**, where instead of removing all access to technology during the intervention, adolescents could "switch" to either a non-technology activity or a technology related activity (i.e., device or app) that was not associated with negative sleep outcomes. **CHAPTER 4** found that phones, laptops, gaming consoles, iPads/tablets and watching YouTube in the hour before bed or in bed before sleep onset, were associated with less favourable sleep outcomes such as delays in bedtimes, later lights out times and less TST. On the contrary, watching TV was associated with *earlier* lights out times. No other devices or apps at either time point were found to be associated with sleep outcomes (e.g., listening to Spotify, texting, Facebook, desktop computers). Overall, YouTube appeared to be the technological pre-sleep activity most consistently related with negative sleep outcomes.

CHAPTER 3 then sought to explore the relationship between parental rule setting regarding pre-sleep technology use and adolescents' compliance to these rules with sleep outcomes. **CHAPTER 3** also investigated the relationship between the individual factors of FoMO or BtP and sleep outcomes to explore whether these individual factors related to sleep and compliance to parent-set technology rules. Here it was found that adolescents who had a parent-set technology rule (whether the rule was implied or followed) went to bed earlier on school nights compared to their peers who did not have rules. However, compliance made a difference for other sleep outcomes where it was found that those who complied to their parent-set technology rules turned their lights out earlier and received more TST on school nights compared to those did not comply or did not have rules. While FoMO and BtP were found to be associated with negative sleep outcomes including later bedtimes and lights out times, longer SOL, less TST, and more daytime sleepiness, these individual factors did not change as a function of parent rules. Therefore, we concluded in **CHAPTER 3** that parents and rule setting may help support adolescents to follow an intervention designed to alter pre-sleep technology use, even for those adolescents who may experience FoMO/BtP. However, it appeared compliance was an important factor to receiving more TST on school nights, which was the overall intended sleep outcome of our proposed technology intervention.

Equipped with this new knowledge, this thesis then sought to expand on the findings of Bartel et al. (2019) in **CHAPTER 4** by including a motivational component and the support of parents with the hope that these additional factors may increase compliance to a 1-hour x 1-week phone restriction study on school nights. We designed the motivational session to enhance compliance due to the low compliance (and uptake) experienced in studies that had previously aimed to alter the evening electronic media use of adolescents and measure subsequent effects on sleep (Bartel et al., 2019; Dunican et al., 2017; Harris et al., 2015; Perrault et al., 2019). Based on findings in **CHAPTER 2**, we extended on the intervention and requested that YouTube and TikTok use were also restricted during this 1-hour along with their phones. While the relationship between TikTok and sleep outcomes was not measured in **CHAPTER 2** (as data collected prior to TikTok becoming an international phenomenon; Williams, 2020) due to the similarities in artificial intelligence (e.g., algorithms) used across both apps, we decided to include TikTok as a restricted app. The technology restriction intervention was initially conceptualised with three conditions: (i) control, (ii) motivational session group, and (iii) motivational session group + parent support. However, due to time constraints, ongoing COVID-19 restrictions and recruitment difficulties, the final study focused on one condition: motivational session group + parent support.

The findings of **CHAPTER 4** (the intervention study) suggested that this technology restriction intervention was a feasible intervention for adolescents. It was found that adolescents stopped using their phones ~58 minutes earlier during the intervention week. However, despite this significant reduction in phone use, no significant changes in sleep outcomes were observed (increase of ~12 minutes of TST at post intervention approached significance *p* =.08). Interestingly, a significant increase in TST of ~22 minutes was observed for those who were classed as the "low adherence" group (adhered to the intervention 0-2 nights), but no increase in TST was observed for those who reported high adherence to the intervention (i.e., did the intervention 3, 4, or every school night). Here, it was thought that the absence of TST change in the high adherence group could possibly explained by the fact that this group appeared to already be "good sleepers" (i.e., receiving close to 9 hours of sleep on school nights). Despite these promising outcomes, it appears that uptake and adherence remain to be ongoing challenges for adolescents and technology restriction interventions. The completion rate in this intervention was approximately ~36%, similar to the uptake and adherence rates observed in previous studies that have attempted technology restriction interventions (Bartel et al., 2019; Dunican et al., 2017; Harris et al., 2015; Perrault et al., 2019).

Since only a small sample of adolescents completed measures and an even smaller sub sample complied to the intervention every school night (~16%), we cannot be certain of this intervention's efficacy. Moreover, only 37 parents (out of 78) watched the provided video describing the intervention their adolescent was doing, why it could be beneficial for their adolescent to participate, and how to support them with the intervention. This number was consistent with the adolescents' report of parent support. Based on the findings in **CHAPTER 3**, it had been hoped that more parents would want to be involved in supporting their adolescent with a 1-week intervention, and that this would moderate the relationship between time and sleep outcomes. However, it appears that future research may need to investigate ways to encourage both adolescents and their parents to participate in technology restriction interventions, with the hope that this might lead to better sleep outcomes on school nights. Especially given recent research that highlighted adolescents seem to want their parents' support to help regulate their sleep (Jakobsson et al., 2022).

