Chapter 4
New Directions in the Link Between Technology Use and Sleep in Young People

Kate Bartel and Michael Gradisar

Abstract Young people have an affinity for technological devices. Several reviews of more than 70 studies over the past 15 years have shown consistent links between young people's use of technology and sleep. This has led the scientific and general communities to deduce that using technology before bed worsens sleep. However, the majority of studies performed have been correlational in nature, making causal inferences difficult. This chapter focuses on two important questions of "how" and "how much" technology use affects sleep. The former question details primarily experimental studies that have tested potential mechanisms, including technology use inducing physiological arousal, displacing bedtime, or screenlight disturbing sleep and circadian rhythms. While the latter question appears straightforward, new meta-analytic results suggest it is not. Furthermore, new studies are identifying important moderators for the link between technology use and sleep. Finally, we consider the reverse relationship – the possibility of technology use increasing in response to difficulty sleeping. Our chapter concludes with a research agenda that does not necessarily point the finger at technology use as the reason why so many young people are sleeping too late and too little.

Keywords Technology use • Sleep • Adolescents • Arousal • Screenlight • Displacement • Bedtimes

Introduction

Apple cofounder Steve Jobs once said "People did not know what they want, but we'll show them" [1]. Mr Jobs' vision for enhancing our lives was laudable – but do you think he considered the cost of his choices on young people? One could easily argue he, or Apple, did not. Just watch the scene in Apple's "Love" TV commercial where

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a young boy's room is brightly lit at night by the glow of his iPad 2. Sure he is loving his iPad, but when does he put it down to go to bed? How does he sleep afterward?

We should not be too unfair on Apple's iconic inventor, for in the early 2000s, parents were advised to position computer screens in areas visible by all [2]. This was when home Internet was hardwired – before domestic Wi-Fi made it possible for Apple to develop iDevices that can be placed in any corner of the household (including the bedroom, which can lead to its use after lights off [3–6]). But more than a decade beyond the invention of Wi-Fi, with the introduction of touch screen "gorilla glass" in iPads and iPods (and associated copycat devices), is there a cost of this accelerated technology on young people's sleep?

This chapter can only provide a snapshot in time of what we now know, but it does not pretend to assume that we know it all. Apple spent $1.68 billion in the 2014 September quarter on research and development [7], and Samsung invested $13.4 billion in 2013 [8], yet when one reviews the scientific literature of investigations into the harms to sleep health from technology use, the funding for such science pales in comparison. We will learn more over the next decade as the research attempts to catch up to the advances in technology. But what we aim to achieve in this chapter is to (1) convey what the data are currently telling us about the relationship between technology use and young people's sleep[1] (you may be surprised) and thus (2) provide direction to researchers for where future research should be focused.

In the hope of achieving these aims, we will concentrate on two key questions:

1. How much does technology use affect young people's sleep?
2. How does technology use affect young people's sleep?

However, before addressing the "how much" question, let us turn our attention to the possible mechanisms between technology use and sleep.

How Technology Affects Sleep?

In 2010, both van den Bulck [9] and Cain and Gradisar [10] performed reviews of the scientific literature reporting links between various technological devices and sleep in school-aged children and adolescents. These reviews were later updated by Gradisar and Short [11] and more recently with a systematic review by Hale and Guan [12]. At the end of this section, we present an update of the original model, which now incorporates new moderating factors for the relationship between technology use and sleep.

After reviewing 36 papers, Cain and Gradisar [10] concluded that the majority of studies that investigated various devices, including televisions, computers/the Internet, and phones, found significant relationships with primarily reduced total sleep time,

[1] By current data we mean that we wish to not provide an exhaustive review of studies in this area as this has already been performed; rather, we wish to focus on new studies that have provided new insights in this area.

