Adolescents' electronic device use, sleep, and wellbeing

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Abstract

Many adolescents regularly use electronic devices, and a substantial proportion of adolescents use these devices in bed before they go to sleep. They are also at risk of using alcohol, recreational drugs, and tobacco, of becoming overweight or obese and having poor mental health. This thesis has investigated how adolescents' electronic device use affects their sleep and their wellbeing and examined (a) whether weekday and weekend sleep are explained using the same variables, (b) how device use affects sleep, and (c) how poor sleep affects mood. This thesis consists of three studies. Study 1 (N = 405) and study 2 (N = 489) both examined whether device use predicted poor and ill-timed sleep whilst simultaneously including other variables which are known to affect adolescents' sleep. Moreover, the studies also examined whether the factors which predicted weekday sleep also predicted weekend sleep. Thirdly, the studies examined the relationships between device use, sleep, and health related factors. The third study (N = 19) examined whether the blue light, content that was viewed on devices or the timing of device use affected adolescents' sleep and their following day mood.

This thesis has shown that adolescents' weekday and weekend sleep are explained differently. Adolescents who were more anxious or were more aroused had poorer weekday sleep and adolescents who socialised more at the weekend had poorer weekend sleep. Importantly, the thesis has shown that more frequent device use, later use of electronic devices and using more interactive content predict poorer sleep quality and ill-timed sleep. Finally, this thesis has shown that poor and ill-timed sleep predicted worse mood.

The findings from this thesis show that research should recognise that adolescents sleep differently on weekdays than they do at the weekend. The findings also show that researchers should investigate how the timing and content that individuals view on their electronic devices affects sleep.

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Dedication

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Abbreviations

AIC	Akaike Information Criterion
AAS	Alertness at School
AAW	Alertness at the Weekend
ASHS	Adolescent Sleep Hygiene Scale
BIS/BAS	Behavioural Inhibition System/Behavioural Activation System
BMI	Body Mass Index
BTs	Weekday Bedtime
BTw	Weekend Bedtime
CA	Cognitive Arousal
CASQ	Cleveland Adolescent Sleepiness Questionnaire
Comp	Computer
Covid-19	Coronavirus Disease 19
DLMO	Dim Light Melatonin Onset
DSM-5	Diagnostic and Statistical Manual of Mental Disorders 5
DVD	Digital Video Disc
EEG	Electroencephalogram
Email	Email use
ER	E-reader
FF	Facebook Friendships
FOPC	Frequency of Phone Checking During the Night
HADS	Hospital Anxiety and Depression Scale
I-PANAS-SF	International Short form Positive and Negative Affect Schedule Short Form
ipRGC	intrinsically photo-Sensitive Retinal Ganglion Cells
KSS	Karolinska Sleepiness scale

LED	Light Emitting Diode
Log	Logarithmic
M	
Media	Media Sharing
Mins	Minutes
MP	Mobile Phone
MP3	Motion Picture Experts Group Audio Layer III
NREM	non-Rapid Eye Movment
OF	Online Friendships
PC / Phone	Phone Calling
Pref	Preference for Task Switching
PSG	Polysonography
PVT	Psychomotor Vigilance Task
Refs	Weekday Waking Feeling Refreshed
Refw	Weekend Waking Feeling Refreshed
REM	Rapid Eye Movement
RHT	Retinohypothalamic Tract
SART	Sustained Attention to Response Task
SAS	Sleepiness at School
SAW	Sleepiness at the Weekend
SCN	Suprachiasmatic Nucleus
SD	Standard Deviation
SDs	Weekday Sleep Duration
SDw	Weekend Sleep Duration
SIE	Sleepiness on Weekday Evenings
SM	General Social Media Usage
SOLs	Weekday Sleep Onset Latency

SOLw	Weekend Sleep Onset Latency
SP	Smartphone Use
SQs	Weekday Sleep Quality
SQw	Weekend Sleep Quality
Std.	Standardised
SWA	Slow Wave Activity
Tab	Tablet
Text	Text messaging use
TIBs	Weekday Time in Bed
TIBw	Weekend Time in Bed
TV	Television
UK	United Kingdom
VG	Video Gaming use
VLPO	Vento-lateral Preoptic Nucleus
Web	Internet searching use
WTs	Weekday Wake Time
WTw	Weekend Wake Time

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1. Chapter 1: An introduction to adolescents' sleep and device use

1.1. Introduction to the thesis

This thesis will examine whether electronic devices affect adolescents' sleep. The literature surrounding electronic device use and sleep has predominately focused on understanding how light which is emitted from devices affects circadian timing and sleep. There are few papers which have examined whether a variety of electronic devices increase adolescents' pre-sleep cognitive arousal and lead to poorer sleep outcomes (Hale and Guan, 2015; Gradisar et al, 2013; Weaver et al, 2010). These studies have argued that interactive devices are associated with poorer sleep outcomes, whereas passive devices are not. A device is not inherently interactive or passive. It is the activity that an individual is engaging with which is either interactive or passive. This thesis will argue that devices displace sleep timing and increase pre-sleep cognitive arousal which leads to poorer sleep outcomes. The findings from study 1, study 2 and study 3 all showed that adolescents who used devices later or who were in a state of high arousal before going to sleep went to bed later, woke up later and had a poorer quality of sleep. The findings from study 3 also showed that adolescents who used electronic devices before going to sleep or who used interactive activities on their smartphone went to bed later, went to sleep later, woke up later and rose out of bed later the following day.

This first chapter will first describe why it is important to understand whether and how device use affects adolescents' sleep. The chapter will then explain how sleep is regulated and will then discuss the evidence for how light characteristics impact sleep and the circadian rhythm. The chapter will then discuss the evidence for how electronic device use may affect sleep.

1.2. What is the problem?

Approximately 67% of adolescents do not get enough sleep to function properly, with many reporting that insufficient sleep impacted their mood, academic performance, family life, social life, and social activities (Gradisar et al, 2013). Recent findings have shown that adolescents do not get adequate sleep. A systematic review showed that 12 – 14-year-olds slept for approximately 8.05 hours and 15 – 18-year-olds slept for approximately 7.4 hours (Figure 1). These findings were based on actigraphy measures of sleep (Galland et al, 2018). Figure 1 was removed to avoid copyright issues.

Expert panels, commissioned by the National Sleep Foundation and American Academy of Sleep Medicine, have provided recommendations for how long children and adolescents should sleep for per night. The panels recommended children, who were aged between 6 – 13 years old, should obtain approximately 9 – 12 hours sleep per night and adolescents, who were aged 14 – 18 years old, should obtain approximately 8 – 10 hours sleep per night (Figure 2) (Hirshkowitz et al, 2015; Paruthi et al, 2016). Figure 2 was removed to avoid copyright issues.

These findings show that adolescents are losing at least an hour of sleep per night. This is concerning as sleep loss has been related to a multitude of health risk factors relevant to adolescents including, but not limited to, poor mood and mental health, higher BMI, and greater substance use (Baum et al, 2014; Kelly and El-Sheikh, 2013; Jarrin et al, 2013; Bartel et al, 2016). Chapter 2 will describe in detail how sleep is related to these health risk factors. It is vital that the causes of adolescents' inadequate sleep are examined to avoid serious health complications.

Adolescents are keen users of light emitting devices, such as smartphones and tablets. Approximately, 83% of adolescents aged 12 – 15 years old own a smartphone and 72% of these adolescents take their smartphone to bed with them (Ofcom, 2018). Additionally, 77% of adolescents, aged 13 – 18 years use a laptop or computer in the hour before bed. Individuals who used more devices in the hour before bed struggled to fall asleep, struggled to stay asleep and woke feeling less refreshed the following morning (Gradisar et al, 2013).

Before examining how device use affects sleep, it is important to understand how sleep timing is regulated within humans as device use may disrupt both processes (process S and process C) which regulate sleep.

1.3. <u>How is sleep regulated?</u>

Zeitgebers (German for "time givers") are external factors (such as light, meals and exercise), which entrain the individual's circadian rhythm to the time of day. Aschoff (1965) was amongst the first to note that when zeitgebers are absent human sleep/wake patterns slightly deviate from the 24-hour period. This is because the intrinsic circadian period is slightly longer than 24 hours. The re-introduction of zeitgebers synchronised the circadian rhythm with local time. A two-process model of how sleep propensity is regulated was proposed (Borbély et al, 1982; Daan et al, 1984; Achermann and Borbély, 1990; Borbély et al, 2016).

The following section will discuss the two processes and how the two processes interact to regulate sleep.

1.3.1. Two process model

Sleep/wake patterns are under constant intrinsic control by two processes, these are process S (homeostatic sleep pressure) and process C (circadian rhythm). The two processes work simultaneously to regulate sleep propensity (Borbély, 1982, Borbély et al 2016; Daan et al, 1984).

1.3.1.1. Process S

Process S, or homeostatic sleep pressure, is sleep-dependent. Homeostatic sleep pressure increases as a function of time spent awake and exponentially dissipates with time spent asleep. Sleep deprivation studies have shown that sleep debt is not repaid on a 1:1 basis. After several days of continuous wakefulness, individuals slept for 10 – 14 hours (Blake and Gerard, 1937; Gulevich et al, 1966). These findings led researchers to question whether the intensity of sleep changes to repay sleep debt (Borbély, 1982). Slow wave activity is considered to be a physiological correlate of process S and reflect sleep intensity (Daan et al, 1984; Dijk et al, 1999; Blake and Gerard, 1937). Slow wave activity[1] decreased exponentially as time was spent asleep (Borbély, 1982). Moreover, sleep deprivation studies found participants had more slow wave sleep during the recovery night. Slow wave activity was higher immediately after the recovery sleep began (Berger and Oswald, 1962; Dijk et al, 1990). Sleep disruption studies (whereby participants were woken when slow wave sleep was detected) showed that participants spent a longer period in slow wave sleep and had a higher proportion of slow wave activity during the recovery nights (Dijk et al, 2010). These findings showed that sleep deprived, or sleep disrupted individuals had more slow wave activity in the following nights to repay the sleep they lost during the deprivation or disruption protocol. Daytime naps also influence slow wave activity. Slow wave activity was lowest when daytime naps were scheduled early in the day. Slow wave activity increased when daytime naps were scheduled for later in the day (Dijk et al, 1987). Not only did the individual have more slow wave activity during the daytime nap but the individual also had lower slow wave activity that night too (Werth et al, 1996).

1.3.1.2. Process C

Process C, or circadian rhythm, is sleep independent. The circadian rhythm is regulated by a circadian oscillator (Suprachiasmatic Nucleus- SCN), located in the hypothalamus (Leak

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[1] Delta waves with a frequency in the range of 0.75 – 4.5 Hz.

and Moore, 2001). The SCN (master circadian pacemaker) regulates all the body's biological clocks and lesions to the SCN have resulted in the absence of sleep/wake patterns (Edgar et al, 1993). Regardless of how long the individual has been awake for there are certain times in the day when their propensity for sleep is higher than other times in the day (Dijk and Czeisler, 1995). The SCN regulates the daily fluctuations in the secretion of hormones (such as cortisol and melatonin) and in core body temperature and operates across a near 24-hour period (M = 24.18 hours). As such, core body temperature and melatonin are regularly used as markers of circadian rhythm (Czeisler et al, 1999). In everyday life (i.e., under entrainment) melatonin secretion and core body temperature begin to rise in the early evening (Lavie, 1986). The circadian drive for sleep is at its lowest in the early evening when subjective and objective measures show that the individual is more alert. This increase in alertness opposes the accumulating homeostatic sleep pressure to an extent. This time is referred to as the "wake maintenance zone" or "sleep forbidden zone" (Strogatz et al, 1987; Dijk and Czeisler, 1995). On a normal waking day[2], individuals are more alert and perform well on measures of cognitive performance such as sustained attention, working memory and visuoperceptual functioning during the "wake maintenance zone" (Shekleton et al, 2013). During sleep deprivation, the ever-increasing homeostatic sleep pressure also influences cognitive performance. During the "wake maintenance zone" individuals, who had been sleep deprived for 13.5 hours, had improved performance on response inhibition tasks. Individuals who had been sleep deprived for 40 hours had improved sustained attention during the "wake maintenance zone". There were no other improvements in other aspects of cognition such as working memory (de Zeeuw et al, 2018).

The circadian rhythm is heavily influenced by Zeitgebers which are environmental cues that can advance or delay the circadian phase. Circadian phase delay is when sleep/wake patterns are delayed relative to local time, which results in the individual falling asleep later. Light which is presented in the late subjective night induces phase advances. Circadian phase advance is when the sleep/wake patterns are advanced relative to local time, which results in the individual waking and feeling alert earlier in the morning (Johnson and Nakashima, 1990; Czeisler et al, 1999). The strongest zeitgeber is light. The impact of light on the circadian rhythm and sleep will be discussed in further detail in the section "How does light impact sleep?".

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[2]This refers to when individuals are not under sleep restriction, deprivation, or disruption protocols.

Process C causes rhythmic variations in sleep propensity by controlling the thresholds for sleep and wake initiation and consequently has been likened to a thermostat and termed "Somnostat" (Daan et al, 1984).

1.3.1.3. The interaction between process S and process C

Process S and C regulate sleep propensity by interacting together. During the day homeostatic sleep pressure increases whilst the circadian drive for wakefulness increases. Once the homeostatic sleep pressure has risen above the higher asymptote (threshold) set by the circadian rhythm, sleep is initiated. A similar process occurs during sleep, homeostatic sleep pressure dissipates as time is spent asleep, thus promoting wakefulness, the circadian rhythm begins to promote sleep to avoid early awakenings (Edgar et al, 1993; Dijk and Czeisler, 1995). Once the homeostatic sleep pressure surpasses the lower asymptote (threshold) set by process C, wake is initiated (Figure 3). Figure 3 shows that as time is spent awake (over a 16-hour waking period), process S increases. As time is spent asleep, process S reduces. After sleep deprivation (the red line), sleep propensity and process S are higher than after a regular waking period. Evening naps (green line) reduced process S and so process S was lower when nocturnal sleep was initiated. Despite homeostatic sleep pressure being greater after sleep deprivation and lower after evening naps, homeostatic sleep pressure dissipates at a similar rate regardless of whether the individual is sleep deprived, well slept or has been awake for a normal waking day. Figure 3 was removed to avoid copyright issues.

1.4. <u>How does device use affect sleep?</u>

The impact of electronic device usage on sleep has been extensively researched. The three pathways in which electronic device usage is thought to impact sleep were set out by Cain and Gradisar (2010), these are:

1. Blue light which is emitted by light-emitting devices delays the circadian phase and suppresses melatonin secretion, which delays sleep onset.
2. The content that is viewed on light-emitting devices increases cognitive stimulation which makes pre-sleep relaxation harder to achieve, which delays sleep onset.
3. The time that is spent on devices could be spent asleep. This reduces sleep duration when there is a fixed wake time (i.e., school schedule). Homeostatic sleep pressure increases as the time spent awake increases. This means that individuals will fall asleep quicker.

Hale and Guan's (2015) systematic review on the impact of adolescents' device use on their sleep found that adolescents who used their devices for a longer period of time had adverse sleep outcomes (specifically shortened sleep duration and delayed sleep onset). Their findings also showed that, in the studies they reviewed (67 studies), computers, video games and mobile phones were consistently associated with poorer sleep outcomes. There is ongoing debate as to how device use affects sleep and so Hale and Guan's (2015) systematic review findings may be interpreted in several ways. Their findings may be due to computers, video games and mobile phones being used at a closer distance to the eye (< 40 cm) than televisions. The distance in which a device is used is related to lower melatonin secretion and poorer sleep outcomes (Oh et al, 2015; Yoshimura et al, 2017). Alternatively, it may be that the computers, video games and mobile phones require more interaction from the user. Finally, the findings could be due to individuals preferring to use computers, video games and mobile phones as they can contact their peers and so these devices directly delay sleep onset.

It is important to first understand how light[3], which is administered under very strict protocols, affects the circadian phase and sleep. The following section will discuss how light affects the circadian phase and sleep as a function of the timing, intensity, duration, prior light history, and wavelength of light. It should be noted that these studies were conducted in laboratory settings and so the conditions were strictly controlled. The findings from these studies are not directly clinically relevant as most of the studies have examined the impact of extreme conditions and these conditions are unlikely to occur in real life. The findings do, however, provide insight into how light impacts circadian timing and sleep. The section "How does blue light that is emitted from devices impact sleep?" will then discuss the evidence from studies which have examined the impact of technology on circadian timing and sleep, which are more clinically relevant as these studies use light emitting devices rather than light lamps.

1.4.1. How does light impact sleep?

Light is used by the eye for image forming and *non-image forming* responses. As can be seen in Figure 4, light hits the back of the retina where it is detected by intrinsically photosensitive Retinal Ganglion cells (ipRGCs) which contain melanopsin and pituitary adenylate cyclase activating polypeptide (Berson et al, 2002). Melanopsin is a photopigment

[3] The timing, intensity, duration, and wavelength of this light are often meticulously controlled and often participants are subject to a very strict protocol before the study begins to reduce the amount of light they are exposed to beforehand.

found within a subset of ipRGCs. It has a peak absorption of ~ 460nm and is responsible for the non-image forming responses of light. ipRGCs project to the suprachiasmatic nucleus (SCN) in the hypothalamus via the retinal hypothalamic tract (RHT) (Gooley et al, 2001; Berson et al, 2002). The SCN is the master circadian pacemaker, which strictly regulates all daily recurring processes within the body e.g., hormone secretion [4] and core body temperature (Moore and Leak, 2001). The SCN projects to the pineal gland, found within the hypothalamus, which synthesises and secretes melatonin (sleep/wake hormone) (Arendt, 1994). ipRGCs also project to the lateral geniculate nucleus and superior colliculus, which moderate the response to light/dark cycles (Miller, 1998). The SCN also projects to the pretectum, which plays a pivotal role in mediating the light/dark cycle (Miller, 1998). The SCN also projects to the ventrolateral preoptic nucleus (VLPO), which is thought to be critical in sleep regulation. Lesions to this area have resulted in insomnia and sleep fragmentation (Sherin et al, 1996). The SCN also projects to the locus coeruleus, which is involved in the regulation of arousal (Lockley et al, 2006). The light/dark cycle entrains the circadian rhythm. Exposure to artificial light in the evening and night cause disturbances to the circadian rhythm resulting in phase delay or phase advance depending on the timing of the stimulus administration. Figure 4 was removed to avoid copyright issues.

The wavelength, timing, intensity, and duration of the light exposure all determine how light exposure influences the circadian phase and sleep (Hastings and Sweeney, 1958). The first pathway set out by Cain and Gradisar (2010) specifically claims that short wavelength light which is emitted from devices results in adverse sleep outcomes. The following section will briefly describe how the timing, intensity, and duration of light exposure impacts sleep.

1.4.1.1. How does the timing of light exposure affect the response?

The timing of light exposure affects the circadian rhythm. Light which is presented in the early subjective night induces phase delays. As has been previously described, phase delays are when sleep/wake patterns are delayed to an earlier clock time, which results in the individual falling asleep later. Light which is presented in the late subjective night induces phase advances. Phase advances are when sleep/wake patterns are advanced to a later clock time, which results in the individual waking and feeling alert earlier in the morning (Johnson and Nakashima, 1990; Czeisler et al, 1999).

The timing of light administration is crucial in determining the phase response on circadian period. Crowley and Eastman (2017) subjected adolescents[5] to 4-hour light/dark cycles

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[4] Melatonin and cortisol are under the control of the SCN.
[5] Participants were aged (M ± SD) 16.2 ± 1.0 years.

where participants were exposed to 80 minutes[6] of bright white light (~ 5000 lux) and then given a 2-hour sleep opportunity. Different participants were exposed to the bright light at one of the following times: 18:05, 22:05, 02:05, 06:05 and 10:05. They found that light exposure which was administered 1.9 hours after dim light melatonin onset[7] resulted in -1.8 hours phase delay and light exposure which was administered 0.2 hours after dim light melatonin onset resulted in 1.5 hours phase advance.

Administering light in the evening has been shown to have several effects on sleep which have been measured both objectively and subjectively. Light exposure in the evening lowered sleep propensity, lengthened sleep onset latency, latency to stage 2 sleep and latency to slow wave sleep (Carrier and Dumont, 1995; Santhi et al, 2012). As well as impacting objective sleep parameters, studies have found that evening light also affects subjective ratings of sleep. Bright light administered in the evenings lengthened self-reported sleep onset latency and individuals reported a poorer quality of sleep (Skeldon et al, 2017).

Administering light in the morning results in circadian phase advance. Individuals who were exposed to light in the mornings before wake time spent a shorter period of time in bed, slept for a shorter period and woke up earlier the following morning (Kohsaka et al, 2000; Dijk et al, 1989).

It is important to note that the research reported above were conducted using adult participants and so the findings may not show how adolescents' respond to light. Carskadon (2011) noted the circadian phase becomes naturally delayed during adolescence. Crowley et al (2015) demonstrated that younger adolescents had greater melatonin suppression to light that was administered in the evening[8] and that there were no differences in adolescents' melatonin suppression to light that was administered in the morning. Chapter 2 will discuss how the circadian rhythm and homeostatic sleep pressure changes across adolescence.

These studies show the importance of asking individuals when they used their devices during the evening. The studies would suggest that individuals who use their devices later in the evening may have greater melatonin suppression and thus have a longer sleep onset latency and poorer sleep quality. Moreover, Crowley and colleagues' work would suggest that this response may be heightened in younger adolescents and so it is even more important to ask adolescents when they began and finished using their devices in the evening.

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[6] The 80 minutes were made up of 4 x 20-minute exposures
[7] Determined by linear interpolation across the time points before and after the melatonin concentration increased to and stayed above 4 pg/mL.
[8] Melatonin suppression was measured using the area under the curve (AUC).

1.4.1.2. How does the intensity of light exposure affect the response?

It was originally thought that high irradiances (1000 lux +) of white polychromatic light were required for greater melatonin suppression, increased core body temperature and increased heart rate. Lewy et al (1980) findings showed that at least 1,000 lux was required to suppress melatonin. Less than 1000 lux did not reduce melatonin secretion. They concluded from these findings that higher irradiances of light were required to suppress melatonin secretion in humans in comparison to animals. Subsequent researchers have found that lower light intensities (< 1000 lux) were required to cause circadian phase shifts. Santhi et al (2012) exposed individuals[9] to light[10] for 4 hours. The light was timed to begin 04:25 before sleep onset. The findings showed that individuals who were exposed to bright blue enhanced light (~ 700 lux) for four hours had greater melatonin suppression[11] and took longer to fall asleep than participants who were exposed to lower light intensities.

As little as 100 lux has been shown to affect the circadian phase and subjective alertness. Zeitzer and colleagues showed that 6.5 hours of 100 lux, which was administered 6.75 hours before core body temperature minimum and finished 0.25 hours before core body temperature minimum, caused half of the maximal phase delay, melatonin suppression and reduction in subjective alertness at 9,000 lux did (Zeitzer et al, 2000; Cajochen et al, 2000). This is particularly important as devices typically emit light that is between 50 - 100 lux (Cajochen et al, 2011; Chinoy et al, 2018). These findings would suggest that the light which is emitted from devices has a substantial effect on an individual's circadian phase, melatonin secretion and alertness.

1.4.1.3. How does the duration of light exposure affect the response?

Longer durations of light exposure result in larger phase shifts per se, however shorter intermittent light exposures result in the largest phase shifts per minute of light exposure. Gronfier et al (2004) exposed participants to either for 6.5 hours of continuous bright light (9,500 lux)[12], intermittent bright light (6 x 15 min bright light pulses) separated by 60 minutes of very dim light (< 1 lux), or the control group (continuous dim light [< 1 lux]). Exposure to 100% bright light induced phase delay shifts of approximately -3.00 hours for

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[9] Participants were aged (M ± SD) 23.1 ± 4.7 years.

[10] The conditions were near darkness (~ 1 lux), blue depleted light (~ 225 lux), blue intermediate light (~ 135 lux), blue enhanced light (~ 135 lux) and bright blue enhanced light (~ 700 lux).

[11] Melatonin samples were taken every half an hour and melatonin suppression was calculated using AUC.