Contribution of thesis findings to current evidence base

This thesis contributed to our current theoretical knowledge and understanding of adolescent sleep by exploring some of the under researched, yet proposed mechanisms in models by which technology use may affect adolescents sleep (Bartel & Gradisar, 2017; Cain & Gradisar, 2010; Crowley et al., 2018). To the best of our knowledge, the use of specific 'apps' at two distinct time points and their relationship with adolescent sleep outcomes had not yet been explored. Previous research had investigated activities such as talking on the phone (Tavernier et al., 2017) or social media collectively (Harbard et al., 2016; Scott et al., 2019), but individual 'apps' and device use specifically at these two distinct time points had not yet been explored. Following data collection and during the completion of this PhD, three studies with similar aims have been published (Galland et al., 2020; Hisler et al., 2020; Smith et al., 2020). However, measuring device and app use individually and at two distinct time points is unique to our study in **CHAPTER 2**. Our findings also contributed to the limited evidence base surrounding parent-set technology rules and sleep outcomes (Khor et al., 2020), and the newly emerging evidence base on FoMO and BtP and sleep outcomes in adolescents in **CHAPTER 3** (Kadzikowska-Wrzosek, 2020; Scott et al., 2021; Scott & Woods, 2018). To the best of my knowledge, in my final study in **CHAPTER 4**, this was the first technology restriction study in adolescents that included a motivational session and parent support. This study adds to the ongoing yet limited evidence base on manipulating technology use and observing the effect on sleep- especially in those with a high affinity for using devices- adolescents (Bartel et al., 2019; Dunican et al., 2017; Harris et al., 2015; Perrault et al., 2019). In summary, this thesis provides important insights into future avenues of research for technology interventions with adolescents.

Theoretical contributions

There are three main models that propose the direction of the relationship and mechanisms by which technology use may affect adolescent sleep. These were highlighted in the introduction of this thesis: The "Perfect Storm" model of adolescent sleep by Crowley et al. (2018; Figure 1), and the original (Cain & Gradisar, 2010; Figure 2) and updated (Bartel & Gradisar, 2017; Figure 3) mechanistic models by which technology use is proposed to affect sleep. Cain and Gradisar (2010) initially queried whether parental control could be a factor that may influence the presence and use of electronic media devices in the bedroom. When Bartel and Gradisar (2017) updated this model, they suggested that a combination of both age and parental involvement could be moderating factors of technology use. Our findings in **CHAPTER 3** suggest that parental control through rule setting that restricts access to devices in the pre-sleep period is associated with favourable sleep outcomes independent of age (and gender). While it was noted that the presence of parent-set rules did decrease with age, our findings in **CHAPTER 3** propose that compliance is a more important factor than age that may determine the success of technology rule-setting by parents. Therefore, we propose to update the Bartel and Gradisar (2017) model in Figure 12 to include parental control, but also parental monitoring to ensure compliance to set rules. Additionally, we suggest that parental control and monitoring can be separated from age as a single moderator, and that age should be considered as its own individual factor.

Figure 12: Suggested updates for model of mechanisms by which technology use may affect sleep. Initially proposed by Cain and Gradisar (2010) and updated by Bartel and Gradisar (2017). Additions to the model indicated in blue.

<This image has been removed due to copyright restriction. Available online from: Bartel, K., & Gradisar, M. (2017). New directions in the link between technology use and sleep in young people. Sleep disorders in children, 69-80>

In **CHAPTER 3**, we also found that the individual characteristics of FoMO and BtP were factors that may influence the relationship between adolescents' technology use and sleep. Consequently, these have been added to the Bartel and Gradisar (2017) model alongside other individual traits such as risk-taking and flow (Figure 12). Finally, we propose an update to the possible mechanisms and sleep outcomes in the Bartel and Gradisar (2017) model by replacing displaced bedtimes and later *bedtimes* with displaced and later *sleep attempt times* (or shut-eye times).

At the time of writing, sleep displacement is theorised to be a two-step process whereby evening electronic media leads to later bedtimes (i.e., delaying getting into bed = one step), and continuing or additional portable electronic media use occurring in bed is thought to delay "shut-eye" time (i.e., the time one attempts to sleep once in bed = two step; Exelmans & Van den Bulck, 2017). The concern for adolescents is that this process is thought to impede on evening time that could be spent sleeping, and consequently, shorter sleep durations on school nights (Cain & Gradisar, 2010; Exelmans & Van den Bulck, 2017; Van den Bulck, 2010). Our findings provide support for this two-step sleep displacement hypothesis occurring, where many adolescents surveyed in **CHAPTER 2** reported the use of a range of portable devices both in the hour before bed and in bed before sleep onset (i.e., before getting into bed = one step, and in bed leading up to "shut-eye" time). In **CHAPTER 3** we also found support for this hypothesis, where BtP was found to be associated with later bedtimes and lights out times, longer SOL, less TST and more daytime sleepiness. Therefore, the final update we propose for the Bartel and Gradisar (2017) model is adding "displacing the sleep attempt" to the possible mechanisms and "later sleep onset times" to poor sleep and its consequences (Figure 12).