but occasionally with a longer sleep latency and/or a later bedtime. The authors presented a model potentially explaining how technology use could affect sleep, which is not unlike the model presented at the end of this section. First was that technology use has been linked to a later bedtime. This was initially proposed by van den Bulck as the displacement hypothesis [13]. This hypothesis states that technology use displaces sleep by delaying bedtime. Second, some studies had provided evidence of increased physiological arousal (e.g., increased heart rate, body temperature, objective alertness via EEG trace) in the evening due to technology use (e.g., [14, 15]). This reduces the body's preparedness for sleep [16]. The third potential mechanism was that the bright light from screens could potentially decrease evening levels of melatonin and even delay its onset. Finally, and although not contained within the model, Cain and Gradisar alluded to some evidence that electromagnetic radiation from devices (e.g., phones) had shown effects with altered sleep architecture and suppressing endogenous melatonin [17, 18]. Cain and Gradisar [10] provided the first illustrative framework for future research to test these proposed mechanisms, yet explained:

> It would be useful for future studies to comprehensively test this model, using research designs that move beyond the correlational analyses which are prevalent in this area. (p.741)

Five years since this review, Hale and Guan [12] performed an updated systematic review of technology use and the sleep of children and adolescents. Their search results yielded a further 31 studies additional to those found in the Cain and Gradisar [10] review. This alone provided a clear indication of the popularity of researchers investigating this particular field. Unfortunately, the vast majority of new studies were correlational in nature. Yet there had been some advances that not only helped to test Cain and Gradisar's model but also began to find that there were important moderators that heightened, or dampened, the link between technology use and sleep.

Several experimental studies have attempted to test the mechanism of *physiological arousal* induced by technology use. For example, an increased heart rate was found in three studies [14, 19, 20], one testing Japanese young adults and two using older Swedish adolescents. However, the effects on sleep latency were anticlimactic, with an extension of objective sleep latency (via polysomnography [PSG]) of only 2.3 min and an extension of subjective sleep latency by up to 18 min. Two separate Australian studies could not detect differences in heart rate between their active and control conditions [15, 21], and both reported PSG sleep latency extensions of less than 5 min. It is worth noting that, for the exception of one study [14], studies asked participants to attempt sleep at their usual time. This avoids the confound of a buildup in sleep homeostatic pressure, which would decrease sleep latency the later young people attempted sleep. Thus, by holding bedtimes constant, researchers are able to more cleanly observe effects of physiological arousal on sleep due to technology use. However, as mentioned above, there has been little support for the physiological arousal-sleep mechanism.

The second mechanism to receive attention from experimental studies is the effect *screenlight* may have on the sleep of young people. Originally, Higuchi and colleagues [14] found little evidence for an effect on sleep from a dim vs bright screen, which was likely due to asking their young adult participants to attempt

sleep at 2 AM. In contrast, Cajochen et al. [22] found that compared to a dim laptop screen, using a bright screen for 5 h attenuated the natural rise in melatonin of their young adults and increased both objective and subjective alertness in the pre-bedtime period. This was possibly the first evidence to confirm bright screenlight's effect on sleep. Unfortunately, sleep was not measured in this study. In 2012, Wood et al. [23] measured possible melatonin suppression effects from the screenlight of an iPad in their sample of young adults and adolescents. Although 1 h of screenlight showed no significant melatonin suppression, melatonin was significantly suppressed after 2 h of bright screenlight. Again though, sleep was not measured. In 2014, Heath and colleagues [24] compared the effects from 1-h use of a dim vs bright iPad, as well as a filtered iPad screen (Fig. 4.1), on both pre-bedtime alertness and subsequent sleep and next-morning functioning. Compared to the dim light condition, the bright screen induced greater cognitive alertness in the pre-bedtime period, but no significant effects were found for sleep (e.g., sleep latency, REM, or SWS sleep). However, the pre-bedtime alertness effects were of questionable real-world significance, with only a 23-ms difference for speed processing and 13 % difference in accuracy. Furthermore, pre-bedtime melatonin levels were not measured. Recently though, van der Lely and colleagues [25] designed an excellent study that measured the pre-bedtime alertness (subjective, objective, melatonin) as well as sleep and next-morning functioning of older adolescents.