[12] Exposing participants to 6.5 hours of continuous bright light (9,500 lux) will be referred to as 100% bright light; exposing participants to 6 x 15-minute bright light pulses will be referred to as 23% bright light. The control group were exposed to < 1 lux.

core body temperature and dim light melatonin onset (DLMOn[13]) in comparison to the control group. Exposure to 23% bright light induced a median phase delay shift of approximately -2.00 hours for core body temperature and DLMOn in comparison to the control group. These findings show that intermittent bright light produced larger phase responses per minute of light exposure than the continuous bright light exposure. Whilst these findings show how exposure to bright light in the early subjective night (i.e., prior to core body temperature min) impacts the circadian phase, individuals rarely expose themselves to either 6.5 hours of continuous or intermittent bright light. In 2018, individuals aged 18 – 24 years old spent an average of 03:30 hours online on their smartphone per day (Ofcom, 2018). To properly understand how the light emitted from devices impacts sleep, several brief bright light pulses should be administered to replicate electronic device use in the evening and night.

Shorter light exposures have also been observed to affect individual's circadian phase, melatonin secretion and sleepiness. Chang et al (2012) administered a single high intensity light pulse[14] which was timed to begin 0.5 – 4.5 hours after melatonin onset for either 0.2 hours, 1 hour, 2.5 hours or 4 hours, on young adults'[15] circadian phase, melatonin secretion and sleepiness. Participants who were exposed to the bright light for 0.2hours showed phase delay shifts in their melatonin secretion of 1.07 ± 0.36 hours, those who were exposed to the bright light for 1 hour showed phase delay shifts in melatonin secretion of 1.55 ± 0.38 hours, those who were exposed to the bright light for 2.5 hours showed phase delay shifts in melatonin secretion of 2.29 ± 0.28 hours and finally, those who were exposed to the bright light for 4.0 hours showed a phase delay shift in melatonin secretion of 3.05 ± 0.45 hours. The findings show that shorter light exposure durations induced greater phase delay shifts per minute than the longer light exposure durations.

Furthermore, very brief light exposures (~ 2ms) have been shown to impact individuals' circadian phase. Najjar and Zeitzer (2016) exposed adults[16] to 60 minutes of either continuous or intermittent light flashes[17] that lasted for 2ms (with inter-stimulus intervals ranging between 2.5 – 240 seconds). The results showed that intermittent light was more effective at delaying circadian phase. Per minute, larger phase shifts were observed with

[13] Dim light melatonin onset was recorded as the time in which melatonin secretion remained above 25% threshold.
[14] The intensity of the single light pulse was ~ 10,000 lux.
[15] Participants were aged (M ± SD) 22.18 ± 3.62 years.

[16] Participants were aged (M ± SD) 26.4 ± 5.06 years.

[17] The intensity of the light was 1,800 lux for both continuous and intermittent light flashes.

shorter light pulses. These findings show that brief exposure to light in the evening and during the night has a profound impact on individuals' circadian phase and melatonin secretion. This may be problematic for adolescents who check their phone just before going to sleep or check their phone during the night as these brief exposures to light may mean it takes them longer to fall asleep and reduce their quality of sleep.

1.4.1.4. What is the impact of prior light history on sleep?

Prior light history is also thought to play a role in determining the effect of light exposure on melatonin suppression and circadian phase. Several studies have shown that participants prior light exposure also determines participant's responses to light exposures. Smith et al (2004) examined the impact of 6.5 hours of light exposure on individuals who had either been exposed to 0.5 lux or 200 lux for 3 days before the study began. The findings showed that individuals who had been exposed to 0.5 lux for 3 days prior to experimental light exposure[18] had greater melatonin suppression[19] than the individuals who were exposed to 200 lux prior to the study.

More recently, Chang et al (2013) showed that participants who had been exposed to 1 lux before the experimental light exposure were less sleepy, had greater melatonin suppression[20], had quicker psychomotor vigilance task (PVT) mean reaction times, fewer PVT lapses and lower delta/theta activity whilst awake than participants who were exposed to 90 lux prior to the experimental light exposure. These findings suggest that exposure to moderate or bright light intensities desensitises the neurons. The neurons then require greater light intensities to be restimulated. In darkness or minimal light exposure, the neurons are not desensitised.

In the real world, adolescents are constantly exposed to light, whether that is natural (~ 10,000 lux) or artificial via light emitting devices (~ 50 -100 lux) (Cajochen et al, 2011; Chang et al, 2014). These findings suggest that the light which is emitted from devices may not have as much of an impact as originally thought. Exposure to light on a regular basis means that greater light intensities are required to restimulate the neurons. Therefore, it is important to examine how device use impacts sleep/ wake patterns in real world contexts to account for individuals' prior light history.

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[18] The experimental light exposure was ~200 lux.
[19] Melatonin samples were taken every 20 minutes and melatonin suppression was calculated using AUC.
[20] Melatonin samples were taken every 30 - 60 minutes and the circadian phase angle was calculated as the midpoint between melatonin onset and melatonin offset.

1.4.1.5. How does the wavelength of light impact sleep?

The wavelength of the light suppresses melatonin, increases core body temperature, and increases heart rate (Brainard et al, 2001; Thapan et al, 2001; Cajochen et al, 2005). Brainard et al (2001) and Thapan et al (2001) demonstrated that a novel opsin photopigment (melanopsin) had a peak spectral sensitivity within the short wavelength section of the visible electromagnetic spectrum. Both Brainard and colleagues and Thapan and colleagues demonstrated that shorter wavelength light (446 – 477nm) resulted in greater melatonin suppression compared to longer wavelengths. These findings showed that melanopsin, was most sensitive to short wavelength light and was responsible for the non-visual response to light. Thus, short wavelength light has a larger impact on sleep/ wake patterns than longer wavelength light (~ 600nm). Short wavelength light occupies the blue section of the visible electromagnetic spectrum. Longer wavelength light occupies the red section of the visible electromagnetic spectrum.

Whilst short wavelength light has a larger impact on circadian markers, medium wavelength light (~ 540nm) has also been observed to suppress melatonin. Cajochen et al (2005) compared the effects of 2 hours of short wavelength (~ 460nm; blue light; 12.1 μW/cm2) and medium wavelength light (~ 555nm; green light; 10.05 μW/cm2) on participants' melatonin secretion[21], core body temperature, heart rate. These findings showed that exposure to short or medium wavelength light resulted in greater melatonin suppression in comparison to not being exposed to light. The findings also showed that exposure to short wavelength light also resulted in higher core body temperature, faster heart rate and feeling less sleepy. These findings show that the wavelength of light disrupts circadian markers. Short wavelength light (~ 446 – 477 nm) has the most profound impact as the ipRGCs are most sensitive to this wavelength.

Short wavelength light has been noted to also affect sleep parameters. Münch et al (2006) investigated the impact of exposure to 2 hours short and longer wavelength light on sleep parameters. The findings showed that participants had reduced slow wave activity in the first sleep cycle and significantly greater slow wave activity in the third sleep cycle after exposure to short wavelength light. Slow wave activity is a physiological correlate of homeostatic sleep pressure and sleep intensity. The findings also showed that exposure to blue light reduced REM sleep duration during the first and third sleep cycle. These findings suggest that shorter wavelength light reduced individuals' sleep intensity and suggests that exposure to short wavelength light from devices may result in a lower sleep intensity.

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[21] Melatonin samples were collected every 30 minutes.

Blue blocker glasses goggles (which filter out light that is < 555nm) have been used to investigate how short wavelength light affects circadian phase and sleep. There is very little research which has examined how blue blocker glasses impact adolescents' circadian phase and sleep. Van der Lely et al (2015) investigated the impact of wearing blue blocker glasses whilst viewing a LED screen for 3 hours[22] on adolescents'[23] sleepiness, melatonin secretion[24] and subsequent sleep as measured using PSG. Adolescents who wore blue blocker glasses were sleepier during the evening, had a greater rise in melatonin secretion in the evening and reported feeling less alert in the evening than those wearing clear goggles. There were no differences in sleep architecture or sleep timing between those wearing blue blocker glasses and those wearing clear goggles. These findings show that the blue blocker glasses protected the individual from the negative effects of blue light. Most light emitting devices typically have a peak spectral distribution within the blue portion of the visible spectrum. Van der Lely and colleagues' findings show that blocking the blue light that is emitted from these devices will result in the individual feeling sleepier and less alert in the evening and will have higher melatonin secretion, thus increasing sleep propensity. Most adolescents do not have access to blue blocker glasses and so in practice this research suggests that adolescents should avoid using devices which emit blue light to avoid a circadian phase delay and reduced sleep propensity.

These findings are all important in understanding how electronic device usage impacts sleep. Most electronic devices, for example smartphones, emit short wavelength light (~ 460nm). Thus, evening device use is likely to affect the circadian phase, melatonin secretion and sleep.

The studies reported in this section were conducted using laboratory lamps which did not replicate real world contexts and so it is important to examine how light emitting devices affect the circadian phase and sleep.

1.4.2. How does blue light that is emitted from devices impact sleep?

Studies have also shown how blue light which is emitted from devices affects the circadian phase and sleep. This is the first of the three pathways in which electronic device usage may affect sleep (Cain and Gradisar, 2010). As described above, it is thought that the short wavelength or blue light suppresses melatonin secretion which delays sleep onset. Short wavelength light alters the circadian phase, reduces melatonin secretion, increases alertness,

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[22] LED screens were viewed for 3 hours between 20:30 and 23:30.
[23] Participants were aged (M ± SD) 16.46 ± 0.66 years.
[24] Saliva samples were taken every 30 minutes. Dim light melatonin onset was measured using the Hockley-stick method Danilenko et al (2013).

and compromises several sleep parameters. These include lengthening sleep onset latency and reducing slow wave sleep (Cajochen et al, 1992; Münch et al, 2006).

Newer models of computers, smartphones and tablets have light emitting diode (LED) screens which have been shown to peak in the short wavelength region of the visible electromagnetic spectrum (~ 450 – 480nm) (Oh et al, 2015; Cajochen et al, 2011). It is important to understand how the blue light that is emitted from these screens affects adolescents' sleep as recent evidence has shown that 83% of 12 – 15-year-olds have a smartphone and 71% of these adolescents are allowed to take it to bed with them and 50% of 12 – 15-year-olds have their own tablet and 61% of these adolescents are allowed to take it to bed with them (Ofcom, 2018).

Most of the experimental evidence which has examined the impact of electronic devices on melatonin production and sleep parameters has used adult participants. It is important to recognise this, given that Crowley and colleagues (2017; unpublished) showed that younger adolescents[25] were more sensitive to light in comparison to older adolescents or adults. Thus, the findings from studies that have examined the impact of light exposure on adults may not reflect adolescents' response to light and be relevant to adolescents.

Cajochen et al (2011) exposed adults[26] to 5 hours of light (< 100 lux) from computers and laptops from 20:00. Participants were either exposed to a white light emitting diode (LED) backlit screen with more than twice as much short wavelength light (454 – 474nm) as a white non-LED back light screen[27]. Melatonin and sleepiness[28] were measured every 30 minutes from 20:00 – 01:00. After the first 2 hours of light exposure, participants watched a 20-minute relaxing movie which was also shown on either a non-LED or a LED screen. Every hour participants completed the Karolinska Drowsiness Test and a GO/NOGO task. Sleepiness was also measured using slow rolling eye movements (SEMs). Their findings showed that the LED screen suppressed and delayed the evening rise in melatonin. Melatonin secretion rose later under exposure to the LED screen, but the secretion was lower than under a non-LED screen. There were no significant differences between using a non-LED and a LED screen on subjective sleepiness. However, participants who watched the short, relaxing movie on a non-LED screen reported feeling sleepier than those who watched the movie on a LED screen. Participants who were exposed to a non-LED screen also had a

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[25] Participants were aged (range; M ± SD was not provided) 9 – 14 years.
[26] Participants were aged (M ± SD) 23.8 ± 5 years.
[27] The photon flux for the LED backlit screen was 2.1 x 10^{13} in the wavelength range of 454 and 470nm. The photon flux for the non-LED backlit screen was 0.7 x 10^{13} in the wavelength range of 454 and 470nm.
[28] The Karolinska Sleepiness Scale measured sleepiness. The minimum detectable concentration of melatonin was 0.2 pg/ml.

higher frequency of SEMs than those who were exposed to a LED screen. Both findings show that the LED screens made participants feel less sleepy. Participants who were exposed to the LED screen performed better on the GO/NOGO task than those who were exposed to the non-LED screen, which shows that the LED screen increased alertness. Finally, participants' reaction times were faster when they completed the GO/NOGO task on a LED screen later in the night whereas participants reaction times were slower later in the night on the GO/NOGO task when using a non-LED screen. This finding shows that individuals who used LED screens for sustained periods of time felt more alert than individuals who used a non-LED screen for a sustained period. Finally, the Karolinska Drowsiness Test showed that participants who were exposed to LED screens had lower EEG power density than participants who were exposed to non-LED screens, which further shows that exposure to LED screens increased alertness. These findings show that individuals who are exposed to short wavelength light from LED screens[29] for substantial periods of time may have delayed and suppressed melatonin secretion, may be less sleepy and more alert just before they go to sleep. Cajochen and colleagues' findings tie in with van der Lely et al (2015) findings that adolescents who wore clear goggles and thus were exposed to short wavelength light, were less sleepy in the evening, had suppressed melatonin secretion and felt more alert than adolescents who wore blue blocker glasses.

Chang et al (2014) examined how reading a print book[30] or reading a light emitting book[31] for 4 hours[32] affected adults'[33] sleep parameters and melatonin secretion[34]. Participants read for 4 hours before bedtime in otherwise dim light (~ 3 lux) for five consecutive evenings. The findings showed that participants who read from a light emitting book took longer to fall asleep, were less sleepy in the evening[35], had delayed and reduced melatonin secretion[36]and were less alert the following morning than participants who read a print book. These findings support Cajochen et al (2005) and van der Lely et al (2015) findings that short wavelength light delays and suppresses melatonin, makes individuals feel less sleepy and more alert. E-readers are owned and used by a small proportion of the population. Only 13% of 13 – 16-

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[29] LED screens are often used in computers and smartphones.
30 The reflected peak spectral distribution of the print material was ~ 612 nm.
31 The peak spectral power distribution of the light emitting book was ~ 450 nm.
32 Participants were asked to read from 18:00 – 22:00.
33 Participants were aged (M ± SD) 24.92 ± 2.87 years.
[34] Melatonin samples were collected every hour and melatonin secretion was calculated using AUC, by trapezoidal method. DLMO was calculated as the time in which melatonin rose above 25% of the peak-to-trough amplitude of a three-harmonic waveform fitted to the 24-hour melatonin data from the constant posture procedure.
[35] Sleepiness was measured using Karolinska Sleepiness Scale.
[36] Dim light melatonin secretion onset was > 1.5 hours later in light emitting book condition than print book condition)

year-olds use e-readers (Merga, 2014). Research which uses a wider variety of devices (such as smartphones) would be more clinically relevant as 83% of 12 –15-year-olds own their own smartphone, and a substantial proportion of these adolescents take their smartphone to bed with them (Ofcom, 2018).

Cajochen et al (2011) and Chang et al (2014) both experimentally manipulated the light which participants were exposed to in a laboratory setting. Whilst laboratory studies are required to properly establish cause and effect relationships, they lack ecological validity and clinical relevance. Chang et al (2014) and Cajochen et al (2011) exposed participants to electronic devices for 4 and 6 hours, respectively. It is highly unlikely that adolescents would be exposed to electronic devices for this amount of time without any interruptions and so the studies lack real-world relevance.

Wood et al (2013) exposed individuals[37] to light emitting tablets for 2 hours from 23:00 to 01:00. They exposed participants to either: a tablet only condition[38], tablet and blue light condition[39] or a control condition[40]. Participants who viewed the tablet through clear goggles had greater melatonin suppression[41] than participants in the control condition after one and two hours. After two hours, participants in the tablet only condition had greater melatonin suppression compared to the control condition. There was no difference in melatonin suppression after one hour for participants in the tablet only and the control condition. This supports Brainard et al (2001) and Thapan et al (2001) work which showed that the photopigment, melanopsin, is most sensitive to short wavelength light (446 – 477nm). One – two hours is a typical length of time that an individual may use a device for in the real world. These findings have shown how electronic devices and the duration of usage impacts individuals' melatonin secretion.

Most of the research which has examined the impact of light on sleep and circadian phase has exposed all participants to light for the same period of time. This is often several hours as laboratory-based research has shown that longer durations of light exposure result in larger circadian phase shifts and greater melatonin suppression (Gronifer et al, 2004; Chang et al, 2012). In real world contexts, individuals can choose when and how long they use their

[37] Participants were aged (M ± SD) 18.9 ± 5.2 years.
[38] The tablet was viewed through blue blocker glasses, was set to full brightness and the spectral power distribution peaked at ~ 450 nm.
[39]The tablet mentioned above was viewed through clear goggles fitted with short wavelength LEDs and the spectral power distribution peaked at ~ 470nm.
[40] The tablet mentioned above was viewed through orange tinted glasses, which filtered out radiation below 525nm.
[41] Melatonin samples were collected after one hour (midnight) and two hours (01:00am) exposure and the limit of detection was 0.9 pg/ml.

devices for. Chinoy et al (2018) compared the impact of using a light emitting tablet or reading print material on young adults'[42] circadian phase, melatonin secretion[43] and sleep parameters. Participants were instructed to use the tablet (activities were not controlled) or read their printed material from 18:00 – 20:45. At 20:45 participants were allowed a 15-minute break and then completed a 5-minute computerised task before they were asked by the technician if they wanted to continue with their activity or go to sleep. All participants were fitted with PSG before they went to sleep. Participants who used the light emitting tablets reported feeling less sleepy in the evenings, chose to go to bed later, had greater melatonin suppression, took longer to fall asleep, had more stage 3 sleep, less wake after sleep onset and reported feeling less alert during the first hour after waking up the following morning. The light emitting tablets suppressed melatonin secretion, which resulted in the participants feeling less sleepy and choosing to go to bed later. By choosing to go to bed later participants may have had greater homeostatic sleep pressure (increased stage 3 sleep). Participants will have felt less alert the following morning because the light exposure delayed their circadian phase, and they went to bed later. Thus, participants may have been waking whilst their circadian rhythm was still promoting sleepiness. Whilst Chinoy et al (2018) findings appear to show that the blue light that is emitted from devices is responsible for adverse sleep outcomes, they did not monitor the content of the material that participants were exposed to. Individuals may have been exposed to more cognitively stimulating content on the light emitting tablets than the content that individuals who were reading the print books read.

It is unlikely that adolescents would use only one application on their electronic devices and so allowing participants the freedom to choose how they spent their time on the tablets increases the ecological validity of the study. It is still important to monitor the content that participants view on devices to ascertain *how* device use affects sleep. Jones et al (2018) examined the impact of completing stimulating puzzles[44] and reading text on either paper or on a light emitting tablet in adolescents[45]. Their findings showed that participants reported feeling less alert after reading print materials or reading from a tablet than after completing print or tablet-based puzzles. These findings suggest that more stimulating activities increase

[42] Participants were aged (M ± SD) 25.7 ± 3.0 years.
[43] Melatonin samples were taken every 60 minutes. DLMO was calculated as the time in which melatonin levels rose above 25% of the peak-to-trough amplitude which was determined using a 3-harmonic fit of the melatonin data from the baseline constant procedure. Melatonin secretion was also assessed using AUC.
[44] Participants were given a selection of puzzles to choose from such as word search, sudoku and logic puzzles. These were all deemed to be stimulating and researchers changed the puzzle every 20 minutes to maintain interest. Print materials consisted of uninteresting magazines on finance, cars and medical practice. These were all deemed to be uninteresting.
[45] Participants were aged (M ± SD) 18 ± 1 years.

alertness. Interestingly, the findings also showed that participants' melatonin concentration increased after completing tablet-based reading compared to when they completed tablet-based puzzles. Jones and colleagues' findings highlight the importance of monitoring the content of light emitting devices in experimental studies. The findings from Chang and colleagues' and Chinoy and colleagues' studies may also have been due to participants being exposed to more cognitively stimulating content on their devices. Monitoring the content that adolescents are exposed to on their light emitting devices would indicate whether this is the case.

Light emitting devices can be used for a variety of different activities. Device users can communicate with their peers, scroll through social media posts, play video games and read the news amongst many other activities. These activities not only differ in how interactive they are, but they also differ in how relevant they are to the user, for example social media applications generally show highly relevant and interactive content whereas video games show less relevant yet interactive content. Wang and Scherr (2021) recently investigated how TikTok[46] is associated with pre-sleep cognitive arousal and daytime fatigue in adults[47]. The findings from the study showed that greater TikTok use was associated with greater daytime fatigue and this relationship was mediated by greater pre-sleep cognitive arousal. These findings suggest that users of applications which show highly relevant content (such as TikTok or other social media platforms) find it harder to fall asleep at night and have poorer daytime functioning the following day. Future research should investigate how the relevant vs non-relevant interactive content affects adolescents' sleep. This was not something that was examined in this thesis studies as Wang and Scherr findings were published after the thesis studies had finished.

The studies discussed above have all examined how a single device affects sleep. Adolescents use several devices in an evening and so a number of studies have examined how general electronic device usage affects sleep. Whilst this measure takes all device use into account, the measure does not account for the devices being used at difference distances, intensities and some being more stimulating than others. Mazzer et al (2018) investigated the associations between time spent using electronic devices and adolescents'[48] sleep duration. Electronic device usage was measured by asking participants how long they used electronic devices for on weekdays. Their results showed that adolescents who used

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[46] TikTok is an application which shows users short videos that fit the user's preferences (Forces, 2018). An algorithm learns the users preferences by monitoring what the user have previously "liked", commented on or viewed (Chen et al, 2019).

[47] Participants were aged >18 years (M = 29.66 + 7.88 years).

[48] Participants were aged (range; M ± SD age was not reported) 14 – 17 years.

electronic devices for longer periods of time slept for a shorter period. This measure of electronic device usage asked adolescents how long they used their devices for during the day. Using devices for longer periods of time throughout the day does not necessarily mean that the devices were used before sleep. Previous work has shown that light exposure or electronic device use in the evening has a greater influence on sleep than light which is administered or electronic devices which are used throughout the day (Woods and Scott, 2016). Woods and Scott examined how evening device usage predicted sleep quality amongst adolescents[49]. Their findings showed that night-time electronic device use predicted poor sleep quality, but overall use did not. Research should concentrate on understanding how evening device use, rather than overall device use, affects sleep.

Lemola et al (2014) examined how adolescents'[50] evening device use was related to sleep duration, sleep disturbance and depression. Device use was measured by asking participants how often they used electronic device before sleep. Their findings showed that using electronic devices in bed before sleep predicted shorter sleep duration which predicted greater depression. Using devices in bed before sleep also predicted greater sleep difficulties which predicted greater depression. Similarly, Seo et al (2017) examined how the timing of device use was associated with sleep, depression, and suicide in adolescents[51]. Device use was measured by asking participants to report when they finished using devices (including televisions, computers, and mobile phones) for the day on weekdays and how much time they spent watching television/ using their computer on weekdays and weekends. The findings showed that late night device use on weekdays predicted shorter sleep duration on weekdays which predicted higher depression and higher suicidality. Path analysis was not conducted on weekend electronic device use and sleep variables. Seo and Lemola's findings show that night-time device use predicted shorter sleep duration which in turn predicted poorer wellbeing. Neither of the studies recognised that different devices are used at different distances and thus will have varying impacts on melatonin secretion. Oh et al (2015) showed that using a device 10 cm away from the eye resulted in greater melatonin suppression than using the same device 20 or 30 cm away from the eye.

Adams and Kisler (2015) examined how individuals'[52] night-time mobile phone usage predicted sleep quality and anxiety and depression. Individuals were asked to report how frequently they responded to their mobile phone after they had been asleep when they

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[49] Participants were aged (range; M ± SD age was not reported) 11 – 17 years.
[50] Participants were aged (M ± SD) 14.8 ± 1.3 years.
[51] Participants were aged (M, SD was not provided) 15.34 years.
[52] Participants were aged (M ± SD) 22.13 ± 4.24 years.

received texts or phone calls and how long they would use their mobile phone for during this time. Their findings showed that individuals who used their mobile phones during the night after they had woken from sleep had a poorer quality of sleep and were more anxious. Their findings also showed that individuals who used their mobile phones during the night after they had woken from sleep had a poorer quality of sleep and were more depressed. These findings show that using mobile phones during the night affects the quality of sleep which then increases the likelihood of the individual developing anxiety or depression.