On the contrary, in **CHAPTER 4**, our intervention that somewhat aimed to disrupt the displacement process by ceasing phone, YouTube, and Tiktok use for 1-hour earlier, did not find any significant change in bedtimes, lights out times, sleep attempt times or TST, despite adolescents reporting that they stopped using their phones ~58 minutes earlier. Here it was thought that it could be possible that socially desirable responding accounted for this effect, and that adolescents did not significantly change their technology use rather than the idea that sleep displacement might not occur. Although speculative, it seems a possible explanation for the absence of any significant changes in sleep variables which contrasts the findings of similar studies (Bartel et al., 2019; Perrault et al., 2019). However, it should be noted that a significant change in TST of ~22 minutes was observed for those who reported low adherence to the intervention. It was also observed that those adolescents in the low adherence group were receiving significantly less TST compared to their peers in the high adherence group (who appeared to already be good sleepers) at baseline. While we can only speculate, it could be possible that these adolescents in the low adherence group were greater tech users, or had more tech autonomy (i.e., less or no rules), or might identify with traits such as BtP or FoMO compared to the adolescents in the high adherence group. Thus, a technology restriction intervention (even with limited or inconsistent adherence) might have been able to improve TST. However, none of this speculation can be confirmed without measuring these factors (e.g., parent-rule setting, FoMO, BtP, objective measurement of tech use). Regardless, the findings of **CHAPTER 4's** intervention are not able to confirm or deny any possible effects of sleep displacement, or other factors in the model.

In relation to the sleep outcomes component of theoretical models, it should also be noted that we intended to measure daytime functioning (i.e., sleepiness) in the intervention study in **CHAPTER 4** using the Karolinska Sleepiness Scale (KSS; Åkerstedt & Gillberg, 1990) to test the consequences of poor sleep in the Bartel and Gradisar (2017) model. The KSS, a single-item scale, was chosen to reduce adolescents' response burden instead of using another scale such as the PDSS. Unfortunately, due to circumstances beyond our control, the collection of the post questionnaires was rescheduled to an afternoon time slot instead of the same morning time slot the baseline questionnaires were collected a week earlier. Since the KSS is a state measure of sleepiness (Åkerstedt & Gillberg, 1990), this sleepiness data captured at two different time points between baseline and post would not have been a true reflection of sleepiness. Therefore, we could not report these data.

Our findings from **CHAPTER 2** suggest there may be some devices and apps that could be associated with daytime sleepiness (e.g. Netflix). In **CHAPTER 3**, the role of parent-set technology rules and how they relate to daytime sleepiness was yet to be explored until our study (Khor et al., 2020). Here it was found that parent-set technology rules were not related to daytime sleepiness, however it was found that FoMO and BtP were associated with more daytime sleepiness. Due to this conflicting evidence, we propose daytime sleepiness remains in the current model as a possible by-product of the effect of technology use on sleep (Figure 12). The findings of this thesis cannot comment on any other mechanisms or moderating factors in the Bartel and Gradisar (2017) model (e.g., flow, screen light, cognitive/physiological arousal) as these were not measured in the presented studies.

Finally, we also propose an addition to the Crowley et al. (2018) "Perfect Storm" model. Here, based on the findings in **CHAPTER 3** we propose to add "technology autonomy" as a psychosocial pressure experienced by adolescents (Figure 13). It appears that factors such as parent-set technology rules, FoMO or BtP might impact on an adolescent's ability to regulate their technology use autonomously. Our findings in **CHAPTER 2** did not find evidence to support "social networking" while investigating apps more specifically as we did not find significant effects between Instagram, Facebook, and Snapchat and sleep variables. While arguably screen time (e.g., device use) and social networking based on other evidence remain relevant to this model (Crowley et al., 2018; Scott et al., 2019), we propose that YouTube (and arguably TikTok) are considered as part of the "social networking" umbrella since YouTube use was found to be significantly related to many negative sleep outcomes. Alternately, "social networking" could also include or be re-stated as "apps with artificial intelligence/algorithms" to reflect not only the social aspect, but the underlying design mechanisms that aim to keep users engaged on their platforms for as long as possible.

Figure 13: Suggested updates for the "Perfect Storm" model. Initially proposed Carskadon (2011) and updated by Crowley et al. (2018). Additions to the model indicated in blue.