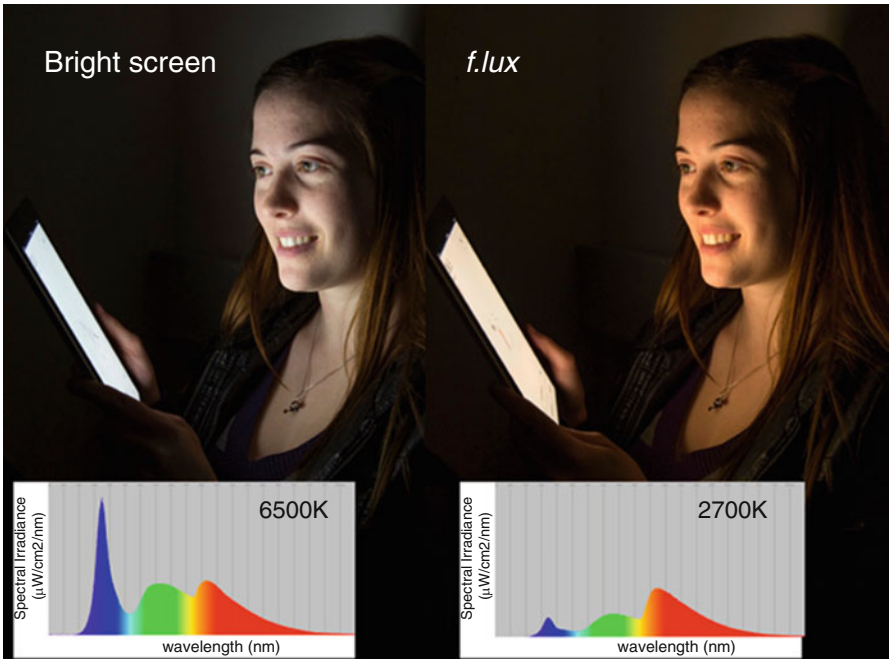

Fig. 4.1 Heath and colleagues [24] comparison of bright iPad screenlight (*left*) vs screen filtering short-wavelength light using the *f.lux* app (*right*; stereopsis.com)

Their findings showed that 1.5 h (or more) of a bright screen attenuated the rise in evening melatonin and increased subjective alertness compared to wearing blue-blocking glasses (designed to filter alerting short-wavelength light). However, no effects were found on sleep. The abovementioned studies all tested young people in a controlled laboratory setting on single nights, which thus suffer from poor external validity, as many adolescents use technological devices frequently throughout the week [26]. A study by Chang and colleagues [27] overcame this limitation by securing young adults in the laboratory for 14 consecutive days (and nights) and exposed them to either a brightly lit e-book or a printed book in dim light for 5 h each night for 5 days (counterbalanced). Their findings not only confirmed a suppression of melatonin in the e-book condition but also a meaningful delay in circadian timing (by 1.5 h), providing the first support for a circadian delay mechanism. Interestingly, although significant effects were found for an increase in sleep latency from the e-book condition, this was only 10 min longer, which is not overly meaningful.

Taken together, the abovementioned studies suggest that at least 1 h of bright screenlight can induce increased alertness (whether perceived or objective); 1.5 h of screenlight can suppress the natural rise in melatonin, but does not affect the sleep of young people. Thus, there is limited support for this mechanism in the relationship between technology use and sleep. Chang et al. [27] have confirmed a delay in circadian timing, yet these findings require replication. Yet one question that remains is that if adolescents did use a bright screen and felt alert, would they continue to use their device beyond their usual bedtime?

There is a paucity of experimental research into the ability of technology use to *displace* young people's bedtimes. Indeed, to our knowledge only one study has done so. Reynolds and colleagues [28] allowed older adolescents to play a novel video game for as long as they wanted. More importantly, the researchers anticipated that the teenagers would differ in when they would "switch off" and thus explored what characteristics might determine a later vs earlier bedtime. They found those adolescents who reported more consequences of risk-taking were more likely to cease video gaming and retire for bed. This study reinforces others which have shown that the link between technology use and sleep may be moderated by other characteristics, including gamer experience/habituation [20] and more recently parental involvement and flow [29] (Fig. 4.2).

If we were asked to write this chapter a couple of years ago, this is where we would end, as we would not be considering the question: whether technology use affects the sleep of young people. However, our new work suggests otherwise.

How Much Technology Affects Sleep?