Other studies have been more specific about the devices they are concerned with and asked about several devices at once. Gamble et al (2014) investigated the association between using electronic devices in bed before sleep with adolescents'[53] sleep outcomes. Participants were asked to rate their evening television usage, mobile phone usage and computer usage. The findings showed that adolescents who used their computers more frequently before bed slept for a shorter period of time on weekdays, went to sleep later on weekdays, went to sleep later at the weekend, woke up later on weekdays and woke up later at the weekend too. Adolescents who used their mobile phone more frequently before bed went to sleep later on weekdays, went to sleep later at the weekend, woke up later on weekdays and woke up later at the weekend. Adolescents who watched television more frequently before bed went to sleep later at the weekend, woke up later on weekdays and woke up later at the weekend. These findings show that computer and mobile phone usage affected sleep to a larger extent than television usage. This finding is consistent with Hale and Guan (2015) systematic review in that more frequent computer and mobile phone usage resulted in more adverse sleep outcomes than television usage.

Hysing and colleagues' findings also supported Hale and Guan (2015) conclusions. Hysing et al (2015) investigated the relationship between a range of electronic devices and adolescents'[54] sleep. Participants were asked whether they used any devices[55] in their bedroom in the hour before they went to sleep. Their findings showed that adolescents who used computers in the hour before sleep took longer to fall asleep and spent a shorter period of time asleep. Mobile phones were the second strongest predictors of lengthened sleep onset latency and shorter sleep duration. These findings may suggest that the light which was emitted from the computers and mobile phones delayed the individual's circadian phase and suppressed their melatonin secretion which resulted in individuals taking a longer time to

[53] Participants were aged (M ± SD) 15.2 ± 1.4 years.
[54] Participants were aged (M, SD was not provided) 17 years.
[55] The devices which were examined were computer; mobile phone; MP3-player; tablet; video games; and television.

fall asleep and sleeping for a shorter period of time as the adolescents will have had to wake up for school the following morning. Computers and mobile phones are typically used at closer distances to the eye than televisions are. Thus, individuals who use their computers and mobile phones before going to sleep may have had greater melatonin suppression which led to them taking longer to fall asleep, sleeping for a shorter period of time and waking up later the following morning. Measuring devices separately rather than as a global overall electronic device usage score is important as; different devices emit various intensities of light (Gringras et al, 2015), devices are used at different distances from the eye (Oh et al, 2015; Yoshimura et al, 2018) and devices having varying levels of interactivity (Gradisar et al, 2013). Taken together, Hale and Guan (2015) systematic review, Gamble and Hysing and colleagues' findings show that electronic device usage should be measured by device rather than as an overall electronic device usage score. Studies which aim to investigate the impact of device use on adolescents' sleep should measure devices separately as this will account for the fact that different devices: have different levels of interactivity, emit different light intensities, and are used at different distances from the eye.

1.4.3. How do devices increase cognitive arousal?

The content that is viewed on devices may increase cognitive arousal, which may make pre-sleep relaxation harder to achieve (Cain and Gradisar, 2010). Most of the research that has been conducted into understanding whether the content on devices increases cognitive arousal has specifically examined the impact of video games on sleep. Within the last decade, Gradisar et al (2013) suggested that interactive devices, not passive devices, were associated with poorer sleep outcomes. A device is not inherently interactive or passive. Activities vary in the level of interaction they require from the user. This section will review the literature which has examined how electronic device use may increase cognitive arousal via video games and how activities which demand more interaction from the user affect sleep.

1.4.3.1. Increasing cognitive arousal using video games

Video games deliver emotion provoking content and demand a great deal of interaction from the user. Thus, if device use does increase cognitive arousal, then it is likely to be observed in studies which expose participants to video games.

One way to observe the impact of increasing cognitive arousal is to expose participants to violent video games. Higuchi et al (2005) investigated the impact of a computerised video game compared to low mental load tasks on a bright (45 lux) or dim (15 lux) display in young adults[56]. Participants who had been playing video games were less sleepy than when they were given low mental load tasks. Participants who had been playing video games also took longer to fall asleep than when they had been completing low mental load tasks. There was no effect of light on how sleepy participants felt or how long it took participants to fall asleep. These findings show that exciting video games reduced how sleepy individuals felt and increased how long it took them to fall asleep, albeit by approximately 2 minutes. Importantly, participants went to bed approximately 3 hours later than usual. Participants' homeostatic sleep pressure will have continued to increase whilst they were using the computer. There may have been no observed effect of the light condition as participants homeostatic sleep pressure was driving them to fall asleep. If participants had gone to bed at their usual bedtime, then the individual's homeostatic sleep pressure would not have confounded the results. The increased homeostatic sleep pressure may have counteracted the alerting effects of the video game and so a larger effect may have been observed if participants had gone to bed at their typical bedtime.

As Higuchi and colleagues delayed participant's bedtimes the findings from the study are confounded. Weaver et al (2010) replicated the study whilst maintaining participants' typical bedtimes. They investigated the impact of playing a violent video game or watching a non-violent DVD prior to bedtime on male adolescents'[57] sleep. Participants who played the violent video game took longer to fall asleep and were less sleepy than participants who watched the non-violent DVD. Participants who played the violent video game were also more cognitively alert[58] whilst participants who watched the non-violent DVD were less cognitively alert. These findings show that video games increase cognitive alertness, lengthen sleep onset latency, and reduce sleepiness. Weaver and colleagues claimed that the video gaming was active and the DVD watching was passive. Participants were told to play "Call of Duty 4: Modern Warfare (Infinity Ward, 2007), which as the name suggests is stress-filled and moves at a fast pace. The DVD chosen was March of the Penguins (Warner Independent Pictures, 2005). The content of the two conditions irrespective of the interactivity is unbalanced. One is exciting and stress filled (cognitively arousing) and the other is less exciting or stressful. A more balanced design which uses stimuli of similar cognitive arousal is required to determine the impact of emotionally valanced content on sleep.

[56] Participants were aged (M ± SD) 24.7 ± 5.6 years.
[57] Participants were aged (M ± SD) 16.6 ± 1.1 years.
[58] Alertness was measured using alpha power from Polysomnography.

The content viewed on devices has been investigated using more balanced comparisons. Dworak et al (2007) investigated the difference between watching a film and playing an interactive video game for 60 minutes (approximately 2 – 3 hours before bedtime) on male adolescents'[59] sleep. Participants were given a choice of three films "Harry Potter and The Prisoner of Azkaban", "Star Trek- Nemesis" and "Loves Music, Loves to Dance" and were not allowed to watch a film if they had seen it before. In the video gaming condition participants were asked to play "Need for Speed- Most Wanted". The findings showed that participants playing video games had significantly more stage 2 sleep and lower % slow wave sleep. There were no significant differences between the DVD condition and control condition. These findings showed that video games changed individuals' sleep architecture and reduced their homeostatic sleep pressure. Whilst both the DVD and video gaming condition are likely to sustain participants' attention, playing a video game requires more interactivity from the individual than watching a DVD. Additionally, whilst the content viewed in the DVD and video gaming condition appear to be of similar valence (i.e., exciting), participants' interpretation of the different content was not measured. "Loves Music, Loves to Dance" is described as a murder mystery, "Harry Potter and The Prisoner of Azkaban" is fantasy and "Star Trek: Nemesis" is described as thriller/Sci-Fi. Understanding how the participants felt after playing the video game or watching one of the three films would have indicated how various levels of cognitive stimulation impact sleep.

The content viewed on electronic devices may evoke certain emotions and thus disturb sleep through causing pre-sleep relaxation harder to achieve. King et al (2013) investigated the impact of spending a "prolonged" (150 minutes) and "typical" (50 minutes) amount of time playing video games on male adolescents'[60] emotion and sleep. There was no significant difference between the two groups' objective sleep onset latency[61]. Participants who played video games for a "prolonged" period of time spent a shorter period of time asleep and had lower sleep efficiency compared to when participants played video games for a "typical" period. There was no difference in participants' reports of enjoyment, excitement, frustration, boredom, or curiosity. Other emotions such as anxiety should be investigated to gain a better sense of whether content has increased cognitive arousal.

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[59] Participants were aged (M ± SD) 13.45 ± 1.04 years.
[60] Participants were aged (M ± SD) 16 ± 1 years.
[61] Objective sleep onset latency was measured as the time taken from lights out to the first of three 30-second epochs where there was a 50% reduction in alpha wave activity.

Ivarsson et al (2013) investigated the impact of violent video gaming and non-violent video gaming and high[62] vs low experience on adolescents'[63] sleep, anxiety, and emotionality. Their findings showed that participants who had low experience and played violent video games were more alert at bedtimes and had a poorer quality of sleep than those participants that played non-violent video games. Finally, the findings showed that participants who played violent video games, regardless of experience, were more anxious than those who played non-violent video games. These findings show that the content viewed on devices increased anxiety, which may have delayed the onset of sleep. The findings also show that the content viewed on devices increased alertness prior to bedtime and thus may have further delayed sleep onset and reduced sleep quality.

The research reported in this section appears to suggest that certain light emitting devices may be more interactive than others, it should be noted that the activities that individuals were engaging with on televisions required less interaction than the activities that the computers were used for. Until recently researchers have investigated whether electronic devices increase pre-sleep cognitive arousal and the impact of this on sleep outcomes using video gaming consoles. Adolescents use a wide variety of electronic devices including smartphones, laptops and tablets. Therefore, studies which investigate a wider variety of electronic devices would be much more clinically relevant than studies which solely focus on the impact of video gaming consoles. The research which has investigated the impact of a wider variety of devices on pre-sleep cognitive arousal will be discussed in the following section.

1.4.3.2. Increasing cognitive arousal via interactive activities

It is not yet fully understood whether and how the interactivity of devices or device activities affect sleep. As described above, Weaver et al (2010) concluded that more interactive devices (video gaming consoles) resulted in poorer sleep outcomes than passive devices (televisions). In recent years, Gradisar and colleagues have pursued this line of enquiry and hypothesised that using interactive devices before bed resulted in more adverse sleep outcomes.

Gradisar et al (2013) noted that individuals who used interactive devices[64] in the hour before bed struggled to fall asleep and had less refreshing sleep. Individuals who used their mobile

[62] High experience is when the participants played the video games for 3 hours per day and low experience is when the participants played the video games for 1 hour per day.
[63] Participants were aged (range; M ± SD age was not reported) 13 – 16 years.
[64] Interactive devices included mobile phones, video gaming consoles and laptops; passive devices included televisions, e-readers and MP3 Players.

phone in the hour before bed struggled to stay asleep. Passive devices did not predict poorer sleep. A similar study was conducted that investigated the impact of a variety of devices on a wider range of sleep variables in adolescents[65] (Arrona-Palacios, 2017). The findings showed that interactive devices[66] were associated with going to bed later on weekdays, spending a shorter time in bed on weekdays, going to bed later at the weekend and spending a shorter time in bed at the weekend. Using MP3 players were also associated with going to bed later on weekdays, spending a shorter time in bed on weekdays, going to bed later at the weekend and spending a shorter time in bed at the weekend. MP3 players allow individuals to listen to music and podcasts. It is not known what the participants were listening to in this study. Listening to music could be argued to a passive activity, whilst listening to podcasts could be argued to be more interactive as individuals typically listen to podcasts about topics which they are interested in, and so they could be more cognitively arousing.

Weaver, Gradisar and colleagues' and Hale and Guan's work suggests that more interactive devices, which require the user to make decisions or react to content and interact with the device, resulted in more adverse sleep outcomes. This thesis will question this line of enquiry and will argue that activities vary in the level of interaction they require from the user. Future research should analyse device use from this perspective rather than taking a simplified view that a device is interactive or passive.

Devices can carry out a vast array of activities and assigning devices as either interactive or passive does not take this into account. Laptops and computers can be used to play video games (interactive) or stream television programmes (passive). A more sophisticated approach should be taken in which the interactivity is assigned based on the activity the user is completing. Jones et al (2018) investigated the difference between completing puzzles and reading on a tablet compared to print materials on athletes' sleep. This study has been described in greater detail in the previous section "How does blue light that is emitted from devices impact sleep?". Participants who completed puzzles on paper were less sleepy compared to participants who read print materials. This finding is particularly interesting as participants were not exposed to electronic devices in the print condition and so they may have felt less sleepy because completing puzzles was a more interactive activity than reading print materials.

[65] Participants were aged (M ± SD) 14.08 ± 0.72 years.
[66] Interactive devices were smartphones, computers, and video games.

Arora et al (2014) investigated how different activities which were completed on various light emitting devices affected adolescents'[67] sleep. Participants who "usually/ always" used the internet, used their mobile phone, played video games, and used their computer/laptop to study slept for a shorter period of time on weekdays. All of these activities require interaction from the individual. Their findings also showed that watching television and listening to music were the weakest predictors of weekday sleep duration. Both of these activities do not require as much interaction from the user.

Similarly, Twenge et al (2017) investigated how social media, using the internet to read the news, and watching television affected adolescents'[68] sleep. Their findings showed that participants who used social media everyday were at higher odds for shorter sleep duration (< 7 hours). Using the internet to read the news and watching television for 3+ hours a day were associated with lower odds of short sleep duration (< 7 hours). Social media demands more interaction from the user whereas using the internet to read the news or watch television does not. Both Arora et al (2014) and Twenge et al (2017) findings present strong evidence that studies should examine the impact of interactive and passive activities separately. The activities that can be carried out on devices vary hugely in the amount of interaction they require from the user for example, computers and mobile phones can both be used to listen to music and message friends. Both computers and mobile phones were categorised as interactive devices by Gradisar et al (2013) regardless of what the device was used for. Researchers should be aware that electronic devices are continuously evolving and the activity that an individual is engaging with should be examined rather than the device itself.

1.4.4. How do devices displace sleep?

The final pathway in which device use may impact sleep is through time displacement (Cain and Gradisar, 2010). Time that is spent on electronic devices prior to going to sleep may hinder or directly delay the time that individuals go to sleep, thus reducing the amount of time individuals sleep for when there is a fixed wake time the next morning (i.e., school start time).

This section is about how electronic devices may directly displace sleep. Sleep can be directly displaced by any activity, not just device use, for example studying and socialising with friends (Twenge et al, 2017; Van den Bulck, 2004). Recent qualitative findings from the Media Lives research (Ofcom, 2018) showed the importance of understanding whether electronic device usage impacts sleep through delaying bedtimes. Grant (16 years old)

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[67] Participants were aged (range; M ± SD age was not reported) 11 – 13 years.
[68] Participants were aged (range; M ± SD age was not reported) 13 – 18 years.

reported taking his phone to bed with him so he could “watch programmes until… [he]... fell asleep”. It is clear from this excerpt that adolescents use their devices to pass time until they fall asleep.

Most studies which have aimed to understand whether electronic device usage directly displaces sleep, by delaying the time individuals go to sleep, are observational. Hysing et al (2015) [described in detail on page 20] examined the influence of computers, mobile phones, MP3 Players, tablets, consoles, and televisions on adolescents’ sleep. All of the electronic devices were associated with increased odds of sleep deficit (> 2 hours). These findings show that electronic device usage reduced adolescents’ sleep duration. It is not clear from these findings whether electronic device usage delayed the time that adolescents went to sleep or whether device usage increased awakenings and time spent awake during the night.

To ascertain whether devices delay the time that individuals go to sleep it is important to ask adolescents whether they use their devices before going to sleep. Eggermont and Van den Bulck (2006) investigated the impact of using electronic devices and media as a sleep aid on adolescents’ [69] sleep. Their findings showed that adolescents who had a computer or television in their bedroom used electronic devices to aid them in getting to sleep. Adolescents who used televisions and computers as a sleep aid spent a shorter period of time asleep on weekdays. It is unclear from these findings whether the adolescents spent a shorter period of time asleep because they delayed the time, they went to sleep to continue using their devices. Thus, it is unknown whether device use displaced adolescents’ sleep or whether the electronic devices shortened the amount of time that adolescents spent asleep by increasing sleep onset latency or increasing wakefulness during the night.

Bartel et al (2016) investigated the risk factors and protective factors of later weekday bedtimes, longer weekday sleep onset latency and shorter weekday sleep duration in adolescents. They investigated Canadian, Dutch and Australian adolescents. Their findings showed that adolescents who finished using their mobile phone and the internet later went to bed later and spent a shorter period of time asleep on weekdays. This provides good evidence that device use displaced sleep by delaying the time that adolescents went to sleep. Adolescents should be asked whether they use their electronic devices whilst they should be asleep to examine whether electronic device use displaces sleep through delaying the time individuals go to bed and shorten the time they sleep for.

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[69] First year participants were aged (M ± SD) 13.16 ± 0.43 years; fourth year participants were aged (M ± SD) 16.37 ± 0.71 years.

A small number of studies have asked participants whether they use devices during the time in which they should be asleep. Gamble et al (2014) investigated the impact of computer, mobile phone, and television usage on adolescents'[70] sleep. Gamble and colleagues measured electronic device usage by asking participants to report how often they would use electronic devices[71] in bed when they should have been sleeping. Their findings showed that adolescents who used their computer more frequently went to sleep later on weekdays and spent a shorter period of time asleep on weekdays. These findings suggest that adolescents delayed the time they went to sleep and shortened the time they spent asleep to spend more time on their computers, and so their computer use directly displaced their sleep. Adolescents who frequently used their computers went to sleep later on weekends. Interestingly, adolescents who frequently used their computers did not spend a shorter period of time asleep on weekends. There are fewer restrictions on weekend sleep and so adolescents were able to compensate for going to sleep later by waking up later the following morning.

Adolescents can extend their sleep at the weekend and so device does not restrict the amount of time adolescents spend asleep at the weekend. King et al (2014) investigated how electronic device use affected the time that adolescents[72] went to sleep and how long they slept for on weekdays and at the weekend. Electronic device usage was measured by asking participants to report their frequency of use of each device, function, and social context of media use. The impact of electronic device usage related sleep disruption was measured using the Sleep Activity and Media Questionnaire[73]. This measure includes a bedtime delay measure which asked adolescents whether their electronic device use has ever made them stay up later than they intended. Approximately 50% of adolescents reported "always" / "often" staying up later to use electronic devices. Adolescents who reported staying up later to use electronic devices spent a shorter period of time asleep on weekdays and at the weekend. These findings support the argument that electronic device usage directly displaces sleep as they show that adolescents who continued to use electronic devices during the hours that they should have been asleep went to bed later and spent a shorter period of time asleep.

It is important to highlight that the research reported in this section, which has investigated whether electronic devices directly displace the time that adolescents go to sleep, relied upon self-report measures of sleep. These are convenient and cost-effective measures to use, however they are inaccurate measure. Several studies have reported weak correlations

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[70] Participants were aged (M ± SD) 15.2 ± 1.4 years.
[71] Devices included watching television; listening to the radio; using the computer; using their mobile phone.
[72] Participants were aged (M ± SD) 16 ± 1 years.
[73] This measure was designed for this study and was based on screening questions used in Ivarsson et al, (2009) and Li et al (2007) and examined weekday and weekend sleep as recommended by Short et al, 2013.

between self-reported and actigraphy measures of sleep (Wolfson et al, 2003; Arora et al, 2013). Whilst actigraphy is still not as accurate as the gold standard measure of sleep (Polysomnography [PSG]), the accuracy of actigraphy is strongly correlated ($r = 0.73$) with PSG. Self-reports may be over or underestimates of the time that participants fell asleep, how long it took them to fall asleep and how well they slept and so the strength of these studies is only as good as the accuracy of the self-reported sleep responses.

This section has shown research which supports all three of the proposed pathways set out by Cain and Gradisar (2010). To the researcher's knowledge there has been no examination of all three of these pathways in one study. Simultaneously measuring blue light, cognitive arousal, and time displacement may indicate the extent to which the pathways affect sleep outcomes.

Most of the research which has investigated how device use affect sleep reported in this section has not examined how other factors such as age, mood and BMI all affect sleep. It is important to understand how these factors all relate to one another to understand the true impact of device use on adolescents' sleep. This will be examined in the following chapter.

2. Chapter 2: An introduction to adolescents' health risk factors

2.1. Summary of chapter 1

Chapter 1 has shown the importance of investigating whether and how adolescents' device use affects their sleep and health risk factors. It has shown that, on average, adolescents do not get enough sleep per night, that many adolescents say that not getting enough sleep impacts their mood amongst many other aspects of life and that many adolescents are allowed to take their devices to bed with them.

Chapter 1 then discussed the evidence for the three pathways which were proposed by Cain and Gradisar (2010) and highlighted how these findings related back to the literature on how various light characteristics affect circadian phase and sleep. The chapter also identified that there are various other factors such as the school schedule, mood and BMI which affect and are affected by sleep. This chapter will examine how sleep is related to these factors and will discuss why it is important to examine the impact of device use simultaneously with these factors to understand the factors which influence adolescents' sleep.

2.2. Adolescents' health risk factors

The health risk factors which have been examined through the studies in this thesis have been determined using predominately the Royal College of Paediatric and Child Health report (2017) as the report focused on adolescents residing in the UK and so the health risk factors discussed were directly relevant to the samples which would be used in this thesis's studies. Systematic reviews from the sleep literature were also used to capture a variety of risk factors relevant to adolescents were being measured (Bartel et al, 2015; Carskadon, 2011). Carskadon and colleagues provided an update to their systematic review once the studies had commenced (Crowley et al, 2018). These reviews highlighted several factors which are associated adolescents' sleep including, but not limited to obesity, mental health, sleep hygiene, academic achievement, school schedule, alcohol use, injury and pain (Matricciani et al, 2019, Chaput et al, 2016). This thesis will concentrate on the following factors: age, school schedule, obesity, mental health, sleep hygiene and alcohol and tobacco use as Bartel et al (2016) study, which examined a number of these factors, predicted adverse sleep outcomes for Australian, Canadian, and Dutch adolescents.

2.2.1. Age

As previously described in chapter 1, sleep/ wake patterns are regulated by the interaction of process C and process S. During adolescence both processes undergo developmental changes. Tau[74] becomes delayed and process S accumulates at a slower rate. These changes result in adolescents going to bed and sleep later. This section will discuss the developmental changes to these two processes.

Despite the literature on adolescents' sleep ever growing, there is no single age range that all studies use to define an individual as an adolescent. The term "adolescent" is defined differently by everyone, for example Crowley and Eastman (2018) used defined adolescents as individuals aged between 14 – 17 years old whereas Sawyer et al (2018) categorised individuals as adolescents if they were aged 10 – 25 years old. Adolescents undergo several physiological and psychosocial changes and gradually acquire greater autonomy. There is no doubt that part of the confusion over the onset and offset of adolescence is due to puberty commencing at different time points for individuals. There has also been a great deal of variance in the onset and offset of puberty in individuals from different countries. Individuals from low-income countries reach menarche[75] earlier than individuals from higher income countries (Ibitoye et al, 2017). The age in which girls reach menarche has also changed throughout the years. Girls who were born between 1908 – 1919 reached menarche at approximately 13.5 years whereas girls who were born between 1990 – 1993 reached menarche at approximately 12.2 years (Figure 5) (Morris et al, 2011). Figure 5 was removed to avoid copyright issues.

To account for there being a vast amount of variance in puberty onset and offset, some researchers have used tanner stages as a measure of physiological maturity (Tanner, 1962). Tanner stage is a pubertal maturity rating and is based on sexual characteristics including breast and genitalia development and pubic hair growth and distribution (Tanner, 1962). Whilst it may be more accurate to understand how sleep changes as a function of pubertal development, categorising individuals into separate Tanner stages is a laborious and costly exercise.

2.2.1.1. Changes in circadian rhythm

Initial research which investigated whether there was any difference between less mature and more mature adolescents showed substantial differences in less mature and more mature

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[74] Tau refers to the length of the circadian rhythm when the individual is held in constant conditions (i.e., in the absence of light, time etc)
[75] Menarche is the beginning of menstruation.

adolescents' chronotype preference[76] and preferred bedtime. Andrade et al (1993) found that more mature adolescents[77] reported going to bed later than less mature adolescents. Similarly, Carskadon et al (1993) found that more mature adolescents rated themselves as "more evening type" than their less mature peers. These findings suggest that tau becomes naturally delayed during adolescence[78]. Carskadon and colleagues tested this hypothesis by examining the relationship between adolescents' melatonin offset, pubertal maturation (Tanner stage) and age (Carskadon et al, 1998). They observed positive correlations between melatonin offset and tanner stage and age. These findings showed that more mature adolescents had a later melatonin offset than less mature peers.