<This image has been removed due to copyright restriction. Available online from: Crowley, S. J., Wolfson, A.R., Tarokh, L., & Carskadon, M.A. (2018). An update on adolescent sleep: New evidence informing the perfect storm model. Journal of adolescence, 67, 55-65>

Clinical implications

Historically, the way humans sleep was theorised to have changed with access to electric light (Yetish & McGregor, 2019). Some research that has studied the sleep of indigenous communities who rely on natural light compared to communities with access to electric light, has suggested that artificial light may have been a key factor in the reduced or delayed sleep observed in industrialised societies (De La Iglesia et al., 2015; Peixoto et al., 2009; Smit et al., 2019). This seems concerning given that in the modern day, small artificial light emitting devices are not only in the house, but often now come to bed with us as well (Exelmans & Van den Bulck, 2017).

A quick Google search will generate many results, some even from credible public health websites (e.g., The National Sleep Foundation, Raising Children's Network), or articles written by doctors, or individuals with PhDs, stating that the use of all electronic devices should be ceased at least 30-60 minutes before bed (Breus, 2022b; Raisingchildren.net.au, 2020a; Sleep Foundation, 2022b, 2022c). The reason many of these reputable sources state technology should be ceased in the hour before bed is due to the negative effects of bright screen light from devices, thought to be suppressing the natural secretion of melatonin, thus delaying sleep onset and/or circadian timing (Breus, 2022b; Raisingchildren.net.au, 2020a; Sleep Foundation, 2022b, 2022c). However, when we look closer at the findings for the effects of bright light on sleep, the magnitude of some of these sleep effects (albeit statistically significant) are not clinically meaningful (e.g., 2-3 minute delay in sleep onset; Chang et al., 2015; Heath et al., 2014; Van der Lely et al., 2015). In fact, when we take a closer look at many of the other factors that contribute to teenager's sleep (e.g., biology), technology itself is thought to only explain ~ 3% of teenagers' sleep (Bartel & Gradisar, 2017). Taken together, these findings question the validity (and ethical promotion) of "blue-light blocking glasses" or night mode (Duraccio et al., 2021) that are often written about on reputable websites, and being commercially sold across the world to consumers looking to improve their sleep and "reduce the effects of screen light on sleep" (Breus, 2022a; Kahn, 2021; ResMed, 2022; Sleep Foundation, 2022a). While screen light was not a focus of this thesis, it appears to be a focus of many of the public health recommendations to do with sleep and technology use. It is necessary to highlight that the evidence in this field suggests that this is perhaps a less potent mechanism in the technology and sleep model (Bartel & Gradisar, 2017), and that other factors are arguably more relevant to focus on in the public health messages.

Based on the findings of this thesis and previous research (Exelmans et al., 2019; Exelmans & Van den Bulck, 2017, 2021), it seems that a more likely mechanism by which technology use may affect sleep in adolescents is *sleep displacement*. The current public health messages that device use should be ceased in the hour before *bed* is no longer a realistic public health message. It is evident from the results of this thesis and other previous research (Exelmans & Van den Bulck, 2017; Smith et al., 2020) that many adolescents are continuing to use technology *after* they get into bed. Our findings suggest that certain devices and apps are likely to be very engaging (e.g., YouTube) in that they delay not only the time one gets into bed (i.e., bedtime) but also the time they decide to initiate a sleep attempt. Consequently, the current public health message needs to be updated to reflect this evidence that not all screens are bad (e.g., TV), but that some devices and apps (e.g., phones and YouTube) have the capability to delay not only getting into bed, but delay teenagers' decision to initiate sleep due to their addictive/engaging nature. It is also worth noting that some adolescents who identify with traits such as BtP may be at higher risk of sleep displacement (based on the findings of **CHAPTER 3**). This points to one sensible solution to offset the problem of sleep displacement- access to devices in bed.

Our findings from **CHAPTER 3** suggested that approximately half (~ 49%) of adolescents had at least one technology rule set by their parents that limited device access at night-time, and that the presence of technology rules significantly decreased with age. In addition, only ~ 51% of adolescents reported that they always complied to their parent-set rules (~ 49% reported they did not always comply). Many parents may not realise the potential they have to help their adolescent regulate their technology use, and likelihood their child may receive more sleep on school nights as a result, by setting rules and monitoring that they are followed. Adolescents seem to be aware of their difficulty regulating technology use, with adolescents previously stating that they recognise technology is problematic for their sleep, but it is often too difficult to resist (Jakobsson et al., 2022; Toh et al., 2019). In fact, they have even suggested that support from their parents may be able to help them with overcoming this (Jakobsson et al., 2022). This difficulty to self-regulate technology use makes sense when we consider the increase of risk-taking and reward sensitivity during this period of human development (Reynolds et al., 2015).

While our intervention study in **CHAPTER 4** aimed to motivate adolescents to take control and reduce their technology use, perhaps the focus should have shifted to motivating parents to take control and set boundaries around pre-sleep technology use (i.e., parents are the intervention). In fact, motivating parents may be an important focus of future research given that ~53% of adolescents reported their parents did not assist them with the intervention, despite the fact information was sent directly to parents from the school encouraging them to participate (accompanied with the video). Our assumption that parents would want to support their adolescents with this intervention may not have been accurate. Consequently, educating parents on their important role and motivating them to set limits on technology use to protect their adolescents' sleep should be of high importance when disseminating public health information and working with families 1:1 in clinical practice. This could be as simple as setting a technology rule that their adolescents' mobile phone is to be removed from their bedroom from a certain time of night until the morning.