Much of the revised literature on technology use and sleep used binary significance testing (which reflects the nature of the science during this time). In other words, researchers were primarily testing whether there was a significant relationship

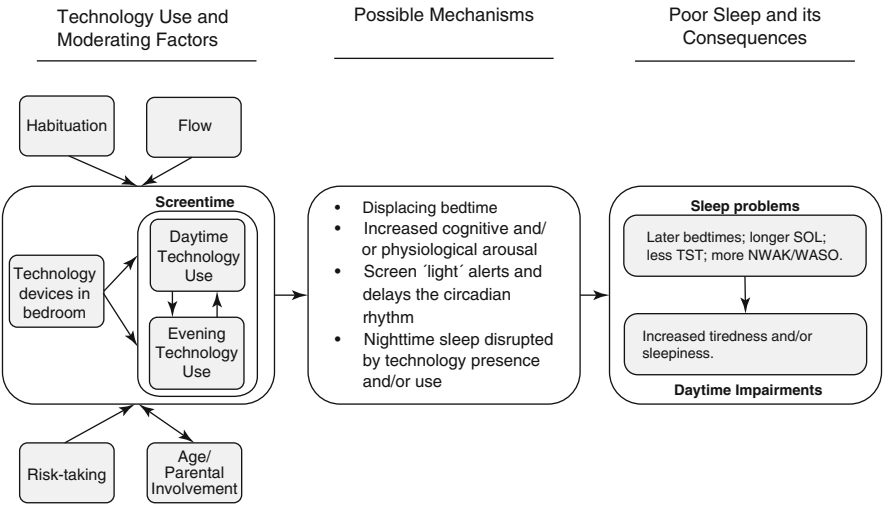

Fig. 4.2 Revised model of the mechanisms linking technology use and sleep

between technology use and sleep, and significance was usually defined as obtaining a significance level of $p<0.05$. More recently, binary significance testing has been criticized [30]. For example, a relationship may occur between two variables, but it may be so small that it does not mean much in the real world.

The field of technology use and sleep seemingly neglected the size of the real-world effect between these two variables. However, a meta-analysis by Bartel et al. [31] was able to estimate the magnitude of the effects between various technological devices and teenagers' sleep, along with a multitude of other risk (and protective) factors. Surprisingly, the correlations between technological devices and sleep were negligible. The use of technology was not related to sleep latency, and only computer use was associated with a decrease in total sleep time. Technology did appear to correlate, to a small extent, with bedtime. Namely, as video gaming, phone use, computer use, and Internet use increased, bedtime became later [31]. Figure 4.3 provides an illustrative look of the relative protective and risk factors for adolescents' sleep, including "technology use." The segments of the pie chart demonstrate the percentage of variance from each factor. We have used the mean-weighted correlations between "technology use" and "sleep" (i.e., between Internet use and bedtime, which showed an $r=0.212$) from the meta-analytical findings from Bartel and colleagues – thus, at best, technology use represents just a sliver of a contribution toward adolescents' sleep. At a glance, there appear other more important contributions, including family influences (i.e., parent-set bedtimes, family environment). The most obvious piece is represented by the question mark. Normally, this would mean we do not know what this extra contribution is and may elect to claim it is a measurement error, other methodological anomalies, or simply things we do not know. However, Bartel and colleagues were unable to