It was originally thought that more mature adolescents may categorise or rate themselves as "evening" type due to them having longer intrinsic circadian periods than their younger counterparts or adults. Carskadon et al (1999) investigated adolescents' circadian period[79] through a forced desynchrony protocol[80]. Carskadon and colleagues compared their findings for adolescents' intrinsic circadian periods with Czeisler and colleagues' results for adults' intrinsic circadian periods. The comparison showed that adolescents had a slightly longer circadian period than adults' circadian period (adolescents' M = 24.33 ± 0.2 hours; adults' range = 24.1 – 24.2 hours, longest = 24.4 hours, M ± SD was not provided) (Czeisler et al, 1999). Circadian periods longer than 24 hours are indicative of more evening like tendencies and so Carskadon and colleagues' findings supported the theory that the circadian period lengthens during adolescence. Carskadon and colleagues' evidence for the hypothesis is reliant on their study's protocol and Czeisler and colleagues' protocol being similar. Slight differences to protocols or methodology can produce different results purely due to the methodology used. Thus, examining whether adolescents and adults' circadian phases are substantially different to one another requires controlled observation of both adolescents and adults' circadian periods in the same laboratory under the same conditions. Crowley and Eastman (2018) investigated older adolescents and adults[81] "free running"[82] circadian rhythm. Participants underwent an ultradian protocol where they spent 2 hours in the dark (opportunity for sleep) and then were

[76] Chronotype indicates when individuals prefer to engage with activities and behaviours, an early chronotype or "morning type" refers to individuals who wake and go to bed early. Late chronotypes or "evening type" refers to individuals who wake and go to bed late.
[77] Maturity was determined using Tanner stages.
[78] Adolescents were aged (range; M ± SD for age was not provided) 11 – 12 years.
[79] Core body temperature was used as a marker for circadian phase.
[80] These adolescents were aged (range; M, SD was not provided) 13.7 years
[81] Older adolescents were aged (range; M ± SD was not provided) 14.3 – 17.8 years, adults were aged (range; M ± SD was not provided) 30.8 – 45.8 years.
[82] Free running period refers to when the circadian rhythm is allowed to run on its own. This requires the removal of timing cues such as light and time.

kept awake for 2 hours in dim room light (~ 20 lux). The ultradian protocol began at 04:00 and finished at 14:00 3.4 days later. The findings from this study showed that approximately 16% of adolescents had a circadian period < 24 hours in comparison to 20% of adults having a circadian period < 24 hours. There were no significant differences in the circadian periods or "morning-ness" scores of adolescents (range = 23.56 – 24.7 hours) and adults (range = 23.76 – 24.63 hours). Crowley and Eastman's findings showed that there were no differences between older adolescents' and adults' circadian period duration. However, the circadian period duration may lengthen at an earlier age or maturational stage, and this may explain why there were no differences found between older adolescents and adults.

Despite Crowley and Eastman's findings suggesting no difference between adolescents and adults circadian period duration, tau may change at an earlier age or maturational stage. Wu et al (2015) also explored the length of adolescents' circadian rhythm. Wu and colleagues investigated the differences between younger and older[83] adolescents homeostatic sleep pressure and circadian period. Adolescents underwent a 3-week protocol in which they first spent 10 days of fixed bed and wake patterns an adaptation night, 36-hour constant routine and a forced desynchrony protocol whereby they had 12 cycles of 28-hour periods[84]. Their findings showed younger and older adolescents had similar circadian periods which shows that older adolescents did not have a longer endogenous circadian period than younger adolescents[85]. Neither Crowley and Eastman (2018) nor Wu et al (2015) work supports the idea that adolescents' endogenous period extends. It is likely that Carskadon et al (1999) findings that adolescents' circadian periods were different to adults' circadian periods because of methodological or protocol differences in theirs and Czeisler et al (1999) work.

A second school of thought regarding how the circadian phase alters during adolescence is that adolescents have an altered circadian response to light. As previously noted, the impact of light on the circadian period is phase dependent. Light administered in the evening results in phase delay and light administered in the morning results in phase advance[86]. Adolescents delayed circadian rhythm may be due to a blunted response to morning light and a heightened sensitivity to evening light (Crowley et al, 2018). Crowley et al (2015) investigated pre, mid, late, and post pubertal adolescents' circadian sensitivity to light by examining the impact of

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[83] Younger adolescents were aged 9 – 12 years old and the older adolescents were aged 13 – 15 years old (M ± SD age = 12.8 ± 1.6 years)

[84] The forced desynchrony protocol gave participants 11 hours 40 minutes of sleep opportunity and 16 hours 20 minutes of wakefulness in each 28-hour period.

[85] The intrinsic circadian period for younger participants M ± SD = 24.26 ± 0.17 hours; the intrinsic circadian period for older participants M ± SD = 24.25 ± 0.25 hours.

[86] Phase response curves can be computed to show the impact of administering light at different circadian phases.

1 hour of 15, 150 and 500 lux on melatonin suppression[87], which was administered in the morning and in the evening. Morning light was timed between 03:00 – 04:00am and evening light exposure was timed between 23:00 - 00:00. Their findings showed that there were no significant differences in melatonin suppression to light which was administered in the morning (Figure 6A). The findings also showed that pre-mid pubertal adolescents showed significantly greater melatonin suppression under 15, 150 and 500 lux of light that was administered in the evening compared to late- post pubertal adolescents (Figure 6B). This finding shows that less mature adolescents were more sensitive to the evening light administration than more mature adolescents and so this finding does not support the idea that older adolescents have a heightened sensitivity to evening light. Figure 6 was removed to avoid copyright issues.

Phase response curves to light administered before or after core body temperature minimum have been constructed. Core body temperature minimum has been shown as the critical turning point in determining the phase response to light (Czeisler et al, 1999; Khalsa et al, 2003). Crowley and Eastman (2017) examined the response to light administered centred around adolescents' bed and wake time [88]. The findings showed that the maximal phase delay was -1.8 hours, and this occurred 1.9 hours after dim light melatonin onset (DLMO), the maximal phase advance was 1.5 hours, and this occurred 9.2 hours after DLMO[89]. These results show that the maximal phase delay and advance were similar suggesting that the phase delay shift is not exaggerated in late and post pubertal adolescents, which further contradicts the idea that adolescents have a heightened sensitivity to light. Moreover, adult (aged 30 – 45 years) and adolescent phase response curves were compared using the same protocol. There were no differences in adolescents' and adults' phase shift responses when exposed to bright light (~ 5,000 lux) (Crowley, unpublished). These findings show that older adolescents and adults respond in a similar manner when exposed to light and further contradicts the idea that adolescents delayed circadian rhythm is due to an increased sensitivity to light.

2.2.1.2. Changes in homeostatic sleep pressure

It has been known for several years that slow wave sleep declines during adolescence by approximately 40% (Carskadon, 1980; Jenni and Carskadon, 2004). Numerous studies have

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[87] Melatonin suppression was measured using AUC to measure overall suppression and melatonin suppression 30 and 60 minutes after light exposure.
[88] Participants were categorised as Tanner stage 4/5 and M ± SD age = 16.2 ± 1.0 years.
[89] In this study, DLMO was measured as the time in which melatonin secretion increased and remained above 4 pg/mL.

demonstrated a slower accumulation of sleep pressure in more mature adolescents compared to less mature adolescents. Taylor et al (2005) examined the relationship between homeostatic sleep pressure in more mature adolescents compared to less mature adolescents after 14.5 and 16.5 hours of wakefulness[90]. Their findings showed that less mature adolescents fell asleep quicker than more mature adolescents. These findings suggest that more mature adolescents can cope with later bedtimes better than less mature adolescents.

In addition to less mature adolescents falling asleep quicker under normal circumstances, Jenni et al (2005) investigated the differences in the time taken to fall asleep in less mature and more mature adolescents after 36 hours of sleep deprivation[91]. More mature adolescents accrued homeostatic sleep pressure slower. More mature adolescents' sleep pressure increased over 15.4 ± 2.5 hours and less mature adolescents sleep pressure increased over 8.9 ± 1.2 hours. More mature adolescents had a higher asymptote[92] than less mature adolescents. A higher asymptote is consistent with a later bedtime as homeostatic sleep pressure must surpass the asymptote for sleep to occur. During the recovery night's sleep more mature adolescents had a greater increase in slow wave activity (a marker of sleep homeostatic sleep pressure). More mature adolescents had 39% more slow wave activity than during baseline, in comparison to less mature adolescents who had 18% slow wave activity more than baseline. Jenni and colleagues' findings suggest that more mature adolescents can tolerate greater homeostatic sleep pressure and because they acquire greater homeostatic sleep pressure, they had more SWA% during their recovery sleep (Figure 7A and B). Figure 7 was removed to avoid copyright issues.

Further support for the hypothesis that more mature adolescents can tolerate higher levels of homeostatic sleep pressure has shown that more mature adolescent mice make fewer attempts, than less mature mice, to sleep when their sleep was delayed by 4 hours (Nelson et al, 2013). Less mature adolescent mice made an average of 21.77 attempts to fall asleep when the time they went to sleep was delayed for 4 hours, in comparison to older, more mature adolescent mice who made on average 9.13 attempts to sleep during the period. The research reported above suggests that more mature adolescents' preference for going to sleep later may be, in part, due to their slower accumulation of homeostatic sleep pressure which results in mature adolescents being less sleepy until a later time point.

[90] Less mature adolescents were M ± SD age = 11.1 ± 1.3 years; more mature adolescents were = 13.9 ± 1.2 years.
[91] Less mature adolescents were M ± SD age = 11. 9 ± 0.8 years; more mature adolescents were = 14.2 ± 1.4 years.
[92] Asymptote is the threshold controlled by the circadian rhythm. The higher asymptote is the upper threshold. When this threshold is crossed sleep is initiated, when the lower asymptote is crossed wake is initiated.

More mature adolescents have a similar phase angle to adults. Crowley et al (2014) investigated adolescents' phase angle of entrainment and their sleep timing[93]. Participants were examined every six months for 2.5 years to calculate their phase angle as they matured. They began collecting saliva samples 5 hours before bedtime and collected the samples every 30 minutes. Adolescents' phase angles were calculated as the interval between dim light melatonin onset (DLMO) and average weekday sleep onset. Older adolescents had a longer interval between DLMO and average weekday sleep onset than the younger adolescents. At 10 years old, the average phase angle was 1 hour, at 18 years old the average phase angle was > 2 hours. The phase angles for older adolescents were similar to adults' phase angles. Burgess and Eastman (2008) investigated the phase angle of young adults[94]. The sample included 57 males and 63 females[95]. The average phase angle for males was 2.5 hours (SD = 1.0 hour) and the average phase angle for females was 3 hours (SD = 1.1 hour). These findings show that more mature adolescents have similar phase angles as young adults. Taken together the findings suggest that the phase angle lengthens during adolescence and possibly into early adulthood which makes individuals feel less sleepy later in the evening and thus they go to sleep later too.

Whilst the accumulation of sleep homeostatic pressure has been observed to change during adolescence, the need for sleep remains constant through adolescence. Carskadon et al (1982) gave adolescents[96] 10-hours sleep opportunity. On average, adolescents obtained 9.25 hours regardless of their age. These findings have been supported by Short et al (2018) who examined the dose response of 15 – 17-year-olds when they were given 5 hours, 7.5 hours and 10 hours sleep opportunity. The findings showed a median sleep need of 9.3 hours. These findings show the need for sleep remains at approximately 9 hours throughout adolescence.

Adolescents require approximately 9 hours of sleep per night regardless of their age and so it is thought that the dissipation of sleep homeostatic sleep pressure does not change either. Gaudreau et al (2001) investigated the decay rate of slow wave activity over 5 hours of slow wave sleep in children and adolescents[97]. Their findings showed that slow wave activity dissipated at a similar rate in both children and adolescents. These findings were supported by Jenni et al (2005) who investigated whether adolescents' dissipation of homeostatic sleep

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[93] Adolescents were aged 9 – 16 years old.
[94] Participants were aged (M ± SD) 27.4 ± 6.5 years.
[95] The male participants were aged (M ± SD) 26.9 ± 7.1 years; and the female participants were aged (M ± SD) 24.9 ± 4.8 years.
[96] The adolescents were aged (range; M ± SD were not provided) 10 - 17 years old.
[97] The children were aged (M, SD was not provided) 7.11 years; the adolescents were aged (M, SD was not provided) 15.33 years.

pressure changed as a function of Tanner stage. In this study, the dissipation of homeostatic sleep pressure was measured using lower asymptote %. There was no significant difference between the lower asymptote % in less mature adolescents compared to more mature adolescents. Furthermore, Tarokh et al (2012) investigated whether sleep homeostasis changed with pubertal maturity using the lower asymptote. Children began the study at Tanner 1/2[98] and advanced at least one tanner stage in between assessments; teenagers began the study at Tanner 5. There were no differences between children's follow-up assessments and young adolescents' initial assessment lower asymptotes. There were also no differences between the follow up assessment for older adolescents and the single assessment obtained for young adults' lower asymptote. These findings further support Gaudreau and Jenni and colleagues' work that the dissipation of homeostatic sleep pressure does not change during adolescence, either as a function of age or of pubertal maturity and sleep need remains relatively constant through to early adulthood.

2.2.2. School schedule

The changes in adolescents' sleep regulation encourage adolescents to delay the time that they go to bed, however societal pressures such as the school day restrict adolescents' wake time on school days. The school day starts in the early morning (approximately 8:00 - 9:00am in the UK). This means that adolescents are waking, commuting to school and beginning lessons whilst their circadian rhythm, which is naturally delayed during adolescence, is still promoting sleepiness. This means that adolescents experience social jetlag (Carskadon, 2011). Social jetlag is where the regular sleep/wake schedule is misaligned with the internal circadian rhythm. Early weekday wake times mean that adolescents do not sleep long enough, which leads to adolescents accumulating sleep debt over the week. Sleep debt must be repaid at the next available opportunity, which is often the weekend. Delaying the time that adolescents wake up at the weekend means there are substantial differences between the time adolescents go to bed, wake up and the amount of sleep they get on weekdays in comparison to at the weekend.

The association between school start time and adolescents' sleep has been well investigated in American adolescents over the years with the majority of the evidence showing that later school start times, resulted in adolescents waking later, sleeping longer and feeling less sleepy on weekdays and feeling less depressed or anxious and performing better at school

[98] Children who were categorised as Tanner stage 1/2 were aged (range; M ± SD was not provided) 11 – 13 years. young adolescents were aged (range) 15 – 16 years; older adolescents were aged (range) 17 – 19 years; young adults were aged (range) 20 – 23 years.

(Allen and Mirable, 1989; Carskadon, 1990; Carskadon et al, 1998; Wahlstrom et al, 1997; Wahlstrom et al, 2014; Owens et al, 2010; Boergers et al, 2014). These studies were all conducted on American adolescents, who typically have an earlier school start time and longer commutes to school than adolescents from the UK. There are inconsistent differences between countries and so further research needs to be conducted which examines the impact of later school start times on adolescents in the UK (Gradisar et al, 2011; Illingworth et al, 2019).

There is a clear association between later school start times and later weekday rise times or longer sleep durations, however the association with weekend sleep duration is less clear. Wahlstrom et al (2014) showed that later school start times were associated with longer weekday sleep durations and less catch-up sleep on weekends than when school start times were earlier. Wahlstrom et al (2014) showed that adolescents increased the amount of time they were asleep for on weekdays from 7.5 hours to 8.2 hours and reduced the amount of time they were asleep for at the weekend from 9.3 hours to 9 hours which meant that weekday-weekend sleep patterns became more consistent. Regular bedtimes (i.e., going to bed at the same time every night regardless of the day of the week) has been shown to result in lower sleepiness over time (Manber et al, 1996).

Owens et al (2010) found that when adolescents[99] started school at 08:30am they slept for an extra 45 minutes than when the same adolescents started school at 08:00am. Moreover, Boergers et al (2014) found that adolescents[100] who started school at 08:25am slept for an extra 29 minutes than when they started school at 08:00am The proportion of students obtaining > 8 hours sleep on school night increased from 18% to 44%. When the school schedule reverted back to the original schedule, adolescents reverted back to spending less time asleep[101]. These findings show that adolescents spend a longer time asleep on weekdays when they are given the opportunity to do so. In contrast to Wahlstrom et al (2014), Boergers et al and Owens et al showed there were no differences in the time that adolescents rose out of bed or slept for at the weekend. These findings may be because adolescents still need to repay the sleep debt that they acquired over the week by extending the amount of time they spend asleep at the weekend. Interestingly, both Boergers et al and Owens and et al found that when adolescents who started school later were less depressed than those who started

[99] Participants were aged (range; M ± SD was not provided) 14 – 18 years.
[100] Participants were aged (M) (SD was not provided) 15.6 years.
[101] Participants spent (M ± SD) 06:58 ± 01:02 at baseline [08:00am], after the 25 minutes delay to the school schedule [08:25am] participants spent 07:31 ± 01:01 and after the school schedule had reverted back [08:00am] participants spent 06:58 ± 01:15 asleep.

school earlier. The relationship between sleep and mood will be discussed in the following section.

2.2.3. Mood

It has become increasingly important to understand the impact of sleep on mood during Covid-19 as statistics show that 90% of adolescents, aged 13 – 18 years old, are anxious (Levita et al, 2020). Whilst the UK government restrictions have started to ease, it is unlikely that the prevalence of anxiety will reduce as adolescents are anxious of returning to "normal" life, catching up on lost learning and getting good grades (Children's commissioner, 2020; NSPCC, 2020).

Mood can be measured in two ways as either a state or a trait. State mood is susceptible to frequent fluctuations. Trait mood is characterised by a prolonged fluctuation in mood (Watson, 1988). Brain areas which are associated with emotion regulation such as the prefrontal cortex remain underdeveloped in adolescents (Davidson, 2002; Giedd, 2004). It is important to examine how trait mood is affected by sleep especially as adolescents at heightened risk of mood disorders due to psychological, social and physiological changes that occur at this time (Paus et al, 2008). However, measuring state mood on a regular basis allows for temporal relationships to be established as they allow researchers to examine how mood fluctuations are related to the most recent night's sleep. This literature review will review the evidence for sleep being related to both trait mood (i.e., anxiety and depression) and state mood (i.e., positive and negative affect).

2.2.3.1. Anxiety and depression

The majority of studies investigating the relationship between sleep and mental health have used self-report surveys. Wolfson and Carskadon (1998) were amongst the first to investigate the impact of poor sleep on adolescents' mental health. Their findings showed that adolescents who slept for shorter periods of time (< 6 hours 45 mins) and/or delayed the time they went to bed on weekend by 120+ mins were more depressed than adolescents who slept for a longer period of time or had a shorter weekend bedtime delay.

Similar findings were reported by Liu and Zhou (2002) who reported that adolescents[102] who obtained < 7 hours sleep per night were 2.9 times more likely to be anxious or depressed[103]. These studies are all limited by the fact that they are cross sectional surveys which rely on adolescents correctly reporting their sleep/wake patterns and do not account for individual

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[102] Participants were aged (M ± SD) 14.6 ± 3.4 years.
[103] Anxiety and depression were measured using Youth Self-Report (Achenbach, 1991).

differences between participants. Longitudinal studies have been used to account for individual differences as they monitor the same cohort of participants over a prolonged period of time. Fredriksen et al (2004) investigated the relationship between short sleep duration and depression in adolescents [104] over three years. The findings showed that adolescents who slept for a shorter period of time in the first or second year were more depressed in year 2 and year 3. These findings suggest that spending a shorter period of time asleep increases the risk of adolescents feeling more anxious or depressed.

Sleep during the school week is very different to sleep at weekends. Often adolescents will go to bed earlier, wake earlier, spend a shorter time in bed and spend a shorter time asleep during the week than at weekends (Carskadon, 1990). As reported in the section "School schedule", one reason for the difference in sleep during the week and at weekends is the school schedule. School start times severely restrict the opportunity for sleep during the week. Weekend sleep does not have this restriction and provides adolescents the opportunity for adolescents to extend the amount of time they spend asleep.

Investigating whether both weekday and weekend sleep predict poorer wellbeing is necessary to understanding whether school start times contribute to an increased risk of depression and anxiety. Pasch et al (2010) investigated how weekday and weekend sleep patterns were related to depression in adolescents[105]. Their findings showed that adolescents who slept for a shorter period of time on weekdays were more depressed. Weekend sleep duration did not predict depression. They did not find any significant relationships between weekend bedtime delay or weekend sleep extension and depression. These findings suggest that the school start time restricted how long adolescents could sleep for on weekdays, which resulted in the adolescents feeling more depressed.

Research which has examined the impact of delaying the time that school starts supports the idea that the school schedule restricts the amount of time adolescents can spend asleep, which may then contribute to the adolescent feeling more depressed. Owens et al (2010) and Boergers et al (2014) found that when adolescents [106] started school approximately 30 minutes later (08:30 and 08:25am) they were less depressed than when the same adolescents started school 30 minutes earlier (08:00am). As was described in the section "Age", adolescents' intrinsic circadian period is naturally delayed, and their homeostatic sleep pressure accumulates slower. These two changes in sleep regulation explain why adolescents

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[104] Participants were aged 11 – 14 years, mean and standard deviation of age were not reported.
[105] Participants were aged (M) (SD was not reported) 16.4 years.
[106] Participants were aged (range; M ± SD was not reported) 14 – 18 years.

sleep for approximately an extra 37 minutes when the school schedule is delayed. The findings also show that adolescents are less depressed when they start school later. Taken together Pasch, Owens and Boergers' findings suggest that early school start times reduce the opportunity for adolescents to sleep during the week which increases the risk of poorer wellbeing. It should be noted that these three studies were all conducted in America. However, as reported in the section "School schedule", Boergers et al (2014) findings showed that the proportion of adolescents who got > 8 hours sleep per night increased from 18% to 44% when school started later and sleeping longer was associated with lower depression rates. On average, UK adolescents aged 11 – 13 years old slept for 7.5 hours per night (Arora et al, 2013). This age group is recommended 9 – 11 hours sleep per night (Hirshkowitz et al, 2015). Thus, Pasch et al, Owens et al and Boergers et al findings are still relevant to UK adolescents despite the research being conducted in America.

Understanding the impact of school start times on sleep/wake patterns can also be understood by examining adolescents' sleep wake patterns in holidays i.e., when there is a greater sleep opportunity and adolescents do not need to wake early to get to school. Bei et al (2017) investigated the relationship between adolescents'[107] sleep wake patterns during school holidays and depression and anxiety. The findings showed no significant association between time in bed and depression or anxiety during holidays. Their findings did show that variable time in bed was associated with higher depression and anxiety, which was mediated by perceived sleep quality. Adolescents who had irregular sleep/wake schedules were more likely to be depressed or anxious than those individuals who had more consistent sleep/wake schedules. These findings support the theory that school start time restricts adolescents' weekday sleep/wake patterns and increases the likelihood of depression and anxiety. The findings also show that inconsistent bed and wake times may contribute to the onset of depression and anxiety through reducing perceived sleep quality.

The research reported above assumes poor or shorter sleep causes an individual to be depressed and anxious. There are few studies which have investigated whether depression or anxiety predicts adolescents' sleep. Patten et al (2000) investigated the relationship between depression and sleep in adolescents[108]. Their findings showed that the presence of depressive symptoms in the first year predicted the development and persistence of sleep disturbances four years later. This suggests that there is a link between poorer sleep and depression. There is no doubt that these individuals will have gone through physiological

[107] Participants were aged (M ± SD) = 16.2 ± 1 years.
[108] Participants began the study aged (range, mean ± SD for age was not provided) 12 – 18 years. At the four year follow up, participants were aged (range, mean ± SD for age was not provided) 15 – 22 years.

(e.g., pubertal maturation), psychosocial (e.g., pressures to use their devices later in the evening and have more bedtime autonomy) and societal (e.g., school schedule is earlier for mid – late teenagers but college or university may begin later in the day) changes during this time and so a causal link cannot be established.