Finally, when using subjective measures working with adolescents and their families (or adolescent participants in research), clinicians and researchers should be aware that the terms bedtime or lights out time cannot be considered synonymously with "sleep attempt time". Based on this thesis' findings, it is evident that many adolescents are using devices after lights out time, with many choosing to put their devices down moments before they decide to attempt sleep. Ensuring "sleep-attempt" time is recorded accurately has significant clinical (and research) implications to ensure SOL is being captured and interpreted accurately as this variable can be important for diagnosing or treating a sleep disorder (e.g., insomnia, delayed sleep-wake phase disorder; Dohnt et al., 2012; Lovato et al., 2013). This recommendation is made as previous research, including RCTs have used sleep diaries that appear to presume the sleep attempt began following lights out time (Bartel et al., 2019; Gradisar, Dohnt, et al., 2011; Richardson et al., 2018), and thus SOL could have been inaccurately calculated. Requesting that sleep attempt time is recorded may also be relevant for actigraphy or apps that aim to measure sleep. For these measures, it would be important to ensure that lying horizontal and still in bed watching Netflix, for example, is not potentially misperceived as sleep by clients, clinicians, and researchers.

Limitations and future directions

There remains a significant need for experimental and intervention studies to continue to test the moderating and mechanistic factors by which technology use may affect sleep (as proposed in this thesis' updated model of the Bartel and Gradisar (2017) model; i.e., Figure 12). While an initial aim of our technology intervention study presented in **CHAPTER 4** was to compare an intervention group to a control group, we were unable to fulfill this aim due to ongoing COVID-19 restrictions, time constraints and recruitment difficulties. The absence of a control group presents as a prominent limitation of the intervention study and future research should consider RCT design trials or longitudinal studies to continue investigating the possible directional links between adolescent technology use and sleep. While having said that, it appears recruitment for such study designs may present as a challenge. Future research may need to further explore motivational avenues to encourage adolescents' uptake in a technology restriction intervention by matching the motivational content to the relevant stage of change (e.g., for pre-contemplative adolescents starting with voicing change talk or exploring the pros and cons of reducing their evening technology use; Miller & Rollnick, 2002). This leads to a final suggestion regarding the involvement of parents in future research. It seems that in our final study presented in **CHAPTER 4**, even parents needed to be motivated to participate in supporting their adolescents with a technology restriction intervention. Future research could consider a more active approach in involving parents (e.g., interactive workshops) or educating parents on the benefits of setting technology rules. Educating the parents of younger adolescents (i.e., age 10-12 years) on the benefits of both bedtime and technology rule setting may help to establish healthy rules and expectations surrounding evening technology use that can be maintained throughout their older adolescent years (i.e., prevention rather than reaction).

In **CHAPTER 3** this thesis considered parents as rule enforcers, how rule-setting may influence sleep in adolescents, and the compliance to these rules from adolescents rather than considering a more autonomous approach. A recent qualitative study that asked adolescents for their suggestions on how their sleep could be improved found that adolescents would like their parents support but still have their autonomy respected (Jakobsson et al., 2022). This included being involved in the decision-making surrounding evening routines, device limit setting, and having parents promote a home that feels safe (among other themes unrelated to parents; Jakobsson et al., 2022). Recent research has also found parents as supporters and good models has been associated with adolescents' health behaviours such as fruit/vegetable consumption, junk food consumption, physical activity and also non-academic screen time (Nakamura et al., 2022). Future research could consider asking parents to support their adolescents to obtain more sleep through methods such as role modelling healthy technology use or making changes to their own technology use alongside their adolescent.

Relevant to all chapters, it is noted that sleep was measured subjectively in this thesis. While subjective measures do have benefits such as reducing participant burden, being able to collect data from large samples simultaneously, and capturing participants' perceptions of their sleep, this comes with the trade-off for objective accuracy. Future research could consider using objective measures to measure sleep definitively. Future research that intends to use subjective measures should consider including a question that asks about "sleep-attempt" or "shut-eye" time (Exelmans & Van den Bulck, 2017), especially in samples where evening technology use is likely to be prevalent (i.e., adolescents/young adults). On a sleep diary, for example, this would be important to ensure SOL is not being overestimated, as the two-step sleep displacement process demonstrates we can no longer assume SOL is occurring from lights out time. Objective measures to capture time spent on technology use would also be desirable for future research. However, this would be difficult to achieve with large samples (e.g., schools). A limitation noted for each study presented in this thesis is that technology use was subjectively reported, meaning that socially desirable responding cannot be ruled out. Finally, future research could consider the differences in age, gender, circadian timing, and other individual factors that might have an impact on the relationship between differences in technology use.