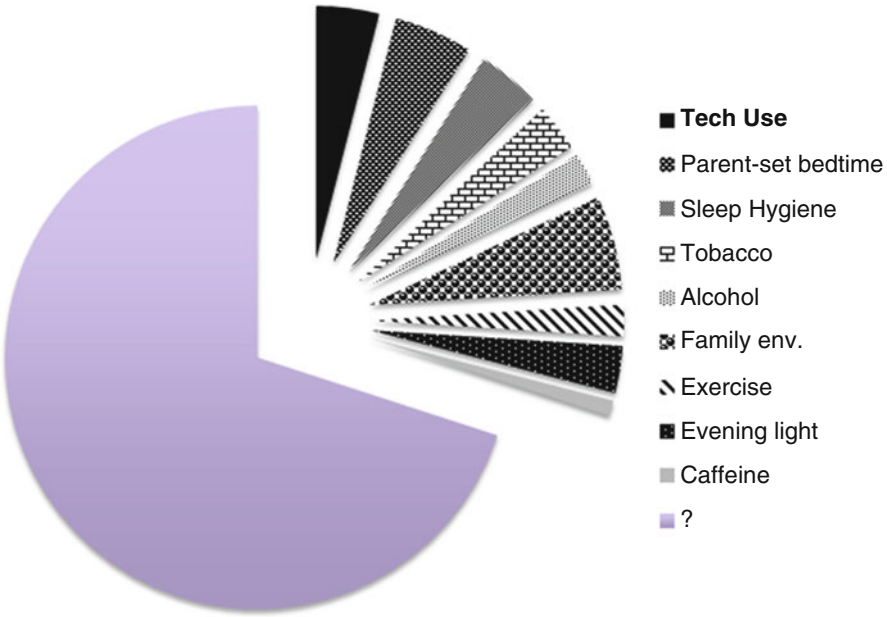

Fig. 4.3 Illustrative pie chart of the relative protective and risk factors for adolescents' sleep (Derived from meta-analytic data from Bartel et al. [31])

meta-analyze biological contributions to teenagers' sleep (i.e., circadian rhythm timing, sleep homeostasis, genetics), which are known to be major influences on teenagers' sleep.

Can Sleep Affect Technology Use?

At the outset of this chapter, we did state that we had two key questions, which we have addressed above. However, we knew, before the reader, that the current data are telling us that there is little effect between technology use and adolescents' sleep. It follows then that we should not close our minds to the possibility that the relationship may occur the other way round – that increased technology use occurs *after* sleep becomes more problematic. After all, the majority of the scientific literature to date are correlational, and the limited experimental studies available suggest when one manipulates technology use, the resultant effect on sleep is small to meaningless.

Our insight into whether the technology use of adolescents occurs after sleep becomes problematic comes from a cross-sectional study of 2,546 Belgian adolescents. The 2006 study, titled "Nodding off or switching off? The use of popular media as a sleep aid in secondary-school children," was likely ahead of its time. Eggermont and van den Bulck [32] asked seventh- (13.2 years) and tenth-grade

(16.4 years) adolescents how often they used either computer games, television, books,[2] or music to *help them fall asleep*. Respondents answered either *never*, *rarely*, *sometimes*, or *often*. One in five adolescents used television at least occasionally as a sleep aid, one in ten used computer games, and one in three used books, but it was music that was used the most, with almost one in every two adolescents using music to help them fall asleep. Despite that only books led to an earlier bedtime, more sleep, and less next-day tiredness (compared to other sleeping aids), this was the first study of teenagers exploring technology use as an aftereffect of trouble sleeping. We are likely overstating this claim, as technically adolescents were not asked to report if they had a sleep problem. We can only infer that by asking teenagers if sleep onset was assisted with an associated technological activity, that at least for some adolescents, difficulty initiating sleep may have occurred before the use of such technology.

Perhaps the best evidence to date attempting to answer the question about whether sleep can affect technology use comes from a prospective study of adults. Tavernier and Willoughby [33] followed 942 emerging adults (age at Time 1 = 19.0 years) for 3 years and measured their average weekly hours of TV watching and online social networking (e.g., Facebook, Myspace, Twitter, e-mail, Messenger), as well as their typical sleep duration, as well as an adapted version of the Insomnia Severity Index (items included difficulty initiating sleep, staying asleep, early morning awakening, and sleep satisfaction [34]), which provided a continuous variable known as "sleep problems." Cross-lagged analyses showed that sleep problems at Time 1 predicted Time 2 television watching and online social networking, but the reverse relationship (i.e., technology use predicting later sleep problems) was not supported. Interestingly, no prospective relationships existed between technology use and sleep duration, which supports the meta-analytical findings in adolescents [31]. Nevertheless, these prospective findings suggest young adults' perceptions of their sleep, including perceived sleep difficulties, are an important perspective for researchers to consider, as like bedtime data, difficulties in sleeping appear to show significant relationships with technology use (e.g., [35]).