Kelly and El-Sheikh (2014) investigated the relationships between sleep, depression, and anxiety over three years. Participants began the study at 8 years old[109] and finished the study at 13 years old. Participants were asked to wear actigraphy for 7 nights at each time point and parents were asked to validate the time that individuals went to bed and woke up at. The findings showed that depression at 8 years old predicted individuals' total sleep time at 10 years old, which in turn predicted depression and anxiety at 13 years old. Depression at 8 years old also predicted poorer sleep quality in these children when they were 10, which predicted higher anxiety and depression etc. The individuals in this study may have experienced bioregulatory changes in sleep regulation, psychosocial changes (e.g., be more inclined to use their devices in the evening) and they will have moved up from Elementary school to Middle school[110] and so they may also have a different school start time.

Examining the longitudinal relationship between sleep and mood over a shorter period of time reduces the influence of other external factors such as pubertal maturation and earlier school start times. Doane et al (2015) investigated the relationships between sleep and anxiety and depression in individuals [111] through a longitudinal study which lasted approximately a year. Adolescents began the study in the spring of their senior year of high school. The second measurement was taken 5 months later in the autumn of their first year of college. The final measurement was taken 4 months after this in the spring of their first year of college. The findings showed that individuals who had a poorer quality of sleep[112] at time 1 were more anxious 5 months later (time 2), who then also had a poorer quality of sleep 4 months later (time 3). These findings show that poorer sleep quality predicted and

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[109] There were 176 [78 males and 98 females] participants who began the study at 8 years old, 142 [62 males and 80 females] participants at 10 years old and 113 [50 males and 63 females] participants at 13 years old. Pubertal status was also measured the Puberty Development Scale (Petersen et al, 1988). Parents were asked to rate how developed pubertally mature their child was. Questions included genital development, the onset of menarche for females and facial hair and voice change for males. At 8 years old, the mean pubertal score for males was 1.25 ± 0.23 and the mean pubertal score for females was 1.45 ± 0.34, thus most individuals were pre-pubertal. At 10 years old, the mean pubertal score for males was 1.49 ± 0.42 and the mean pubertal score for females was 2.06 ± 0.55, thus males were still pre-pubertal whereas females had reached early pubertal status. At 13 years old the mean pubertal score for males was 2.27 ± 0.65 and the mean pubertal score for females was 3.18 ± 0.47, which corresponds to early pubertal status for males and mid-pubertal status for females.

[110] Elementary school is for children aged 5 – 11 years old and middle school is for children aged 11 – 14 years old.

[111] Participants began the study aged ($M \pm SD$) 18.05 ± 0.41 years.

[112] Sleep quality was measured using Pittsburgh Sleep Quality Index (Buysse et al, 1989).

was predicted by anxiety. The relationship between adolescents' sleep and daily mood is also important to understand not least to reduce the prevalence of poor mental health in adolescents. This will be discussed in the following section.

2.2.3.2. Affect

The relationship between sleep and state mood (positive and negative affect is less well understood. Understanding the impact of inadequate sleep on adolescents' state mood is a relatively under researched area. The majority of research has been conducted within recent years. Total sleep deprivation studies have shown that individuals had poorer mood after spending a prolonged period of time awake. Short and Louca (2015), examined the impact of total sleep deprivation on adolescents' mood[113]. Their findings showed that adolescents[114] who spent 36 hours awake were more confused, anxious, angry, and fatigued. Sleep restriction studies have also shown the direct impact of inadequate sleep on adolescents' positive and negative mood.

Many of the studies which have examined the impact of sleep deprivation, disruption and restriction on affect have shown that sleep deprivation, sleep disruption and sleep restriction all result in lower positive affect. It is not clear how sleep deprivation, sleep disruption and sleep restriction impact negative affect. Franzen et al (2008) investigated the impact of a single night of total sleep deprivation on adults'[115] positive and negative affect. The findings showed that a single night of sleep deprivation reduced positive affect but did not impact negative affect.

Disrupting the sleep architecture has also been shown to impact positive affect. Groeger et al (2014) examined the impact of disrupting adults'[116] slow wave sleep. Participants attend the laboratory for 4 nights; a baseline night, two nights of slow wave sleep disruption and a recovery night. Participants were told to sleep from 23:00 – 07:00 for 2 weeks before the study began. Participants were told to sleep from 23:00 – 07:00 during the study, however they were woken when slow waves were detected. The findings showed that participants were less positive when their slow wave sleep had been disrupted.

Similar findings were reported after participants were sleep restricted over two nights. Talbot et al (2010) examined the differences between early adolescents'[117], mid adolescents' and

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[113] Mood was measured using a shortened version of Profile of Mood States (Shacham, 1983).
[114] Participants were aged (M ± SD) 16.17 ± 0.83 years.
[115] Participants were aged (M ± SD) 24.4 ± 2.76 years.
[116] Young adults were aged between 20 – 30 years; middle aged adults were aged between 40 – 55 years and older adults were aged 66 years +.
[117] Early adolescents were aged (M ± SD) 11.5 ± 0.83 years; mid adolescents were aged (M ± SD) 14.29 ± 0.86 years; and adults were aged (M ± SD) 31.20 ± 9.97 years.

adults' worry, positive affect, and negative affect after sleep restriction. Participants were allowed a maximum of 6.5 hours total sleep time on night one and maximum of 2 hours total sleep time on night two. They then had 7 – 8 hours sleep opportunity for nights 3 and 4. The sleep restriction and control conditions were counterbalanced. Participants reported lower positive affect during sleep restriction, however their negative affect did not change. Whilst these findings suggest that negative affect remains unaffected by sleep deprivation or restriction, it has been argued that a single night of total sleep deprivation or two nights of sleep restriction are insufficient to observe the impact on negative affect (Baum et al, 2014).

There is conflicting evidence as to whether longer sleep restriction protocols impact negative affect. Lo et al (2016) investigated the impact of 5 hours sleep restriction for 1 week on adolescents'[118] positive and negative affect. Participants were told to maintain regular sleep/wake schedules and get 9 hours sleep per night for the week before the study. Their findings showed that sleep restricted adolescents reported lower positive affect, but there was no change in their negative affect. Lo et al (2017) further examined the impact of 5 hours sleep restriction and the influence of an hour afternoon nap[119] on adolescents'[120] mood. Sleep restriction was conducted in two cycles, the first cycle consisted of five days of sleep restriction and two days of recovery sleep (to replicate a school week and two nights of longer sleep opportunity) and the second cycle consisted of three days of sleep restriction with two nights of recovery sleep. Mood was measured at 10:00, 15:45 and 20:00 every day. The findings showed that the participants who did not have an afternoon nap had lower positive affect than those who did. During the first recovery sleep cycle, the participants who did not have an afternoon nap and those who did had similar positive affect ratings at all three measurement times (10:00, 15:45 and 20:00). These ratings were only significantly different from the control group in the afternoon measurement at 15:45 on recovery night 1. There was no significant difference between the afternoon measurements on recovery night 2. This shows that positive affect recovers quickly after obtaining sufficient sleep duration. The control group did not take recovery sleep after the second sleep restriction cycle.

Other studies have found that participants who slept for a shorter period of time were more negative. Dinges et al (1997) investigated the impact of 7 days sleep restriction on adults'[121]

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[118] Sleep restricted participants were aged (M ± SD) 16.43 ± 0.94 years. The control group participants were aged (M ± SD) 16.81 ± 1.17 years.
[119] The nap was scheduled from 14:00 and 15:00.
[120] Participants who were sleep restricted with an afternoon nap were aged (M ± SD) 16.75 ± 0.94 years. Participants who were sleep restricted without an afternoon nap were aged (M ± SD) 16.91 ± 1.14 years. The control group participants were aged (M ± SD) 16.81 ± 1.17 years.
[121] Participants were aged (M, SD was not provided) 22.9 years.

mood[122]. Sleep restriction was calculated as 33% reduction in normal total sleep time for each individual[123]. Their findings showed that sleep restricted individuals were more fatigued, more anxious, more confused and more tense. Baum et al (2014) investigated the impact of 6.5 hours sleep restriction vs 10 hours total sleep time for 5 days on adolescents'[124] mood[125]. Participants were randomly assigned either the sleep restriction or sleep extension group first. When adolescents were sleep restricted, they were more angry, more fatigued, and more confused than when they were well slept. These findings support the idea that sustained sleep restriction leads to increased negative mood.

The evidence reported above shows conflicting findings as to whether sleep restriction increases negative mood. Dinges, Baum and colleagues have shown that mood worsened when individuals were sleep restricted. However, Franzen, Groeger, Talbot and Lo and colleagues' findings showed that negative affect did not change. The findings suggest that mood worsens after several nights of sleep restriction rather than after sleep was manipulated for one or two nights.

Whilst mood may only worsen after several nights of sleep restriction the findings from Dinges, Baum and Lo yielded contradictory results, even though the studies all investigated the impact of 7 days of sleep restriction. The differences in the findings from these studies is probably due to whether participants were asked to maintain a regular sleep/wake schedule in the weeks before the study began. Lo and colleagues asked adolescents to maintain regular sleep/wake schedules and to have nine hours sleep per night in the week prior to the study beginning which gave these adolescents the chance to repay the sleep debt they had acquired. Dinges et al and Baum et al asked adolescents to maintain their normal nocturnal sleep duration that they would have had at home or change their bedtimes to accommodate the sleep restriction or sleep extension, respectively. Thus, it is likely that mood worsens after sustained sleep restriction which occurs over several weeks. In allowing participants the opportunity to get adequate sleep in the weeks before sleep restriction their mood was preserved and prevented from worsening during the sleep restriction. These findings suggest that adolescents will have worser mood later in the school term in comparison to earlier on in the school term when they are more likely to be well rested.

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[122] Mood was measured using Profile of Mood States and was measured at 10:00, 16:00 and 22:00 every day.
[123] Sleep restricted participants slept for (M ± SD) 4.98 ± 0.57 hours.
[124] Participants were aged (range, M ± SD was not provided) 14 – 17.9 years.
[125] Mood was measured using Profile of Mood States and was measured after the fifth day of the condition. Participants were asked how much they had felt____ over the last 3 days (including today).

This hypothesis that sustained sleep restriction impacts negative mood is supported by Chue et al (2018) who investigated the impact of insufficient sleep on stress recovery and negative affect in adolescents[126]. Their findings showed that total sleep time on one night did not predict negative affect, however accumulated sleep debt and previous day stress predicted next morning negative affect. These findings show that when individuals restrict their sleep for prolonged periods of time, they acquire greater sleep debt which in turn predicts greater negative affect than when they are well rested. Bei et al (2014) showed that adolescents[127] slept for a significantly shorter period of time during the school term than in the holidays. This difference in the amount of time adolescents spent asleep during the school term is likely to be due, in part, to the school schedule. If the sleep debt that adolescents acquire during the week is not repaid by the end of the weekend, then adolescents will acquire greater and greater amounts of sleep debt as the weeks pass by during the term leading to increased tiredness but also poorer mood.

The majority of studies examined above have examined the impact of sleep restriction on adolescents' mood. Other aspects of sleep, for example sleep onset latency, wake after sleep onset and waking feeling refreshed, may also impact sleep. Shen et al (2018) examined the relationship between sleep duration and sleep quality[128] on positive and negative affect in adolescents[129]. Their findings showed that sleep quality had strong associations with higher negative affect and short sleep duration with lower positive affect. These findings show that, perhaps, sleep duration is not the only important aspect involved in the relationship between sleep and affect. However, it is unclear whether sleep onset latency, wake after sleep onset or how refreshed adolescents feel upon waking is related to negative affect. The research reported above shows the importance of examining the relationship between sleep and state mood. The research suggests that sustained sleep restriction reduces positive affect and may increase negative affect when the individual has had their sleep restricted over several nights.

2.2.4. Obesity

Obesity has also been identified as an adolescent health risk factor (Royal College of Paediatric and Child Health, 2017). In recent years a trend has emerged between adolescents not getting enough sleep and an increased risk of being overweight or obese. As previously mentioned, experts, on behalf of the National Sleep Foundation, recommended that a child

[126] Participants were aged (M ± SD) 16.62 ± 0.81 years.
[127] Participants were aged (M ± SD) 16.18 ± 1.0 years.
[128] Sleep quality was measured using sleep onset latency, wake after sleep onset, how refreshed the individual felt after waking and the presence or absence of sleep disorders.
[129] Participants were aged (M ± SD) 14.55 ± 1.74 years.

aged 6 – 13 years old should get 9 – 11 hours per night and an adolescent aged 14 – 17 years old should get 8 – 10 hours sleep per night (Hirshkowitz et al, 2015). Recent evidence suggests that adolescents do not get their recommended sleep duration. Galland et al (2018) showed that 12 – 14-year-olds slept for 8.05 hours and 15 – 18-year-olds slept for 7.4 hours. As well as adolescents not obtaining sufficient sleep on a daily basis, recent statistics show that 63% of individuals, who were aged 16+ years, were classified as overweight or obese (NHS England, 2019a).

Despite the worrying trend between adolescents' inadequate sleep duration and being overweight, there are few studies which have examined the relationship between sleep/wake patterns and BMI in this age group. The mechanisms behind poor sleep quality or inadequate sleep duration increasing the risk of being overweight or obese remain elusive. Several possible mechanisms have been proposed which include, an imbalance in appetite stimulating and suppressing hormones (Taheri et al, 2004); increased propensity to consume more calories (Hart et al, 2013) and consume higher glycaemic index foods i.e., sweets and desserts, (Beebe et al, 2013), altered insulin sensitivity and resistance (Fatima et al, 2016) and lower engagement in physical activity (Gomes et al, 2014) are amongst some of the proposed mechanisms. Whilst it is important to understand how poor or inadequate sleep may increase BMI, it is also necessary to examine whether there is a relationship between sleep and BMI.

Significant relationships have been reported between shorter sleep duration, poorer sleep quality and higher BMI. Bawazeer et al (2009) investigated the relationship between how long adolescents slept for, whether adolescents woke up during the night, BMI and waist-hip ratio in adolescents[130]. Their findings showed that adolescents who slept for a shorter period of time and woke during the night predicted a higher prevalence of being overweight or obese[131]. The data on adolescents' sleep duration were collected using parental reports. Some of the participants used in this study were 19 years old. Parental reports are likely to be highly inaccurate for any of the older participants. As mentioned in previous sections, adolescents are encouraged to become more independent and have greater autonomy when they decide what time they want to go to sleep at.

Short et al (2013) showed parental reports of weekday wake times, weekday and weekend bedtimes and sleep durations were significantly different to those measured using actigraphy,

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[130] Adolescents were aged (range; M ± SD was not provided) 10 – 19 years.
[131] Being overweight or obesity was calculated using sex and age and was defined as BMI > 95th percentile or waist circumference > 90th percentile.

sleep diaries and adolescent self-report. Parental reported weekday wake times were not significantly different to actigraphy, self-reported or sleep diary weekday waketimes. As Carskadon (1990) reported adolescents naturally delayed circadian rhythm makes them rely upon their parents to wake them up on weekday mornings. Even if the adolescent wakes themselves on weekday mornings it is likely that parents know the school's start time and so they can make an educated estimation on their child's weekday wake time.

Whilst other studies have used self-report methods to examine the relationship between adolescents' sleep and BMI, some of these studies have only measured weekday sleep not weekend sleep. Adolescents do not have to wake early at the weekend. They are able to delay the time they go to sleep and wake up at the following morning and so both weekday and weekend sleep should be examined. Arora et al (2013) investigated the association between adolescents'[132] sleep duration, sleep onset latency, night-time awakenings (measured using school sleep habits survey; Wolfson et al, 2003) and BMI. Their findings showed that adolescents who took longer to fall asleep and slept for a shorter period of time had higher BMI. These findings suggest that shortened weekday sleep duration, which is inherently restricted by school start time, predicts a higher risk of being overweight or obese. Weekend sleep is not restricted by school start time and so there may have been more variability in adolescents' weekend bedtimes, wake times, sleep durations and their risk of being overweight or obese.

It is important to investigate how both weekday and weekend sleep/wake patterns predict BMI to understand whether sleep, which is not restricted by school start time, predicts the risk of being overweight and obese. Sivertsen et al (2014) investigated the relationship between adolescents'[133] weekday and weekend sleep patterns and BMI. Their findings showed a curvilinear relationship between weekday and weekend sleep duration and BMI in adolescents. Adolescents who were underweight, overweight, or obese slept for a shorter period of time on both weekdays and at the weekend in comparison to adolescents who had a normal BMI. Whilst these findings show that individuals who obtained shorter sleep durations on either weekdays or at the weekend are more likely to struggle to maintain a healthy weight it should also be noted that the normal weight individuals' sleep duration was substantially shorter than their recommended sleep duration. This suggests that other factors, possibly device use, have contributed to adolescents not getting enough sleep on weekdays

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[132] Adolescents were M ± SD age = 13.9 ± 2.0 years.
[133] Adolescents were aged M = 17.4 years, SD was not provided.

and at the weekend. This highlights the need for research to examine factors such as BMI in conjunction with other risk factors for poor and inadequate sleep.

More recent research has used more objective measures of sleep (actigraphy) to understand the relationship between sleep/wake patterns and BMI. Arora and Taheri (2015) used a combination of self-report measures (to measure sleepiness) and actigraphy (to measure weekday and weekend sleep). They investigated the relationships between sleepiness, sleep duration, sleep efficiency and BMI in adolescents[134]. Their findings showed that after adjustment (for age, sex, ethnicity and school type) shorter weekday sleep duration, shorter weekend sleep duration and shorter combined sleep duration predicted higher BMI. After further adjustment (for weekday daytime sleepiness, anxiety, depression, dietary behaviours and parental obesity) weekend sleep duration was no longer a significant predictor of BMI. – These findings show that adolescents who had inadequate sleep were more likely to be overweight or obese. Individuals who have inconsistent sleep/wake patterns often report feeling sleepy (Wolfson and Carskadon, 1998). Thus, daytime sleepiness may have been accounting for the variance attributable to weekend sleep duration rendering it not significant after adjustment.

2.2.5. Sleep hygiene

In 2014 almost 50% of adolescents in the UK reported experiencing sleeping difficulties and 36% reported not having enough sleep to concentrate on schoolwork (Brooks et al, 2014). As well as adolescents experiencing a change in the biological regulation of their sleep, they are also given greater independence, and this may mean that they go to sleep and wake at a later time and interact with their friends on their devices for a longer period of time in the evening. Adolescents are also placed under increasing academic pressure to perform well in examinations and so they experience greater anxiety and worries. These behaviours as well as others contribute to adolescents' poor sleep quality and inadequate sleep duration.

Sleep hygiene behaviours are factors which influence sleep quality and sleep duration by facilitating or inhibiting better sleep. Good sleep hygiene behaviours include regular sleep/wake schedules, regular bedtime routines, refraining from electronic device in the hours before sleep, avoiding sleep inhibiting behaviours (such as daytime naps and consumption of substances), engage in relaxing behaviours before sleep and avoid physiologically, cognitively or emotionally stimulating behaviours before bedtime (e.g., ruminating over what happened that day) and sleeping in a comfortable, quiet and dim

[134] Adolescents were aged M ± SD age = 12.0 ± 0.7 years.

environment (Wolfson, 2002). Good sleep hygiene is important for everyone; however, it is particularly important for adolescents. A recent study showed that poor sleep hygiene explained 30% of the variance in depression, 30% of the variance in anxiety, 57% of the variance observed in stress and 51% of the variance observed in general health in adolescents[135] (Lin et al, 2018). As well as being related to poorer mood, increased stress and poorer general health, poor sleep hygiene behaviours are associated with adverse sleep outcomes, which are, in turn, also related to poorer mood such as anxiety (Liu and Zhou, 2002; Pasch et al, 2010; Baum et al, 2014; Shen et al, 2018).

Stimulating behaviours, environments and activities have been shown to increase the risk of adverse sleep outcomes. Worrying or ruminating about what happened during the day makes it harder for the adolescent to engage in pre-sleep relaxation. Manni et al (1997) found that 16.5% of 17-year-olds reported having non-restorative sleep either "often" or "always" over the previous 12 months. Their findings also showed that individuals who had poor sleep hygiene, worried and were anxious before going to sleep had a poorer quality of sleep.

Similarly, Bartel et al (2016) investigated whether pre-sleep cognitive arousal predicted adolescents'[136] weekday bedtime, weekday sleep onset latency and weekday total sleep time. Their findings showed that adolescents who were more cognitively-emotionally aroused had went to bed later on weekdays, took longer to fall asleep on weekdays and spent a shorter time asleep on weekdays. These findings suggest that adolescents were unable to relax and stop worrying before they began trying to fall asleep, which resulted in them going to sleep later, taking a longer time to fall asleep and spending a shorter time asleep.

As well as lengthening sleep onset latency, poor sleep hygiene has been associated with poor sleep quality. Brown (2002) investigated the impact of a sleep hygiene intervention of young adults'[137] sleep. They found that improving sleep hygiene practices improved sleep quality. Their findings showed that the intervention group had shorter sleep latencies than the control group, which is probably due to the intervention group refraining from taking daytime naps. Napping during the day reduces the homeostatic sleep pressure which accumulates whilst the individual is awake and dissipates as the individual is asleep. As the intervention group were not taking naps their homeostatic sleep pressure will have remained high, which explains why the intervention group found it easier to fall asleep.

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[135] Participants were aged (M ± SD) 15.4 ± 1.1 years.
[136] Participants who were Australian were aged (M ± SD) 15.85 ± 1.34 years; Canadian participants were aged (M ± SD) 15.9 ± 1.6 years; and Dutch participants were aged (M ± SD) 16.38 ± 1.86 years.
[137] Participants were aged (M ± SD) 19.46 ± 2.7 years

The Adolescent Sleep Hygiene Scale (ASHS) encompasses all major aspects of sleep hygiene and has been shown to predict sleep quality in adolescents across the world. LeBourgeois et al (2005) investigated sleep hygiene in both Italian and American adolescents[138]. Their results showed that sleep hygiene predicted a substantial proportion of the variance observed in sleep quality in Italian and American adolescents. de Bruin et al (2014) conducted a similar study in Dutch adolescents[139] and found that sleep hygiene score was correlated with weekday and weekend sleep quality, weekday and weekend sleep duration and daytime sleepiness.

Substance use is a sleep hygiene behaviour which hinders sleep. Different substances have different effects on sleep timing and sleep architecture. Substance use was identified as an adolescent health risk factor by the Royal College of Paediatric and Child Health report (2017) and so it will be discussed in detail below.

[138] Participants were aged (M ± SD) 14.6 ± 1.6 years.
[139] Participants were aged (M ± SD was not provided) 14.4 years.

2.2.5.1. Alcohol and tobacco use

Adolescents are much more likely, than children or adults, to engage with risky behaviours such as experimenting with alcohol and tobacco, amongst many other behaviours (Steinberg, 2008). Recent statistics show that 10% of 11 – 15-year-olds said they had drunk alcohol in the last week and 21% of these individuals had more than 15 units. Additionally, 5% of 11-15-year-olds were current smokers and 2% of these individuals were regular smokers (NHS England, 2019b). These statistics are concerning as both alcohol and tobacco use substantially influence sleep. It would be unethical to administer alcohol or tobacco to adolescents and observe the impact on their sleep, however alcohol usage has been observed to reduce sleep onset latency and increases slow wave sleep in the first half of the night, disrupts sleep and increases wakefulness or stage 1 sleep in the second half of the night in adults (Williams et al, 1983; Van Reen et al 2006). Self-reports have shown that adolescents and young adults[140], who had consumed alcohol, went to sleep and woke up later and slept for shorter period of time (Huang et al 2013; Pasch et al, 2012). In a similar way, tobacco usage has been shown to lengthen sleep onset latency, reduce sleep duration, increases stage 1 and stage 2 sleep and reduces stage 3 and 4 sleep and reduces sleep efficiency in adults (Soldatos et al, 1980; Zhang et al, 2006). Self-reports have shown that adolescents and young adults[141] spent a shorter period of time asleep and woke up the following morning feeling tired (Pasch et al, 2012).

Pasch et al (2012) examined the impact of tobacco smoking and alcohol use on whether adolescents delayed the time they went to sleep on weekends, the amount of time adolescents'[142] spent asleep on weekdays and at the weekend and whether they delayed the time they woke up at on weekend. The findings showed that adolescents who consumed more alcohol reported sleeping for a shorter period of time at the weekend and did not delay the time they woke up at the weekend. Adolescents who used more tobacco reported sleeping for a shorter period of time at the weekend and overall (weekday and weekend combined). These findings show that adolescents who regularly smoke or drink alcohol sleep for a shorter period of time. It is not clear whether adolescents delay the time they go to sleep and sleep for a shorter period of time because alcohol and tobacco are often used at parties which occur in the evening, or whether the side effect of these substances are disrupting sleep.