Conclusion

This thesis has provided further contributions to the knowledge surrounding the relationship between adolescent sleep and technology use. It emphasised the important role parents can play in protecting their adolescents' sleep, by setting rules that could help to regulate adolescents' evening technology use. It also provided further evidence for the possible benefits of interventions that target evening technology use and explored whether all or just some devices and apps might be linked to negative sleep outcomes. Future research is required, especially from experimental studies, to test the direction of the effect between some of the moderating and mechanistic factors by which technology use is proposed to effect adolescent sleep. Clinicians, educators, and public health bodies should consider educating and motivating parents on the important role they may not realise they can play in protecting adolescent sleep.

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APPENDICES

APPENDIX A: Supplementary Tables for Chapter 2

Supplementary Table 1

Zero order correlations between sleep variables, device variables, and app variables in the hour before bed

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Bedtime	-																
2. Lights out	.78**	-															
3. SOL	-.09*	.18**	-														
4. TST	-.49**	-.72**	-.57**	-													
5. PDSS	.24**	.32**	.22**	-.37**	-												
6. Phone	.16**	.15**	-0.01	-.10*	0.05	-											
7. iPad/tablet	-0.03	0.04	.12**	-.11**	0.07	0	-										
8. Laptop	0.07	.10**	0.04	-.12**	.10*	.12**	-.10*	-									
9. Desktop	0.08	.08*	0	-0.06	-0.03	-0.04	.11**	-0.07	-								
10. TV	-.08*	-.09*	0.04	-0.01	0.07	.11**	0.05	0.06	0	-							
11. Gaming	0.03	.15**	-0.03	-.11**	0.02	.08*	0.06	-0.01	.08*	0.05	-						
12. Texting	-0.02	0.05	.09*	-.08*	0.07	.12**	.14**	.10*	0	0.04	0.03	-					
13. Instagram	-0.02	0.02	0.05	-.10*	0.06	.25**	.15**	.20**	0.01	.13**	0.04	.30**	-				
14. Snapchat	.14**	.18**	0.01	-.13**	.15**	.30**	0.01	.26**	-0.02	.11**	0.02	.12**	.40**	-			
15. Facebook	.08*	.12**	-0.04	-0.02	0.04	.15**	.12**	.11**	.09*	0.07	0.02	.22**	.26**	.31**	-		
16. YouTube	0.07	.12**	0.08	-.17**	0	.09*	.13**	.16**	0.07	-0.02	.17**	.15**	.15**	.10*	0.06	-	
17. Netflix	0.01	0.01	.08*	-.11*	.14**	.13**	.18**	.22**	0.02	.27**	-0.01	.17**	.28**	.29**	.21**	.14**	-
18. Spotify	0.06	.09*	0.04	-0.08	0.07	.12**	0.04	.31**	0.03	0.03	0.07	.24**	.31**	.30**	.14**	.15**	.18**

Note.

* indicates significance at *p* = .01. ** indicates significance at *p* <.001 SOL = sleep onset latency, TST = total sleep time, PDSS = Pediatric Daytime Sleepiness Scale scores.

Supplementary Table 2

Zero order correlations between sleep variables, device variables, and app variables in bed before sleep onset

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. LOT	-														
2. SOL	.18**	-													
3. TST	-.72**	-.57**	-												
4. PDSS	.32**	.22**	-.37**	-											
5. Phone	.27**	0.07	-.16**	.12**	-										
6. iPad/tablet	.12**	0.06	-0.07	0.07	0.04	-									
7. Laptop	.22**	.09*	-.15**	.12**	.25**	-0.01	-								
8. TV	.11**	-0.03	-.09*	-0.01	.19**	.08*	0.03	-							
9. Gaming	.09*	0.03	-0.08	-0.02	.19**	.09*	0	.54**	-						
10. Texting	.17**	0.06	-.11**	0.07	.25**	.25**	.09*	.09*	.15**	-					
11. Instagram	.14**	.08*	-.18**	.09*	.35**	.11**	.26**	.10*	.17**	.33**	-				
12. Snapchat	.22**	0.01	-.13**	.13**	.32**	0.05	.32**	.14**	0.05	.21**	.42**	-			
13. Facebook	.20**	0.03	-0.07	0.04	.12**	.29**	.10*	0.08	0.06	.28**	.26**	.26**	-		
14. YouTube	.34**	0.07	-.26**	.13**	.24**	.29**	.29**	.14**	.14**	.20**	.32**	.18**	.19**	-	
15. Netflix	.18**	0.01	-.11**	.19**	.20**	.38**	.30**	.18**	0.06	.21**	.28**	.34**	.30**	.26**	-
16. Spotify	.17**	0.04	-.15**	.10*	.21**	.13**	.30**	0.07	.09*	.33**	.32**	.36**	.18**	.14**	.22**

Note. * indicates significance at $p = .01$. ** indicates significance at $p < .001$; LOT = lights out time, SOL = sleep onset latency, TST = total sleep time, PDSS = Pediatric Daytime Sleepiness Scale scores. Bedtime excluded as theoretically bedtime has already occurred.