Conclusions

When we began our first discussions on planning this chapter about technology and sleep, we knew we wanted to "spin readers' thinking" about this relationship. We do not mean to claim that using a technological device does not lead to sleep problems in young people. We have observed this, whether in our own children or

[2] Given the year of data collection, we presume the researchers referred to printed books as opposed to e-books.

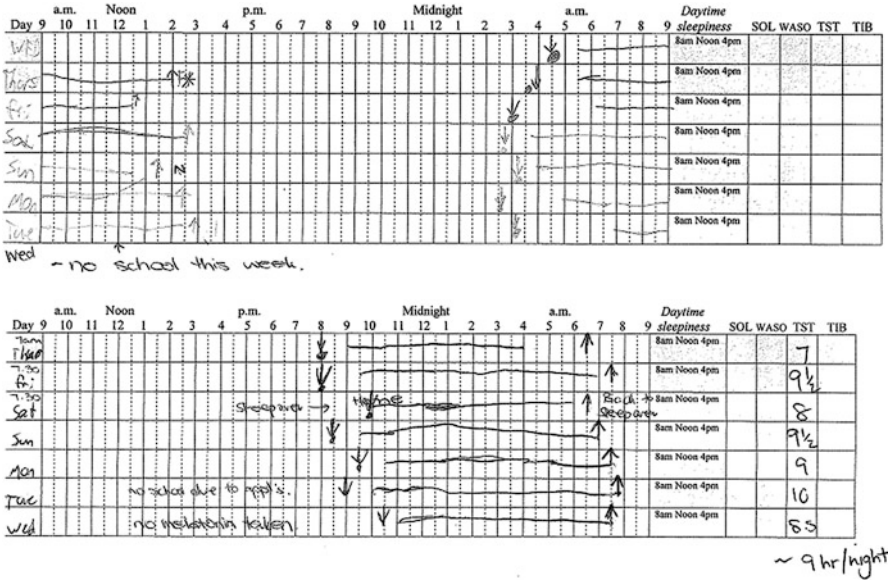

Fig. 4.4 (*Top*) Sleep diary of a 15-year-old male client who regularly plays online games in the evening. (*Bottom*) Sleep diary of the same client after treatment with motivational interviewing to reduce evening online gaming and a combination of evening melatonin and bright light therapy to phase advance his sleep timing

teenagers presenting with sleep problems to our Child and Adolescent Sleep Clinic at Flinders University (Fig. 4.4), albeit temporarily. Instead, we believe we need to work harder than usual to convince readers that, overall, the effect between technology use and sleep is small to negligible. If anything, we lack data to analyze whether technology use fills the void while young people wait for sleep onset to arrive [32]. Sleep problems may already exist in young people [36], and it is possibly better to avoid lying in the quiet darkness ruminating about past events and catastrophizing about future events [37, 38] by distracting oneself with a screen or the sound of music. The displacement hypothesis proposes that technology use may replace other activities, including sleeping [13]. So far, the data provide support for this hypothesis, as if anything, bedtime is related to technology use (more than sleep latency or sleep itself). However, there have been extremely few studies that have attempted to experimentally manipulate technology use and observe the effect on bedtimes [28]. If using technological devices accounts for at best 4 % of the variation in teenagers' sleep (or more accurately, bedtimes; Fig. 4.3), then doesn't this suggest we should turn our attention toward other culprits for why young people may sleep too little and too late [39]? We conclude this chapter by directing readers to Box 4.1, which lists areas for future research – including areas that do not involve technology use.

Box 4.1: Research Agenda
Future Research Directions

- Experimental studies to draw cause and effects between technology use and adolescent sleep
- Considering whether use of technology affects sleep beyond that of employing adequate sleep hygiene
- Designing experiments which focus on other factors which may contribute negatively to adolescent sleep (e.g., negative home environment, evening light)
- Designing experiments focusing on protective factors of sleep (e.g., sleep hygiene, parent-set bedtimes, exercise) and interventions (e.g., motivational interviewing)
- Research into contributions from biological factors (e.g., circadian delay, sleep homeostasis) to young people's sleep

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