[140] On the whole participants were at university and so were aged approximately 18 – 20 years.
[141] On the whole, participants were at university and were aged approximately 18 – 20 years.
[142] Participants were aged (M ± SD) aged 14.68 ± 1.83 years.

In addition to alcohol and tobacco reducing sleep duration, studies have investigated the impact on sleep onset latency. Alcohol and tobacco are both known to influence sleep onset latency in adults, however this result has not been replicated in adolescents. Chan et al (2013) investigated the impact of alcohol use on young adults' [143] sleep onset latency and wakefulness during the night. Their findings showed that there was no change in sleep onset latency but that the participants had more wakefulness during the night. Similar findings were reported by Bartel et al (2016) who investigated the protective and risk factors for adolescents' weekday sleep onset latency and sleep duration. Their findings showed that neither alcohol use nor tobacco use predicted sleep onset latency. These findings are likely due to Bartel and colleagues investigating weekday sleep onset latency. Approximately 67% of adolescents who had drank alcohol in the previous week had drank on Saturday and 38% had drank alcohol on Friday in comparison to less than 10% drinking during the week (NHS England, 2019b). Thus, Bartel and colleagues may have found different findings if that had investigated the impact of alcohol use on weekend sleep onset latency.

Bartel and colleagues also reported that alcohol use predicted longer weekday sleep duration. This is a surprising finding as previous studies have shown a negative relationship between sleep duration and alcohol use. Bartel and colleagues measured weekday sleep duration by asking adolescents "How many hours do you usually sleep?". Several studies have reported that adolescents and young adults reported sleeping for a shorter period of time (Pasch et al, 2012; Reichenberger et al, 2016). Thus, it is likely that the adolescents from Bartel et al (2016) study did not remember waking during the night and so they assumed they slept longer than they did.

Substance use also disturbs sleep/wake patterns. Huang et al (2013) examined whether alcohol use was associated with sleep problems in Hong Kong adolescents[144]. The findings showed that weekend bedtime mediated the relationship between alcohol drinking and difficulty initiating sleep, which suggests that adolescents who were using alcohol went to bed later at the weekend due to consuming alcohol at parties with their friends. These findings show that substance use is associated with a range of adverse sleep outcomes such as shorter weekend sleep duration and delayed weekend bedtimes. Whilst regular bed and wake times has been shown to be associated with better sleep quality, adolescents rarely obtain their recommended sleep duration throughout the week due to the school schedule restricting wake time. Thus, the majority of adolescents rely on having the opportunity to

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[143] Participants were aged (M ± SD) 19.1 ± 1.0 years.
[144] Participants were aged (M ± SD) 14.8 ± 1.9 years.

extend the amount of time they spend asleep at the weekend to catch up on the sleep they have missed during the week.

This section has not only shown that weekday and weekend sleep differ substantially, but that the presence or absence of school and the school start time may be adversely affecting adolescents' sleep and various aspects of their physical and mental health. It is important to understand the true impact of adolescents' sleep on these health risk factors to provide the best advice and support to individuals during this time of change.

2.3. Rationale, aims and hypotheses for the thesis

The studies in this thesis have built upon the literature discussed in chapter 1 and chapter 2. Each study has been designed by considering the shortcomings of the previous study and the questions which remained.

2.3.1. Rationale

This thesis is primarily focused with understanding whether and how electronic devices were associated with poor and ill-timed sleep whilst accounting for a variety of factors that are relevant to adolescents. Previous work has investigated the impact of electronic devices without accounting for other lifestyle factors such as school start time, obesity, and mood (Gradisar et al, 2013; Hysing et al, 2015; Gamble et al, 2014). The true impact of electronic devices on sleep will only be established when other adolescent lifestyle factors are accounted for and so the studies in this thesis will examine whether electronic device use still predicts poor and ill-timed sleep when accounting for various lifestyle factors.

Secondly, much of the literature which has examined how electronic devices use affects sleep quality and timing has not fully considered that electronic devices may be related to adverse sleep outcomes for several reasons (Chang et al, 2012; Chinoy et al, 2018; Cajochen et al, 2011). Recent research suggests that the interaction required from an activity may also be important (Jones et al, 2018; Gradisar et al, 2013; Hale and Guan, 2015). This thesis will examine how all three pathways, set out by Cain and Gradisar (2010) affect sleep outcomes. The three pathways are that: (1) blue light suppresses melatonin secretion and delays sleep onset, (2) content viewed on electronic devices increases pre-sleep cognitive arousal and delays sleep onset, (3) the time that is spent on electronic devices could be spent asleep.

Finally, the literature which has examined the relationship between adolescents' sleep and mood is inconsistent. Several papers have reported that poor or insufficient sleep resulted in lower positive affect. The relationship between sleep and negative is less clear (Lo et al, 2016; Dinges et al, 1997; Baum et al, 2014) and so this thesis will examine how daily sleep diaries are related to daily reported mood.

2.3.2. Aims and Hypotheses

The aims of this thesis are to examine whether and how adolescents' electronic device usage explains weekday and weekend sleep when other factors have been accounted for. After examining adolescents' electronic device usage, sleep and health using cross sectional surveys, this thesis will then examine how adolescents' electronic device use impacts their sleep and mood using a longitudinal study design which will use objective measures of sleep and device use.

Table 1 summarises the purpose of each study in this thesis and identifies the gaps in current literature.

The hypotheses for this thesis are that:

- Adolescents who use their devices more frequently, who have poorer mood, earlier school start times and higher BMI will have poorer and ill-timed weekday and weekend sleep than adolescents who use their devices less frequently.
- Adolescents who use their devices later in the evening, are more cognitively aroused from their devices, are exposed to more blue light, have poorer sleep hygiene, poorer mood, earlier school start times and higher BMI will have poorer and ill-timed weekday and weekend sleep than adolescents who use their devices earlier in the evening, are less cognitively aroused, are exposed to less blue light from their devices, have better sleep hygiene, better mood, later school start times and maintain a healthy weight.
- Adolescents who have poorer and ill-timed weekday and weekend sleep will have poorer mood (they will be more anxious and depressed; and they will have more negative and less positive affect) than adolescents who do not have poor or ill-timed weekday and weekend sleep.

Table 1 Summary of the purpose of each study and the gap each study fills in the literature

Chapter Title	Gap in the Literature	Purpose of the Study
Study 1: Identifying the predictors of adolescents' weekday and weekend sleep.	Research has not yet investigated how adolescents' electronic device usage affects sleep whilst simultaneously examining, mood and BMI (Gradisar et al, 2013; Hysing et al, 2015; Gamble et al, 2014. This will show the true explanatory role of each aspect.	To identify the predictors of weekday and weekend sleep. To explore the relationship between sleep, electronic device usage, mood and BMI.
Study 2: Examining *how* device use affects adolescents' weekday and weekend sleep.	It is unclear how electronic device usage leads to poorer and shorter sleep. Studies have not considered that blue light, content viewed on devices and the time spent on devices may all lead to adverse sleep outcomes (Chang et al, 2012; Chinoy et al, 2018; Cajochen et al, 2011) Sleep hygiene and substance use are important health risk factors to adolescents and should also be included in the model to ascertain the factors which influence adolescents' sleep (Brown, 2002; Bartel et al, 2015; NHS England, 2019b)	To identify the predictors of weekday and weekend sleep. To establish **how** electronic device use predicts poor sleep and mood.
Study 3: To what extent does actual electronic device usage impact adolescents' actual sleep and following day mood?	The impact of adolescents' electronic device usage on sleep relies heavily on cross sectional research (Gamble et al, 2014; Bartel et al, 2016; Gradisar et al, 2013), this study will examine adolescents over 2 weeks and take regular measurements. Previous research has argued that devices are either interactive or passive and that using interactive devices has the most profound impact on sleep outcomes (Gradisar et al, 2013; Hale and Guan, 2015). This study will examine how interactive applications are related to sleep outcomes (Jones et al, 2018). Previous studies have used poor measures to examine device use (Gamble et al, 2014; Gradisar et al, 2013; Woods and Scott, 2016). This study will use objective measures of electronic device use to ensure the data are accurate and reliable as per Kaye et al (2020) recommendations.	To examine how blue light, increased cognitive arousal and time displacement impacts sleep outcomes. To examine how the interactivity of applications impacts sleep outcomes. To examine how sleep is related to following day mood. To help to ensure that measures of electronic device usage are accurate and reliable by using objective measures.

3. Chapter 3: Methodology

This chapter will describe the methods which have been used in study 1, study 2 and study 3. Study 1, 2 and 3 have all used a survey to collect data. Whilst each study is slightly different, most of the survey remained the same for each study. The methods section for each study will only describe how that study's survey was different.

3.1. Participants

The studies in this thesis have used individuals at secondary schools in the UK. These individuals were aged between 11 – 18 years old. This age range is supported by Crowley et al (2014) who examined all of their participants and categorised them into a Tanner stage. Their findings showed that, on average, individuals began progressing through the Tanner stages at approximately 10 – 11 years old and that all individuals had reached Tanner stage 5 by 16 - 17 years old.

Participants were recruited from secondary schools and sixth forms across the UK for each of the three studies. Recruiting adolescents is a difficult process and so it was decided that participants would be recruited through their secondary school. This also reduced the number of extraneous variables which may have affected the results in study 2 and study 3 as the participants came from a small number of schools in these studies.

3.2. Materials

The surveys were distributed using Qualtrics. In study 1 and study 2 this survey was used to collect information on adolescents' sleep, electronic device usage and mood. Study 3 used this survey as a screening questionnaire to check participants' eligibility for the study.

3.2.1. Demographics questions

The demographics subsection comprised fourteen questions which asked participants to provide their age, sex, height, weight, school start time, school end time, time spent at school before classes begin, time spent at school after classes end, numbers of adults, children and pets in their household, whether and what they do in their bedroom. These questions all required participants to type their answer. The questionnaire also asked participants to say whether they were revising for or taking examinations at the time. Participants chose either "yes" or "no" for this question. Body Mass Index (BMI) was calculated as follows:

$$BMI = \frac{Kg}{m^2}$$

These measures were all chosen as the literature, which is discussed in detail in chapter 1 and chapter 2, indicates that these factors are associated with sleep. Older or more physiologically mature adolescents fall asleep later, wake up later and sleep for a shorter period of time. Sleep also differs between males and females and across the menstrual cycle for females (Crowley et al, 2014). The literature discussed in chapter 1 and 2 also highlighted how individuals with an earlier school schedule woke up earlier and slept for shorter periods of time than individuals who woke later (Owens et al, 2010; Boergers et al, 2014). A further reason for adding questions into the survey about school schedule was that much of the literature around understanding how the school schedule and sleep are associated has been conducted in America. There is little research which has shown the relationship between school schedule and sleep in UK adolescents. Finally, BMI was investigated as much of the literature has established a relationship between poor or ill-timed sleep and being overweight or obese (Bawazeer et al, 2009).

3.2.2. Self-report sleep questions

Ten questions were asked to measure self-reported sleep. The measure can be seen in the appendices. These questions measured sleep quality, waking feeling refreshed, sleep onset latency, bedtime and wake time for both weekdays and weekends. Sleep quality and waking feeling refreshed were measured using a 7-point Likert scale (1= very good / very refreshed, 7= very poor /very unrefreshed). Sleep onset latency asked participants to provide their response in hours and minutes. Bedtime and wake time all asked participants to give their answer in 24-hour clock.

The self-report sleep questions asked participants to report the time taken to get to sleep and bed and wake times for both weekdays and weekend days. Time in bed and sleep duration were estimated as follows:

$$Time\ in\ bed = Wake\ time - Bedtime$$

$$Sleep\ duration = (Wake\ time - Bedtime) - Sleep\ onset\ latency$$

It was decided that these questions would allow for participants to be specific about the time that they went to sleep and woke up at. Other studies have used asked participants to categorise themselves into a range, for example Shen et al (2018) used the following categories “less than 6 hours” to “more than 10 hours”. This was not used as it would not have allowed for sleep durations to be calculated. It was also decided that the Pittsburgh Sleep Quality Index (PSQI) would not be used, even though many of the components which were measured in these self-report sleep questions are also included within the PSQI as it had not been validated with English speaking adolescents at this time and this was beyond the scope of the thesis' studies.

3.2.3. Technology use

Study 2 and study 3 measured devices use on weekday and weekend nights by asking participants when they used each of the following devices "TV", "Mobile Phone", "Tablet", "E-Reader" and "Laptop/ Computer". These devices were selected as Ofcom (2016) reported these devices as being most regularly used by adolescents. Participants were told to indicate when they started and finished using each device by ticking the corresponding times. The measure ranged from "17:00" – "01:30 or later" and increased in 30-minute increments. There was also an option for participants to indicate that they did not use the device.

Figure *1 Questions which measured the time adolescents began and finished using each device and how cognitively aroused they felt after using each device.* shows the questions adolescents were asked to answer to establish the time they began using each device, finished using each device and how cognitively aroused they felt after using each device. The same questions were then asked for weekend device use.


These questions are about your device use on **weekday evenings.**

Please indicate when you use each of these devices on **weekday evenings**.

Select the times when you **begin using the device and** when you **put your device down** in an evening.

	I don't use this device.	17:00	17:30	18:00	18:30	19:00	19:30	20:00	20:30	21:00	21:30	22:00	22:30	23:00	23:30	00:00 (Midnight)	00:30	01:00	01:30 or later
use a TV																			
use a mobile																			
use a tablet																			
use an e-reader																			
use a computer/ laptop																			

How much of a "buzz" does using a __________ give you on a **weekday evening**?

Very Little 1 | 2 | 3 | 4 | 5 | 6 | A Lot 7

TV — Not Applicable

Mobile Phone — Not Applicable

Tablet — Not Applicable

E-reader — Not Applicable

Computer/Laptop — Not Applicable

Figure 1 Questions which measured the time adolescents began and finished using each device and how cognitively aroused they felt after using each device.

The scores on the device use questions indicated the timing of device use on weekdays and weekend days. Higher scores on the arousal questions indicated greater induced arousal from the relevant device.

This measure of device use was used as the main aim was to examine how adolescents' device use was related to their sleep. The three pathways, which Cain and Gradisar (2010) set out, were that the blue light which is emitted from devices delays sleep onset; the content viewed on devices increases pre-sleep cognitive arousal and that the time which is spent on devices displaces the time spent asleep. This measure of device use has incorporated all of these three pathways. The time stamped radio buttons were measuring when individuals put their device down, the measuring of different devices was examining how this differed between devices and the final questions which asked participants about how much of a 'buzz' they felt were examining pre-sleep cognitive arousal. A similar method had been employed by Bartel et al (2015) who examined the relationship between the time that adolescents stopped using the internet and their mobile phone on an evening and how long it took them to fall asleep, the time they went to bed and how long they slept for. The studies in this thesis were aiming to improve this measure by also asking participants how cognitively aroused they felt after using each device too.

3.2.4. Cleveland Adolescent Sleepiness Questionnaire - Modified- (Spilsbury, Drotar, Rosen & Redline, 2007)

The Cleveland Adolescent Sleepiness Questionnaire (CASQ) according to Spilsbury et al (2007) was composed of sixteen questions which measured four domains: sleepiness in school, sleepiness in the evening, sleepiness on transport and alertness at school.

The questionnaire was modified for this study. Twenty-three questions were used which measured five domains. The domains measured in this study were sleepiness at school, alertness at school, sleepiness at the weekend, alertness at the weekend and sleepiness in the evening. Of the 23 questions, thirteen questions were from the original questionnaire and asked participants to rate how sleepy they felt at school, in the evening and how alert they felt at school. Ten additional questions were added to measure sleepiness at the weekend and alertness at the weekend. The ten additional questions were modelled on the original sleepiness in school and alertness in school questions, for example an alertness at school question was "I go through the whole weekday without feeling tired", the weekend equivalent was "I go through a whole day at the weekend without feeling tired". Responses were measured on a 5-point Likert scale (1= Never, 5= Almost every day). Responses to the following questions were reverse scored: "I feel wide awake the whole day", "I feel alert during my classes", "When I am in class, I feel wide-awake", "I feel wide-awake the last class of the day", "I feel wide awake for the whole day during the weekend.", "I feel alert during my weekend activities.", "When I am at home during the weekend, I feel wide awake.", "I feel wide awake in the late afternoon at the weekend.". A higher score indicated increased sleepiness and reduced alertness. Total CASQ score was calculated by adding all subscales together. The questions can be seen in the appendix.

This measure was used as it was decided that it was equally important to have a measure of daytime functioning. Even though the questionnaire did not directly measure weekend daytime functioning, it was possible to structure questions relating to weekend daytime functioning based on the questions within the CASQ. Finally, the measure was designed and validated within an adolescent population and the internal consistency values in study 1 and study 2 show that the modified questions were also internally consistent.

3.2.5. Hospital Anxiety and Depression Scale- (Zigmond and Snaith, 1983)

The Hospital Anxiety and Depression Scale has a total of fourteen questions which measured anxiety and depression. Answers are measured on a 4-point Likert scale (0 = Not at all, 3 = Very often/ most of the time). Item 1 “I feel tense or wound up”; item 3 “I get a sort of frightened feeling that something awful is about to happen”; item 5 “Worrying thoughts go through my mind”; item 6 “I feel cheerful”; ‘item 8 “I feel as if I am slowed down”; item 10 “I have lost interest in my appearance”; item 11 “I feel restless as I have to be on the move”; and item 13 “I get sudden feelings of panic” were reverse scored. Higher scores indicated the presence of more anxiety or depression. Scores 8 – 10 indicated the individual was borderline anxious or depressed and scores above 11 indicated an “abnormal case” and the individual had anxious or depressive tendencies.

Woods and Scott (2016) conducted a similar study in which they examined whether evening electronic device, social media usage, anxiety predicted sleep quality. Their findings showed that adolescents who used their devices in the evening, were anxious and depressed had a poorer quality of sleep on weekdays. Thus, this thesis has used HADS to assess whether anxiety and depression predict poor sleep quality or ill-timed sleep whilst accounting for device use amongst other factors such as BMI, age, and sleep hygiene. None of which were accounted for in Woods and Scott (2016).

3.2.6. Behavioural Inhibition System- Behavioural Activation System- (Carver and White, 1994)

Behavioural Inhibition System – Behavioural Activation System (BIS-BAS) has a total of 24 questions which measured two motivational systems. The questionnaire was an operationalisation of Gray’s Reinforcement Sensitivity Theory (Gray, 1972) as it was hypothesised that behaviour is either inhibited to avoid punishment or that behaviour is encouraged to motivate movement towards goals. There are four subscales, Behavioural Inhibition System (BIS), Behavioural Activation System - Drive (BAS- Drive), Behavioural Activation System - Fun seeking (BAS Fun Seeking) and Behavioural Activation System - Reward Responsiveness (BAS Reward Responsiveness). Responses were scored according to Carver and White (1994) and were scored on a scale of 1 = very true for me – 4 = very false for me. All items except item 2 (“Even if something bad is about to happen to me, I rarely experience fear or nervousness.”) and item 22 (“I have very few fears compared to my friends.”) were reverse scored.

Higher scores on BIS indicated a tendency to inhibit behaviour that may have led to negative outcomes. Higher scores on BAS Drive indicated a tendency to engage in behaviours that may have allowed the individual to pursue goal directed behaviour. Higher scores on BAS Fun Seeking indicated a motivation to seek novel experiences and opportunities. Higher scores on BAS Reward Responsiveness indicated a heightened sensitivity to rewards and positive outcomes. BIS/BAS was not used in the analyses as the models would have been tested on a smaller sample of participants.

This measure was used as an additional questionnaire. It was not used in any of the analysis as none of the studies recruited a large enough sample to be able to examine the relationship between sleep and behavioural motivations. The measure was included as it would have shown how poor and ill-timed sleep are related to the various states that either motivate or inhibit individuals' actions. Other measures of personality such as the Eysenck Personality Questionnaire revised (EPQ-r) (Eysenck & Eysenck, 1984)) places individuals into one of several categories and describes the personality traits of individuals in those categories. BIS/BAS assesses the behavioural motivation whereas EPQ-r assesses how the personality traits manifest.

3.2.7. Adolescent Sleep Hygiene Scale- (LeBourgeois, Giannotti, Cortesi, Wolfson & Harsh, 2005)

Adolescent Sleep Hygiene Scale (ASHS) was composed of 26 items, which measured behaviours that may inhibit or facilitate sleep across 9 domains, these are: Physiological, Cognitive/ Emotional, Behavioural Arousal, Sleep Environment, Sleep Stability, Daytime Sleep, Substances, Bedtime Routine and Total ASHS score. Participants were asked to report how frequent these behaviours have occurred in recent months. Scores were measured using a 6-point Likert scale (1= always, 6= never). Item 27 was reverse scored ("I use a bedtime routine (e.g., bathing, brushing teeth, reading)"). Higher scores across the domains and the Total ASHS score indicated better sleep hygiene.

This questionnaire was included as the literature indicated that the activities which an individual engages with before they go to bed is related to their sleep quality and their sleep timing (Brown, 2002). This measure was included as it was designed and validated to be used in an adolescent population.

3.3. Procedure

Participants were recruited via their school. The participants for study 1 were recruited across a number of schools ranging from Bristol, Bolton and Nottinghamshire. A good relationship was built between the schools and the research team and so a couple of schools expressed interest in taking part in the second study. The second study recruited all participants from three schools. Once a school had been recruited, they were randomly allocated one of three surveys: Core, Core +1, and Core + 2. The questionnaires which were included in these three variations depended on the study and they are detailed in the relevant empirical chapters. Participants were given an information sheet and asked to provide informed consent. They then completed the survey once and were then given a full debrief and given the contact details for several support helplines should they wish to access support.

3.4. Ethics

This survey and all the individual scales were approved for use by Nottingham Trent University's ethics committee. Initially, schools were contacted and asked if they would like their students to be given the opportunity to take part in the study. If the school agreed, then parents were contacted and asked if they wanted their adolescent to take part. The adolescent was then required to read the participant information sheet and provide informed consent if they wanted to take part. They were reminded that their participation was voluntary and that they could withdraw at any point without any consequences. At the end of the survey, participants were given a full debrief of the study and its aims. A contact number was provided for the Samaritans and participants were encouraged to seek help if they felt they needed wellbeing support after completing the study.

4. Chapter 4: Study 1: Identifying the predictors of adolescents' weekday and weekend sleep.

4.1. Aims

1. To establish how adolescents' weekday and weekend sleep differ.
2. To examine how the predictors which explain weekday and weekend sleep differ from each other.
3. To examine whether electronic device usage still predicts weekday and weekend sleep when other factors that are relevant to adolescents are included in the model.

4.2. Introduction

The introduction to this chapter will explain the rationale behind the current study. This study has investigated the relationship between adolescents' electronic device usage, their sleep and their mood. The rationale will discuss the differences between weekday and weekend sleep. It will then discuss to what extent electronic device usage predicts sleep when other factors, such as school start time and body mass index (BMI), are accounted for.

4.2.1. The differences between weekday and weekend sleep

The differences in the timing, length and quality of weekday and weekend sleep have been known for a number of decades. Adolescents go to bed earlier, wake up earlier, spend less time in bed, spend less time asleep, have a poorer quality of sleep and wake feeling less refreshed on weekdays than on weekend mornings (Allen and Mirable, 1989; Carskadon, 1990; Carskadon et al, 1998; Wahlstrom et al, 1997; Wahlstrom et al, 2014; Owens et al, 2010; Boergers et al, 2014; Chan et al, 2018). Weekday and weekend schedules are substantially different to each other. Weekdays are restricted by the school schedule whereas weekends are not. The school schedule means that adolescents must wake early to ensure they can make their commute and arrive at school on time. The school day typically starts at approximately 08:00 – 09:00 in the UK. This means that adolescents must wake very early when their circadian system is still promoting sleepiness (Carskadon, 2011).