Supplementary Table 3

Zero order correlations between device variables in the hour before bed and in bed before sleep onset

Variable	1	2	3	4	5	6	7	8	9
19. Phone hour before	-								
20. Phone use in bed	.353**	-							
21. iPad/tablet hour before	-.001	-.015	-						
22. iPad/table in bed	-.062	.043	.461**	-					
23. Laptop hour before	.116**	.106**	-.097*	-.100*	-				
24. Laptop in bed	.074	.251**	-.020	-.012	.275**	-			
25. TV hour before	.108**	.049	.054	.032	.058	.004	-		
26. TV in bed	.054	.188**	.066	.082*	.000	.032	.177**	-	
27. Gaming hour before	.081*	.151**	.055	.115**	-.006	.043	.049	.223**	-
28. Gaming in bed	.093*	.190**	.022	.093*	-.006	.003	.057	.535**	.338**

Key: hour before = duration of use in the hour before bed; in bed = duration of use in bed before sleep onset; * indicates significance at $p = .01$. ** indicates significance at $p <.001$; Desktop not included as no use in bed reported.

APPENDIX B: Supplementary Tables for Chapter 3

Supplementary Table 4

Zero order correlations between sleep variables, bedtime procrastination scale, iNOD scale, and sleep hygiene variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Bedtime	-											
2. Lights out time	.775**	-										
3. SOL	-.088*	.180**	-									
4.TST	-.486**	-.722**	-.570**	-								
5. PDSS	.239**	.321**	.220**	-.367**	-							
6. iNOD	.127**	.229**	.117**	-.220**	.245**	-						
7. BtP	.364**	.538**	.185**	-.495**	.499**	.330**	-					
8. Age	.322**	.311**	-.093*	-.147**	.171**	.140**	.179**	-				
9. Gender	-.102**	-.068	.150**	-.093*	.213**	.120**	.102**	-.072	-			
10. SES rank	-.051	-.122**	-.031	.041	-.071	-.124**	-.128**	-.215**	-.099*	-		
11. Nap duration	.150**	.213**	.026	-.155**	.245**	.111**	.210**	.181**	.081*	-.161**	-	
12. Caffeine	.004	.071	.077*	-.155**	.088*	.072	.062	.080*	.103**	-.054	.125**	-
13. Lights	.003	.019	.105**	-.039	.080*	.083*	.077*	-.064	.050	-.057	-.009	.081*

Note. * indicates significance at $p = .01$. ** indicates significance at $p < .001$ SOL = sleep onset latency, TST = total sleep time, PDSS = Pediatric Daytime Sleepiness Scale scores, iNOD = Index of Nighttime Offline Distress, BtP= Bedtime Procrastination Scale, Gender = Male coded as 1, Female as 2.

Supplementary Table 5

Estimated marginal means (standard error) of self-reported sleep variables on school nights, daytime sleepiness, FoMO and BtP scores for age group

	Age					
	12-13	14	15	16	17-18	
Bedtime (hrs)	21.3 (0.09)	21.9 (0.09)	22.1 (0.05)	22.2 (0.06)	22.4 (0.1)	$F(4, 708) = 24.2$, p <.001*
Lights out (hrs)	21.8 (0.1)	22.5 (0.1)	22.7 (0.06)	22.9 (0.07)	23.2 (0.1)	$F(4, 708) = 21.7$, p <.001*
SOL (mins)	41.2 (3.4)	39.6 (3.7)	30.3 (2.2)	32.0 (2.3)	32.4 (4.6)	$F(4, 710) = 2.61$, p =.035*
TST (hrs)	8.2 (0.1)	7.7 (0.1)	7.7 (0.08)	7.6 (0.08)	7.5 (0.2)	$F(4, 671) = 4.78$, p <.001*
PDSS score	12.1 (0.6)	14.0 (0.7)	14.6 (0.4)	15.3 (0.4)	16.3 (0.9)	$F(4, 664) = 5.68$, p <.001*
iNOD score	6.7 (0.7)	7.8 (0.8)	9.3 (0.4)	9.8 (0.5)	9.6 (0.9)	$F(4, 706) = 4.41$, p =.002*
BtP score	25.8 (0.6)	27.1 (0.7)	28.2 (0.4)	28.8 (0.4)	30.2 (0.8)	$F(4, 704) = 6.28$, p <.001*

Note: SOL = sleep onset latency; TST = total sleep time; PDSS = Pediatric Daytime Sleepiness Scale (score range 0-32); iNOD = Index of Nighttime Offline Distress (score range 0 to 40); BtP = Bedtime Procrastination Scale (score range 9 to 45).

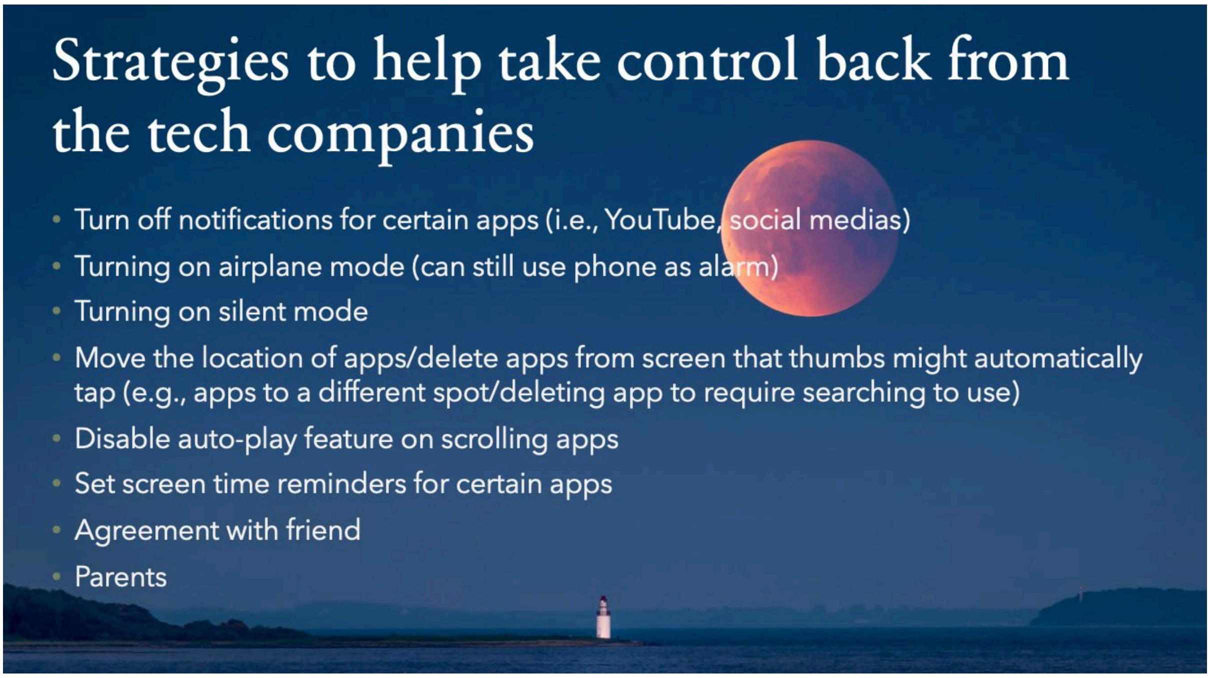
Supplementary Table 6:
Mean (standard deviation) of self-reported sleep variables on school nights, daytime sleepiness, FOMO and BtP scores for gender

	Gender		
	Male	Female	
Bedtime (hrs)	22.1 (0.9)	21.9 (0.9)	*t*(693) = 2.69, *p* =.007*
Lights out (hrs)	22.7 (1.1)	22.6 (1.0)	*t*(693) = 1.81, *p* =.071
SOL (mins)	28.8 (31.0)	39.1 (36.9)	*t*(645.4) = -3.96, *p* <.001*
TST (hrs)	7.8 (1.2)	7.6 (1.2)	*t*(658) = 2.38, *p* =.017*
PDSS score	13.2 (5.9)	15.9 (6.2)	*t*(649) = -5.56, *p* <.001*
iNOD score	8.2 (7.0)	9.9 (7.0)	*t*(691) = -3.18, *p* =.002*
BtP score	27.5 (6.1)	28.8 (6.3)	*t*(689) = -2.70, *p* =.007*

Note: SOL = sleep onset latency; TST = total sleep time; PDSS = Pediatric Daytime Sleepiness Scale (score range 0-32); iNOD = Index of Nighttime Offline Distress (score range 0 to 40); BtP = Bedtime Procrastination Scale (score range 9 to 45). Male coded as = 1, Female = 2.

APPENDIX C: Supplementary Materials for Intervention Study

Tips provided to students during motivational session (and parents within parent video).



"Menu" of alternate "non-scrolling" activities before going to sleep

- Watching TV alone or with family (agree on a series to watch for the week)
- Watching Netflix on a laptop
- Reading a book of your choice
- Talk with your family or other household members
- Meditation/relaxation
- Listen to an audio book/podcast on iPad
- Drawing/art
- Journaling
- Yoga
- Listening to music
- Devices other than **phone**
- Apps other than **YouTube or TikTok**

Tips to reduce the temptation or time spent scrolling

- Turn off notifications for certain apps (i.e., YouTube, social medias)
- Turning on airplane mode (can still use phone as alarm)
- Turning on silent mode
- Move the location of apps/delete apps from screen that thumbs might automatically tap (e.g., moving TikTok/YouTube app to a different spot/deleting app to require searching if planning to use).
- Disable auto-play feature on scrolling apps
- Set screen time reminders for certain apps
- Ask parents to help/make pact with a friend for the week