Adolescents are given much more independence. They rely less on their parents telling them when they should go to bed, and this often means that adolescents go to bed later. Often secondary schools have earlier school start times than primary schools. Ultimately, going to bed later and waking early results in adolescents sleeping for a shorter length of time. Whilst several papers have documented the differences in the timing, duration and quality of weekday and weekend sleep, there has been no investigation into whether weekday and weekend sleep are impacted by the same factors. The school day restricts the time adolescents can wake up at, the time they can spend asleep, the time they can use their devices and the length of time they can use their devices for. Thus, it is likely that the factors which impact weekday sleep will be different to the factors which impact weekend sleep. This study will examine whether this is the case.

4.2.2. To what extent does electronic device usage impact sleep?

Recent statistics show that 83% of adolescents aged 12 – 15 years old own a smartphone and 71% of these adolescents ae allowed to take it to bed with them (Ofcom, 2018). These statistics show that many adolescents have the opportunity to use a device before going to sleep and this may then affect their behaviour and mood on the following day. The impact of electronic device usage on weekday sleep has been well investigated. The vast majority of these research studies have shown that greater device usage negatively impacts sleep. Adolescents who used a greater number of devices used in the hour before bed had a greater difficulty falling asleep, greater difficulty maintaining sleep and woke feeling less refreshed the following morning (Gradisar et al, 2013). Furthermore, adolescents who used their devices more frequently in the hour before bed took longer to fall asleep, were more likely to be sleep deprived by 2+ hours and spent a shorter time asleep (Hysing et al, 2015). In addition, adolescents who used their mobile phone, television and computer whilst they should have been asleep went to bed later, woke up later and spent a shorter time asleep (Gamble et al, 2014). Similar findings were reported for adolescents who frequently used social media just before going to sleep. Woods and Scott (2016) showed that adolescents who frequently used social media just before going to sleep had a poorer quality of sleep. Woods and Scott also examined the impact of anxiety on sleep quality. Adolescents who were more anxious also had a poorer quality of sleep. Their findings show the importance of examining the impact of electronic device usage in combination with other factors relevant to adolescents. The majority of previous research which has examined the impact of electronic device usage on adolescents' sleep has done so without considering the other possible factors that may influence adolescents' weekday and weekend sleep. These studies all demonstrate that adolescents who use more electronic devices in the evening find it harder to fall asleep and as a result fall asleep later, find it harder to stay asleep, wake up later, were less refreshed the following morning and spent a shorter time asleep. This study will investigate whether electronic device usage remains a significant predictor of adolescents' sleep when other health risk factors are incorporated into the model.

Electronic device usage is one aspect which is known to affect sleep. Other aspects such as weight, mental health and the school schedule have been identified as other factors which are related to adolescents' health and negatively impact adolescents' sleep (Royal College of Paediatric and Child Health, 2017; Bartel et al, 2015). It is important to account for these other health risk factors into a model which is being used to explain adolescents' sleep to establish the true impact of electronic device usage on adolescents' sleep.

It is well known that poor and short sleep increase the likelihood of developing mental health problems. Kelly and El-Sheikh (2014) showed that children who were depressed at 8 years old spent a shorter time asleep at 10 years old and these children were then more depressed and anxious at 13 years old. In addition, children who were depressed at 8 years old also had a poorer quality of sleep at 10 years old, these children were then more depressed and anxious at 13 years old. These findings suggest that there may be a bi-directional relationship exists between sleep and mental health problems, however this longitudinal study was conducted over 5 years. The children who were investigated in this study will have undergone substantial changes in several aspects of their lives, for example they will have begun secondary school and so will probably have earlier school start times and they will have begun maturing physiologically. Factors such as these may have influenced their sleep or mental health status. A similar study was conducted in older adolescents over a year. Conducting a longitudinal study over a shorter period of time avoids the results being subject to as many confounding variables. Doane et al (2015) showed that adolescents who had a poorer quality of sleep at time 1 were more anxious 5 months later and these adolescents had a poorer quality of sleep 4 months later. These findings further support the argument that sleep, and mental health status may be bi-directionally related. Whilst this study was conducted over a shorter period of time (approximately 1 year), the participants began the study in their final year of high school and finished the study in their first year of college. Thus, similar to Kelly and El-Sheikh (2014) study, other confounding variables such as the participants' school start time may have also influenced the findings.

Adolescents do not get enough sleep. Galland et al, (2018) showed that adolescents, aged 15 – 18 years, old slept for 7.4 hours. Experts, on behalf of the National Sleep Foundation and the American Academy of Sleep Medicine, recommended adolescents in this age group should sleep for 8 – 10 hours per night (Hirshkowitz et al, 2015; Paruthi et al, 2016). Recent evidence has shown that 63% of individuals, who were aged 16+ years, were either overweight or obese (NHS England, 2019a). This link between shorter sleep and being overweight or obese has been examined by a number of researchers. Bawazeer et al, (2009) examined the relationship between adolescents' sleep duration and whether they were categorised as being “overweight” or “obese”[145]. The findings showed that adolescents who slept for a shorter period of time and those who woke during the night were more likely to be overweight or obese than those who slept for a longer period of time or who did not wake during the night. Bawazeer and colleagues relied upon parental reports to collect their data. Short et al (2013) showed that parental reports of adolescents’ sleep were significantly different to actigraphy, daily diaries and adolescent self-reports. Thus, Bawazeer and colleagues’ findings should be interpreted with caution.

Arora et al (2013) examined the relationship between how long it took adolescents to fall asleep on weekdays, how long adolescents slept for on weekdays, the number of times they woke during the night on weekdays and BMI. Their findings showed that adolescents who slept for a shorter period of time had a higher BMI. Arora and colleagues did not examine the relationship between weekend sleep duration and BMI. Weekend sleep is not restricted to the same extent that weekday sleep is and so adolescents betimes, wake times and sleep durations may have been more variable, and this may have predicted their risk of being overweight or obese.

As has been previously mentioned, the school schedule restricts the opportunity for sleep on weekdays. Owens et al (2010) showed that adolescents who started school 30 minutes later woke up later on weekdays, spent a longer time asleep on weekdays and they felt less sleepy and fatigued in the morning. Boergers et al (2014) reported similar findings for adolescents who started 25 minutes later. Adolescents woke up later, spent a longer time asleep, were less sleepy during the day, were less depressed and consumed less caffeine than when their school day started earlier. Unsurprisingly, these studies showed that later school start times allow adolescents to sleep longer. The studies have also shown that adolescents wake up later, feel less sleepy during the day and consume less caffeine than when they had an earlier school start time. This is because the circadian rhythm becomes delayed during adolescence (Carskadon et al, 1998). Older adolescents accumulate homeostatic sleep pressure at a slower rate, and this allows them to go to sleep at a later time than younger adolescents (Jenni et al, 2005). Regardless of when they fall asleep, adolescents need approximately 9.25 hours sleep per night (Carskadon et al, 1982). Thus, when adolescents go to bed later, they must also wake later the following morning to ensure they get adequate sleep duration. These two studies have shown that later school schedules allow adolescents to wake slightly later, get adequate sleep duration and this makes them feel less sleepy during the day and need less caffeine throughout the day. Most secondary schools in the UK begin classes at

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[145] Participants were categorised as being overweight or obese using their BMI and waist: hip ratio.

approximately 08:30am and some schools tell students that they must be at school even earlier than this. Adolescents who have long commutes to school must wake even earlier than those who have shorter commutes. This means that adolescents must wake whilst their circadian rhythm is promoting sleep and before they have spent enough time asleep. Despite these various factors all being related to inadequate sleep, there has been no study which has investigated whether electronic device usage is related to inadequate sleep when these factors are considered. The current study will examine whether electronic device usage remains a predictor of adolescents' sleep when these other health risk factors are incorporated into the same model.

4.2.3. The current study

Based on the research reported above, the current study will first examine whether and how adolescents' weekday and weekend sleep differ. The study will also examine whether the predictors for weekday sleep also explain weekend sleep. Finally, it will then examine whether electronic device usage still impacts weekday and weekend sleep when other factors that are relevant to adolescents are included.

4.2.3.1. Hypotheses

It is hypothesised that:

1. Participants will report a better quality of sleep, will be more refreshed, will go to bed later, wake up later, spend a longer time in bed and spend a longer time asleep on weekends than on weekdays.
2. Participants who use electronic devices more frequently will have a poorer quality of sleep, wake feeling less refreshed and go to bed later on weekdays.

4.3. Methods

4.3.1. Sampling

This study used opportunity sampling to recruit the participants for the survey. Secondary schools across the country were contacted and asked if they would like to take part in the study. This study recruited 8 schools. The schools included in this study differed across many characteristics such as geographical location, type of school (comprehensive mixed education and independent single sex schools) and the age of the students that the survey was open to. These characteristics may have influenced the results from this survey.

4.3.2. Participants

A total of 405 participants began the survey who were aged between 11.08 – 18.92 years (M = 14.83, SD = 2.10) and were recruited from eight schools nationally. Two hundred and twenty-eight aged between 11.08 – 18.92 years (M = 15.11, SD = 1.97) completed the survey (49.6% were male, 48.2% were female, 2.2% did not disclose their sex) recruited from eight schools nationally.

4.3.3. Methods

The survey was distributed using the online platform, Qualtrics. The survey consisted of a set of core questionnaires, which are described in Table 2. The survey was split into three variations to avoid a long questionnaire as this would have increased participant attrition.

Table 2 The formation of the three survey variations

Core	Core + 1	Core + 2
Demographics questions	Demographics questions	Demographics questions
Self-report sleep questions	Self-report sleep questions	Self-report sleep questions
Media and Technology and Attitudes scale (Rosen, Whaling, Carrier, Cheever & Rokkum, 2013)	Media and Technology and Attitudes scale (Rosen, Whaling, Carrier, Cheever & Rokkum, 2013)	Media and Technology and Attitudes scale (Rosen, Whaling, Carrier, Cheever & Rokkum, 2013)
Other Technology questions (Rosen, Carrier, Miller, Rokkum & Ruiz, 2016)	Other Technology questions (Rosen, Carrier, Miller, Rokkum & Ruiz, 2016)	Other Technology questions (Rosen, Carrier, Miller, Rokkum & Ruiz, 2016)
Cleveland Adolescent Sleepiness Questionnaire (Spilsbury, Drotar, Rosen & Redline, 2007)	Cleveland Adolescent Sleepiness Questionnaire (Spilsbury, Drotar, Rosen & Redline, 2007)	Cleveland Adolescent Sleepiness Questionnaire (Spilsbury, Drotar, Rosen & Redline, 2007)
Hospital Anxiety and Depression Scale (Zigmond & Snaith, 1983)	Hospital Anxiety and Depression Scale (Zigmond & Snaith, 1983)	Hospital Anxiety and Depression Scale (Zigmond & Snaith, 1983)
	Munich Chronotype Questionnaire (Roenneberg, Wirz-Justice & Merrow, 2003)	Behavioural Inhibition Scale- Behavioural Activation Scale (Carver and White, 1994)
		Adolescent Sleep Hygiene Scale (Lebourgeois, Giannotti, Cortesi, Wolfson & Harsh, 2005).

4.3.4. Materials

Many of the questionnaires that were used in this survey have been used in all of the studies in this thesis and so they are described in detail in the methodology chapter. This section will report the internal consistency values for each questionnaire used and will describe any aspects of the survey which are specific to this study.

4.3.4.1. Subjective sleep questions

These questions are described in detail in the Chapter 3: Methodology chapter.

4.3.4.2. Media and Technology and Attitudes Scale- (Rosen, Whaling, Carrier, Cheever & Rokkum, 2013)

This survey used Media and Technology and Attitudes Scale to measure electronic device usage, rather than the device use questions detailed in Chapter 3: Methodology. The questionnaire consisted of 60 items, which was split into 2 sections. The Media and Technology section had 44 items and the Attitudes towards Technology section had 16 items. According to Rosen et al (2013) the variables are scored as follows: Media and Technology usage questions were measured on a 10-point scale (1 = Never, 10 = All the time) and measured frequency of usage of various devices and activities they were used for. Higher scores indicated more frequent usage. Online Friendships and Facebook Friendships subscales were measured on a 9-point Likert Scale (1= 0, 9 = 751+). The Online Friendships and Facebook Friendships subscales measured the number of friends a participant had on various online platforms and so a higher score indicated more friendships. The Attitudes to Technology questions were measured on a 5-point scale (1 = Strongly Disagree, 5 = Strongly Agree) and measured participant's positive and negative attitudes towards media and electronic device and so a higher score indicated stronger agreement with the statement. Item 15 ("I like to finish one task completely before focusing on anything else") on the Attitudes to Technology questionnaire was reverse scored ((1 = Strongly agree – 5 = Strongly disagree). Rosen et al (2013) reported that the subscales "can be used together or separately as they are internally reliable and externally valid" (p.2507).

All the Media and Technology scales were checked for internal consistency, the results are shown in Table 3. According to Bland and Altman (1997) Cronbach α values between 0.7 – 0.8 are satisfactory. As some of the internal consistency values are smaller than 0.7 there was some question as to whether the structure Rosen et al (2013) developed best fits the observed data. Confirmatory factor analysis was conducted to test whether the structure, as detailed by Rosen et al (2013), was present in the observed data.

Table 3 Cronbach's α of the Media and Technology and Attitudes subscales according to Rosen et al (2013) and according to this study.

Subscale	Rosen et al (2013) Cronbach's α	This study's Cronbach's α
Smartphone usage	0.93	0.84
General social media usage	0.97	0.88
Internet searching usage	0.91	0.79
Email usage	0.91	0.83
Media sharing usage	0.84	0.76
Text-messaging usage	0.84	0.64*
Phone calling usage	0.71	0.59*
Television viewing	0.61	0.74

Video gaming usage	0.83	0.75
Online friendships	0.83	0.54*
Facebook friendships	0.96	0.92

Note: * = Cronbach's α did not meet 0.7 and is unsatisfactory.

4.3.4.2.1. Confirmatory Factor Analysis

Confirmatory factor analysis was conducted on the Media, Technology and Attitudes scale (Rosen et al 2013) based on 329 participants' data. Maximum likelihood was chosen as the data were normally distributed. The data were taken from 60 questions on 16 Likert-scale variables which measured emailing, text-messaging, phone calling, smartphone usage, TV viewing, media sharing, internet searching, video gaming use, general social media usage, Facebook friendships, online friendships, positive attitudes towards electronic device, anxiety and dependence on electronic device, negative attitudes towards electronic device and preference for task switching.

The values of the confirmatory factor analysis indicated a poor fit between the hypothesised model proposed by Rosen et al (2013) and the observed data (the comparative fit index = 0.803, the Tucker-Lewis fit index = 0.783 and the Root Mean Square Error of Approximation = 0.053, $p = 0.069$). Exploratory factor analysis was then conducted to determine the number of factors that the questions loaded onto. The scree plot indicated approximately 9 – 11 components, Kaiser's criterion (eigen value > 1) indicated 18 components, the minimum average partial test indicated 10 components, parallel analysis indicated 10 components and broken stick method indicated 4 components. The data were fit to 9, 10 and 11 components and upon inspection of these structures the 10-factor structure was the most meaningful. Regression factor scores were saved across the 10 new factors. These new factors have been used in the hierarchical linear regression analysis and mediational models.

4.3.4.3. Phone location and frequency of phone checking having awoken from sleep- Rosen et al (2016)

There were two questions. One question asked participants "Where do you typically place your phone when you go to sleep?". The possible responses to this question were: (1) under my pillow, (2) on my bed, and (3) next to my bed, (4) in another room, (5) far away from the participant and (6) other.

The second question asked participants "On a typical night, after you have fallen asleep, how often do you awaken and check your phone for something other than the time (e.g. text messages, email, social media, etc.)?" The responses to this question were: (1) never, (2) once, (3) 2 times, (4) 3 times, (5) 4-5 times, (6) 6-8 times, and (7) more than 8 times. This study kept each of these choices as separate categories rather than grouping a number of them together as per what Rosen and colleagues did.

4.3.4.4. Cleveland Adolescent Sleepiness Questionnaire - Modified- (Spilsbury, Drotar, Rosen & Redline, 2007)

These questions are described in detail in Chapter 3: Methodology. As described in the previous chapter, the following items were reverse scored: “I feel wide awake the whole day”, “I feel alert during my classes”, “When I am in class, I feel wide-awake”, “I feel wide-awake the last class of the day”, “I feel wide awake for the whole day during the weekend.”, “I feel alert during my weekend activities.”, “When I am at home during the weekend, I feel wide awake.”, “I feel wide awake in the late afternoon at the weekend.”. All the subscales in the Cleveland Adolescent Sleepiness Questionnaire – modified were checked for internal consistency. The results are reported in Table 4.

Table 4 Cronbach's α of the Cleveland Adolescent Sleepiness Questionnaire- Modified according to this study

Subscale	Spilsbury et al (2007)	This study’s Cronbach’s α
Sleepiness in school	-	0.90
Alertness in school	-	0.86
Sleepiness in the evening	-	0.73
Sleepiness at the weekend	-	0.78
Alertness at the weekend	-	0.81
Total CASQ score	0.89	0.90

All the subscales met the 0.7 threshold set by Bland and Altman (1997). This shows that the subscales are internally reliable. Spilsbury et al (2007) did not provide internal consistency values for the subscales individually. The internal consistency score for the total Cleveland Adolescent Sleepiness Questionnaire- modified score in the current study is similar to the internal consistency value reported by Spilsbury et al (2007). Both values are considered ‘excellent’ by Bland and Altman (1997) scale. The descriptive results for this scale are reported in the results section of this chapter.

4.3.4.5. Hospital Anxiety and Depression Scale- (Zigmond and Snaith, 1983)

This scale is described in detail in Chapter 3: Methodology. Item 1 “I feel tense or wound up”; item 3 “I get a sort of frightened feeling that something awful is about to happen”; item 5 “Worrying thoughts go through my mind”; item 6 “I feel cheerful”; ‘item 8 “I feel as if I am slowed down”; item 10 “I have lost interest in my appearance”; item 11 “I feel restless as I have to be on the move”; and item 13 “I get sudden feelings of panic” were reverse scored. Both the depression and anxiety subscales were checked for internal consistency. The results are shown in Table 5.

Table 5 Cronbach's α of the Hospital Anxiety and Depression Scale according to Woods and Scott (2016) and this study

Subscale	Woods and Scott (2016)	This study's Cronbach's α
Anxiety	0.8	0.88
Depression	0.72	0.85

This study's Cronbach's α scores show that the Hospital Anxiety and Depression Scale (HADS) subscales were internally consistent. As Zigmond and Snaith (1983) did not publish their Cronbach's α scores, the results of this study cannot be compared to the original study. The results from the current study have been compared to Woods and Scott (2016) who investigated the effect of adolescents' social media usage on sleep quality, anxiety and depression. This study's Cronbach's α is larger than those reported by Woods and Scott (2016). The current study's results show that participants interpreted and answered the questions in a consistent way.

4.3.4.6. Adolescent Sleep Hygiene Scale- (Lebourgeois, Giannotti, Cortesi, Wolfson & Harsh, 2005)

This scale was described in detail in Chapter 3: Methodology. Item 27 was reverse scored ("I use a bedtime routine (e.g., bathing, brushing teeth, reading)"). All of the subscales included in the Adolescent Sleep Hygiene Scale (ASHS) were checked for internal consistency and the results are reported in Table 6. The Cronbach's α scores reported by LeBourgeois et al (2005) ranged between 0.46 – 0.74 for the individual sleep hygiene domains (the individual values for each subscale were not reported) and 0.80 for Total ASHS score.

Table 6 Cronbach's α for Adolescent Sleep Hygiene Scale according to Lebourgeois et al (2005) and this study

Subscale	Lebourgeois et al (2005) Cronbach's α	This study's Cronbach's α
Physiological	-	0.25
Behavioural Arousal	-	0.47
Cognitive/Emotional	-	0.78
Sleep Environment	-	0.46
Sleep Stability	-	0.59
Daytime Sleep	-	0.64
Substances	-	0.60
Total ASHS Score	0.8	0.74

Some of the Cronbach's α values reported from this study are considerably lower than the range outlined by LeBourgeois et al (2005) and the 0.7 threshold outlined by Bland and Altman (1997) and would be considered "poor". These differences in the Cronbach's α scores may be due to differences in how the participants in the current study interpreted the questions. Alternatively, it may indicate that the participants in the current study may have become tired of answering the survey and did not answer properly. Some of the subscales have low Cronbach's α values due to the items having low inter-relatedness, for example the physiological subscale consists of "After 6:00 in the evening, I have drinks with caffeine (e.g., cola, root beer, iced tea, coffee)" and "During the 1 hour before bedtime, I am very active (e.g., playing outside, running, wrestling)". The two items do not appear well related. A question regarding caffeine consumption would have been better placed in the substance use subscale. The total sleep hygiene score would have been used if the scale had been included in analysis as this is above the threshold and captures all aspects of sleep hygiene that were measured in the scale.

4.3.4.7. Behavioural Inhibition System- Behavioural Activation System (Carver & White, 1994)

This is described in detail in Chapter 3: Methodology. The scale was not used in the analyses as there were too few complete responses. If the study had recruited more participants, then this would have been examined.

4.3.4.8. Munich Chronotype Questionnaire for Children (Roenneberg et al, 2003)

The Munich Chronotype Questionnaire was comprised of 34 questions, which measured a variety of domains such as participant's sleep / wake routine, school routine, time spent outdoors and stimulant use. Higher scores on time spent outdoors and stimulant use questions indicated greater dosage.

This measure was also not used as there were too few complete responses. If the study had recruited more participants, then this would have been examined.

4.3.5. Procedure

Several schools were contacted across the United Kingdom and asked if they would like to give their students the opportunity to take part in the study. The schools which agreed to take part then contacted and obtained parental consent. There were three surveys (Core, Core+1 and Core+2). Pupils answered one of the variations. All pupils from the same school answered the same variation and schools were assigned strategically so that the number of participants who were answering each variation remained relatively similar. The schools were sent a link to the survey, and this was then circulated amongst the pupils who were taking part in the survey.

Before beginning the survey, the participant was given information regarding the survey and told that they did not need to take part in the survey. They were told they had the opportunity to withdraw at any point during the survey or afterwards and assigned themselves a unique identifier in case they wished to withdraw at any point. Participants then completed the survey and were provided with a full debrief at the end of the survey. Names of organisations and phone numbers were provided in case the survey had evoked feelings of distress or worry for the participant.

4.3.6. Data Management and Statistical Analyses

The responses were downloaded from Qualtrics, and the data were cleaned in Microsoft Excel. At the beginning of the data cleaning process, there were 423 participants. The data cleaning process removed 18 participants. This left 405 participants. There were 69 responses on Core, 125 responses on Core + 1 and 211 responses on Core + 2. There were 228 complete responses, Core = 48 complete responses, Core +1 = 82 complete responses and Core + 2 = 98 complete responses. Participants were removed if they gave inappropriate answers (e.g., a student reporting that they were 6 metres tall). Participants who repeatedly provided inappropriate responses were removed from the entire analysis to avoid the results being contaminated. The questionnaires which were included in "Core" were included in all three of the variations. These scales were used in the analyses to ensure the models were conducted on a large sample size.

The data were then reverse scored and analysed using Statistical Package for Social Sciences (SPSS) (version 24). The data were checked for linearity, homogeneity of variance, normality and for outliers. Upon initial inspection the variable "frequency of phone checking having awoken from sleep" had a large skewness value which exceeded 1.96 (the value at which the deviation from normality is significant, Field 2016) (seen in Table 7). A log transformation was performed. The skewness value after the transformation of data showed that the data were more normally distributed. The skewness and kurtosis values of the original variable and the log transformed variables can been seen in Table 7.

Table 7 Skewness and kurtosis values for frequency of phone checking having awoken from sleep and when the variables were logarithmic transformed (n = 150)

Variable	Skewness value	Kurtosis value	Log transformed Skewness value	Log transformed Kurtosis value
FOPC	3.95 ± .15	17.65 ± .29	1.94 ± .20	3.2 ± .39

Note: FOPC = frequency of phone checking having awoken from sleep

The subscale means and standard deviations from each questionnaire were compared against one another. Some of the questionnaires had different numbers of items loading on to the subscales, for example the smartphone usage scale had 10 items in comparison to Facebook friendships which had 2 items. The mean and standard deviation of a subscale with more items will always be larger than one with fewer items and so the two subscales cannot be accurately compared. Standardised means and standardised standard deviations were calculated to allow a comparison between the subscales. Subscale values were divided by the number of items in that subscale. The mean and standard deviation of these subscale averages were then calculated. When questionnaire subscales consist of the same number of items, means and standard deviations have been compared.

4.3.6.1. Large sleep onset latency values

The sleep onset latency values obtained were larger than expected. The Diagnostic and Statistical Manual 5 criteria (American Psychological Association, 2013) reports that a symptom of insomnia is that the individual has a long sleep onset latency (> 30 minutes). Weekday sleep onset latency values ranged between 0 – 9:00 and weekend sleep onset latency values ranged between 0 – 11:00. Stem and leaf diagrams indicated that values > 2.3 hours and > 2.4 hours for weekday and weekend respectively were outliers. After removing these outliers, 34.4% of participants responded with a value > 30 minutes for weekday sleep onset latency and 27.1% responded with a value > 30 minutes for weekend sleep onset latency. It is possible that these participants assumed the question was asking them how long they spend in bed before they go to sleep. If this is the case, then these participants misunderstood what the question was asking and so the wording of the sleep onset latency question will be slightly altered in the following studies.

4.3.6.2. Bivariate correlations

Bivariate correlations were conducted to examine the direct associations between device usage variables and the weekday and weekend sleep variables. Once bivariate correlations had been conducted, hierarchical linear regressions were conducted to understand which variables predicted weekday and weekend sleep.

4.3.6.3. Hierarchical Linear Regressions

The hierarchical linear regressions were used to examine whether electronic device usage explained a significant proportion of unique variance as several other health risk factors were also included in the model. Hierarchical multiple linear regressions were used so that the variables “sex” and “age” could be accounted for in the first model. The remaining variance was then explained using the additional predictors used in the second model. Hierarchical ordinal logistic regressions were used to explain the variance within sleep quality and waking feeling refreshed. The models were used to predict weekday and weekend sleep variables and the models were determined using the factors identified by Royal College of Paediatric and Child Health (2017) and Bartel et al (2015) systematic review.

The model was constructed as follows:

Model 1: sex and age

Model 2: social media, smartphone usage / internet usage, emailing, media sharing, anxiety and dependence on electronic device, TV viewing / phone calling / texting, technological friendships and video gaming; (log) frequency of phone checking having awoken from sleep; HADS - anxiety and HADS– depression; BMI; school day start time, school day end time.

4.4. Results

This results section has been split into three sections. The first section will describe the characteristics of the participants. The second section will examine whether adolescents' weekday and weekend sleep are different to one another. The final section will then examine whether electronic device usage impacts sleep.

4.4.1. Adolescents frequently used their devices to text and search the internet and were anxious

This subsection will describe the participant's characteristics on the demographic questions, Media and Technology scale (Rosen et al, 2013), other technology questions (Rosen et al, 2016) and on the Hospital Anxiety and Depression scale (Zigmond & Snaith, 1983). The descriptive statistics for Adolescent Sleep Hygiene scale (LeBourgeois et al, 2005), Behavioural Inhibition System- Behavioural Activation System (Carver & White, 1994) and Munich Chronotype Questionnaire for Children (Roenneberg et al, 2003) can be found in the appendices as they were not used in the hierarchical linear regression model used in this study. The descriptive statistics for the Cleveland Adolescent Sleepiness Questionnaire-modified (Cleveland et al, 2007) and subjective sleep questions will be report in the following subsection as these questions asked specifically about weekday and weekend sleep schedules.

4.4.1.1. Demographic

Table 8 shows that participants were on average 15.11 years old (SD = 1.97), had an average BMI of 20.15 (SD = 3.91), started school at 08:56 (SD = 00:23), spent 00:23 (SD = 00:20) at school before classes began, finished school at 15:42 (SD = 00:55) and spent 00:14 (SD = 00:39) at school after classes had finished. The table also shows the demographics of participants by their completion status.

Table 8 Mean (M) and standard deviations (SD) for adolescents' demographics (n = 274)

Variable	M ± SD [hh:mm]	Complete responses (n = 228)	Incomplete responses (n = 177)
Age	15.11 ± 1.97	15.11 ± 1.97	14.98 ± 1.76

School start time	8.94 ± 0.39 [08:56 ± 00:23]	8.76 ± 0.34 [08:46 ± 00:20]	8.8 ± 0.4 [08:48 ± 00:24]
School end time	15.7 ± 0.91 [15:42 ± 00:55]	15.8 ± 0.85 [15:48 ± 00:51]	15.64 ± 0.71 [15:38 ± 00:31]
Time at school before classes	0.38 ± 0.34 [00:23 ± 00:20]	0.35 ± 0.33 [00:21 ± 00:20]	0.4 ± 0.3 [00:24 ± 00:18]
Time at school after classes	0.23 ± 0.65 [00:14 ± 00:39]	0.21 ± 0.45 [00:13 ± 00:27]	0.15 ± 0.57 [00:13 ± 00:34]
BMI	20.15 ± 3.91	19.16 ± 4.05	21.1 ± 2.03

4.4.1.2. Media and Technology usage

Table 9 shows the means, standard deviations, standardised means and standardised standard deviations for the Media and Technology subscales. Table 9 shows that participants used online friendships the least, followed by media sharing, followed by tv viewing, followed by general social media usage, followed by email, followed by video gaming, followed by phone calling, followed by internet searching, followed by text messaging, and finally smartphone usage was used most frequently.

Table 9 Mean (M), standard deviation (SD), standardised mean (Std. M) and standardised standard deviation (Std. SD) for Media and Technology usage scale (n = 244)

Variable	M ± SD	Std. M ± Std. SD
Email use	17.25 ± 8.09	4.31 ± 2.02
Text Messaging	17.60 ± 5.23	5.87 ± 1.74
Phone Calling	8.95 ± 3.77	4.47 ± 1.88
Smartphone Usage	53.77 ± 13.88	5.97 ± 1.54
TV Viewing	8.44 ± 4.54	4.22 ± 2.27
Media Sharing	13.51 ± 7.53	3.38 ± 1.88
Internet Searching	23.23 ± 8.62	5.81 ± 2.15
Video Gaming	12.68 ± 7.49	4.33 ± 1.96
General Social Media Usage	38.97 ± 17.67	4.23 ± 2.50
Facebook Friendships	8.81 ± 3.96	4.41 ± 1.98
Online Friendships	3.75 ± 2.24	1.88 ± 1.12

4.4.1.3. Phone location and frequency of phone use after falling asleep

Two hundred and ninety three participants responded to the question asking where participants leave their phone during the night, 4.4% said they leave their phone “under their pillow”, 3.5% said they leave their phone “on my bed”, 30.1% said they leave their phone “Next to my bed”, 15.3% said they leave their phone “In my bedroom but not next to my bed”, 18.3% said they leave their phone “In another room” and 0.7% said “Other”. Two hundred and ninety-three participants responded to the question asking how frequently they check their phone during the night having awoken from sleep, 58.5% of participants said “Never”, 8.4% said “Once”, 3% said “Two times”, 0.7% said “Three times”, 0.5% said “4 - 5 times” and 1.2% said “6 – 8 times”. Nobody responded with “8+ times”.

4.4.1.4. Anxiety and Depression

As can be seen in Table 10, participants had an average anxiety score of 10.58 (SD = 5.16), which indicated that participants were borderline anxious. Participants had an average depression score of 6.29 (SD = 5.09), which indicated that participants were not depressed. The table also shows the proportion of participants who were categorised as 'normal' (score = 0 – 7), 'borderline' (score = 8 – 10) and 'abnormal' (score = 11 – 21).

Table 10 Mean (M), Standard Deviation (SD) and proportions of participants in the three categories of the Hospital Anxiety and Depression Scale (n = 248)

Variable	M ± SD	Normal %	Borderline%	Abnormal%
Anxiety	10.58 ± 5.16	31.5%	24.1%	44.4%
Depression	6.29 ± 5.09	73.4%	8.1%	18.5%

4.4.2. Adolescents had a better quality of sleep, slept later, woke later, and slept for a longer period of time at the weekend

As can be seen in Table 11, adolescents had a better quality of sleep (Figure 2A), woke feeling more refreshed (Figure 2B), fell asleep quicker, went to bed later (Figure 2C), woke up later (Figure 2D) the following morning, spent a longer time in bed and spent a longer time asleep (Figure 2E) on weekends than on weekdays.

Table 11: Mean (M) and standard deviation (SD) for self-reported sleep variables (n = 306)

Variable	Weekday M ± SD [hh:mm]	Weekend M ± SD [hh:mm]	Paired sample t-test
Sleep quality	**3.68 ± 1.37**	**2.69 ± 1.45**	**t(305) = 10.47, p < 0.001**
Waking feeling refreshed	**4.39 ± 1.59**	**2.98 ± 1.51**	**t(305) = 13.45,p < 0.001**
Sleep onset latency	0.58 ± 0.47 [00:35 ± 00:28]	0.53 ± 0.49 [00:32 ± 00:29]	t(305) = 2.11, p = 0.036
Bedtime	**22.29 ± 1.13 [22:17 ± 01:08]**	**23.30 ± 1.29 [23:18 ± 01:17]**	**t(305) = - 17.48, p < 0.001**
Wake time	**30.88± 0.62 [06:53 ± 00:37]**	**33.17 ± 1.62 [09:10 ± 01:37]**	**t(305)= - 24.43, p < 0.001**
Time in bed	**8.58 ± 1.14 [08:35 ± 01:08]**	**9.87 ± 1.51 [09:52 ± 01:31]**	**t(306)= - 14.33, p < 0.001**
Sleep duration	**8.01± 1.21 [08:01 ± 01:13]**	**9.34 ± 1.57 [09:20 ± 01:34]**	**t(305) = - 14.54, p < 0.001**

Note: results which are significant at p < 0.05 are *italicised*; results which are significant at p < 0.001 are in **bold**.

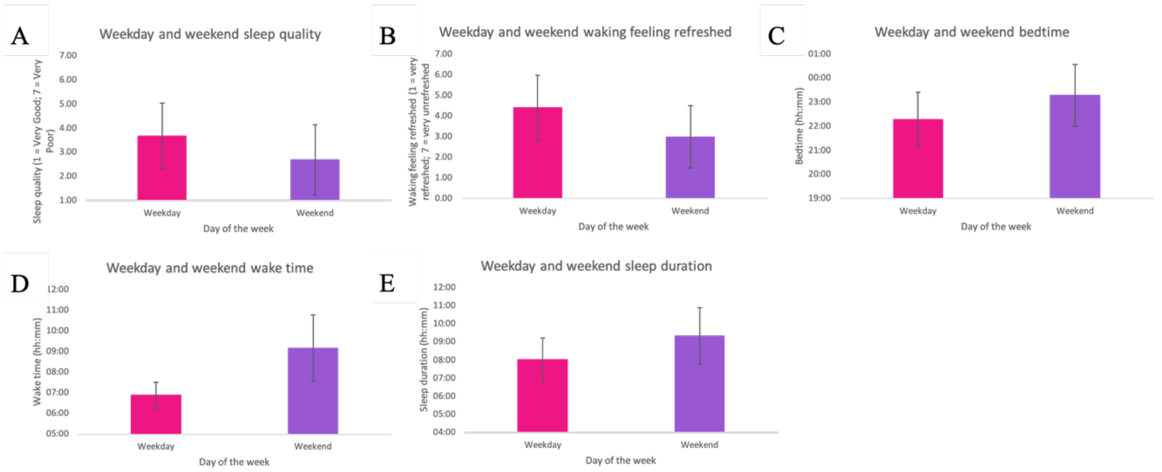

Figure 2 (A) Mean weekday and weekend sleep quality; (B) Mean weekday and weekend waking feeling refreshed scores; (C) Mean weekday and weekend bedtime; Mean weekday and weekend wake time; (E) Mean weekday and weekend sleep duration. Error bars ± SD

Table 12 shows that adolescents felt more alert at the weekend than they did on weekdays, but that they felt more sleepy at the weekend than they did on weekdays.

Table 12: Mean (M), standard deviation (SD), standardised mean (Std. M), standardised standard deviation (Std. SD) and paired sample t-tests for Cleveland Adolescent Sleepiness Questionnaire- Modified (n = 281)

Variable	Weekday M ± SD	Weekday Std. M ± Std. SD	Weekend M ± SD	Weekend Std. M ± Std. SD	Paired sample t-test
Sleepiness	**6.78 ± 3.16**	**1.36 ± 0.63**	**7.91 ± 3.39**	**1.58 ± 0.68**	**t(280) = - 5.24, p < 0.001**
Alertness	**15.53 ± 4.83**	**3.11 ± 0.97**	**13.07 ± 4.63**	**2.61 ± 0.93**	**t(280) = 8.86, p < 0.001.**
Sleepiness on weekday evenings	8.08 ± 2.75	2.69 ± 0.92	-	-	-

Note: A lower value indicates less sleepiness and more alertness; results which are significant at p < 0.001 are in **bold**.

This section has shown that weekday and weekend sleep are very different to one another. Adolescents go to bed later, wake later, have a better quality of sleep, wake feeling more refreshed, spend a longer time asleep and are more alert at the weekend than they are on weekdays. Thus, it is expected that weekday and weekend sleep will be explained differently too.

4.4.3. Adolescents who frequently used electronic device had a poorer quality of sleep and woke feeling less refreshed

Bivariate correlations were conducted to observe the relationship between device usage and sleep variables. Figure 3 shows the relationships between the self-report sleep variables and the electronic device usage variables. The correlations matrix shows that adolescents who: frequently email, frequently use their smartphone, frequently shared media and had many Facebook friends went to bed later, spent a shorter time in bed and spent a shorter time asleep on weekdays. This suggests that adolescents were using their smartphone to interact with their friends before they went to sleep, and this delayed the time they went to bed and shortened the time they spent asleep. Adolescents who had more virtual friends and frequently surfed the internet went to bed later and spent a shorter time in bed on weekdays. Adolescents who frequently used their phone to text spent a shorter time in bed and spent a shorter time asleep on weekdays.

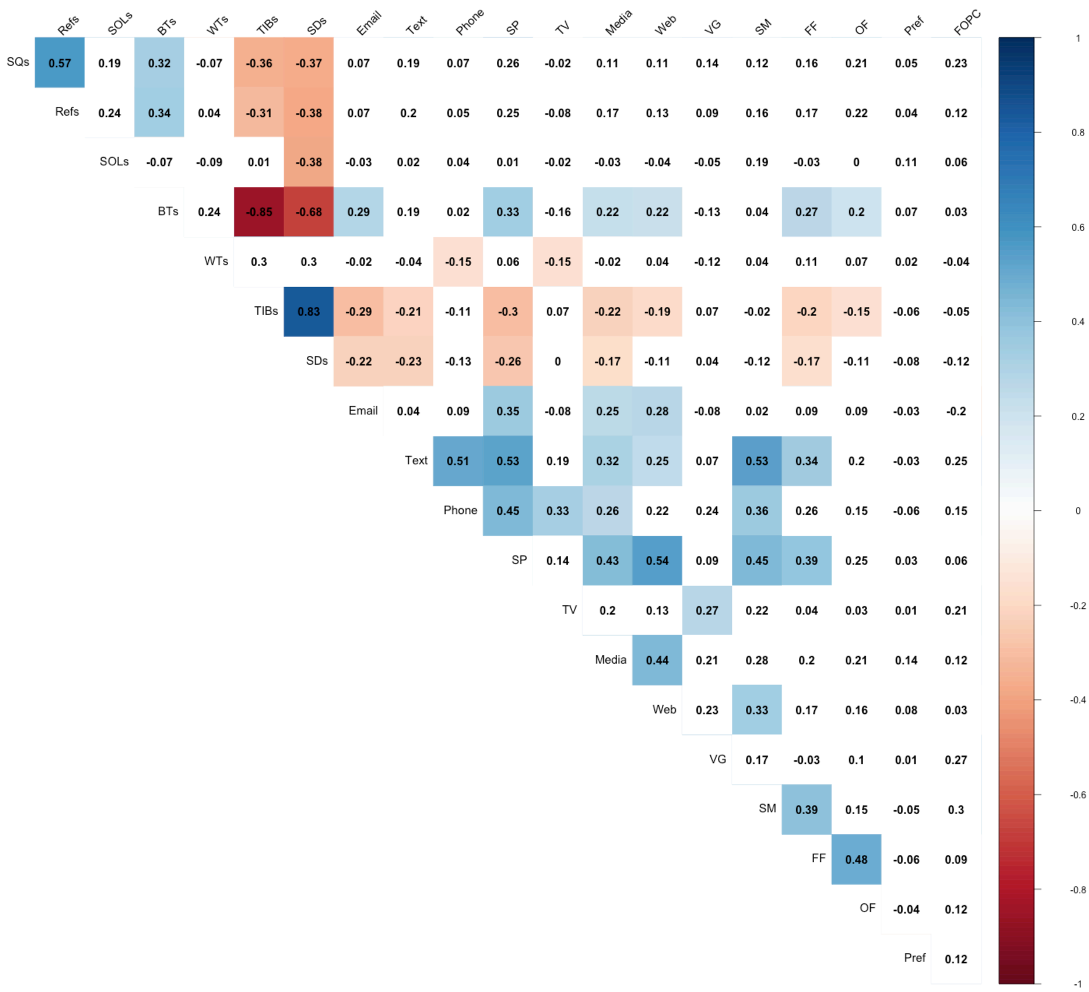

Figure 3 Correlation matrix showing the relationships between weekday self-report sleep questions and the electronic device usage variables.

Note: Significant values ($p < 0.05$) are shaded blue or red. Values which are shaded blue are positive correlations, values which are shaded red are negative correlations; the depth of colour indicates the strength of the correlation. SQs = Weekend sleep quality, Refs = Weekend waking feeling refreshed, SOLs = Weekend sleep onset latency, BTs = Weekend bedtime, WTs = Weekend wake time, TIBs = Weekend time in bed, SDs = Weekend sleep duration, Email = email use, Text = text messaging use, Phone= phone calling use, SP = smartphone usage, TV = TV viewing, Media = Media sharing use, Web = Internet searching usage, VG = Video gaming use, SM = General social media usage, FF = Facebook friendships, OF = Online friendships, Pref = Preference for task switching.

Figure 4 shows the relationships between weekend self-report sleep variables and the electronic device usage variables. Adolescents who frequently used their phone to text and frequently used their smartphone went to bed later, spent a shorter time in bed and spent a shorter time asleep on weekends. It is perhaps more interesting that adolescents who frequently texted and used their smartphone spent a shorter time asleep on weekends as well. In addition, adolescents who frequently shared media on their phone spent a shorter time in bed and spent a shorter time asleep on weekends.

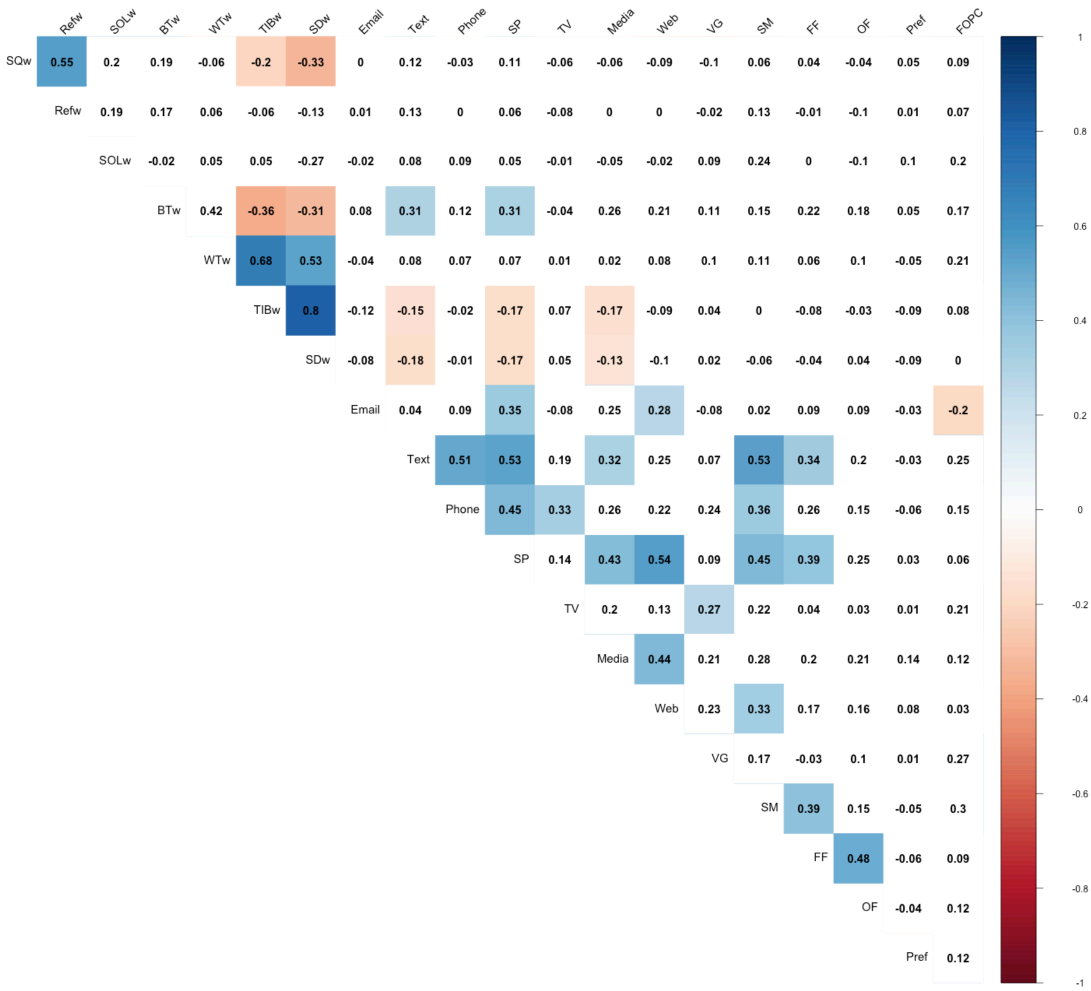

Figure 4 Correlation matrix showing the relationships between weekend self-report sleep questions and the electronic device usage variables.

Note: Significant values (p < 0.05) are shaded blue or red. Values which are shaded blue are positive correlations, values which are shaded red are negative correlations; the depth of colour indicates the strength of the correlation; SQw = Weekend sleep quality, Refw = Weekend waking feeling refreshed, SOLw = Weekend sleep onset latency, BTw = Weekend bedtime, WTw = Weekend wake time, TIBw = Weekend time in bed, SDw = Weekend sleep duration, Email = email use, Text = text messaging use, Phone= phone calling use, SP = smartphone usage, TV = TV viewing, Media = Media sharing use, Web = Internet searching usage, VG = Video gaming use, SM = General social media usage, FF = Facebook friendships, OF = Online friendships, Pref = Preference for task switching.

The correlations matrices have shown the relationships between the self-reported sleep variables and the electronic device usage variables. Hierarchical linear regressions were then conducted to ascertain whether electronic device usage still predicted weekday and weekend sleep when other variables such as age, sex, anxiety, and depression were included in the model.

Table 13 provides an overview of the hierarchical linear regression models and hierarchical ordinal regression models. R^2, Adjusted R^2, F statistics, p values and AIC are indicated for all of the models. The following section will concentrate on reporting, interpreting, and comparing the following models: sleep quality, waking feeling refreshed and bedtime for both weekday and weekend.

Table 13 : Overview of hierarchical linear regressions models, R^2, Adjusted R^2, F statistics and p – values for model 1 and model 2 with significant predictors indicated.

	SQ_s	SQ_w	Ref_s	Ref_w	SOL_s	SOL_w	BT_s	BT_w	WT_s	WT_w	TIB_s	TIB_w	SD_s	SD_w	SAS	SAW	AAS	AAW	SIE
Model 1	AIC = 1191.19	AIC = 1173.56	AIC = 1259.65	AIC = 1202.46	R^2 = 0.02, Adj R^2 = -0.004, F(2,136)= 0.73, p = 0.48	R^2 = 0.01, Adj R^2 = 0.00, F(2,134)= 1.03, p = 0.36	**R^2 = 0.22, Adj R^2 = 0.204, F(2,144) = 19.68, p < 0.001**	**R^2 = 0.1, Adj R^2 = 0.84, F(2,144)= 87.69, p = 0.001**	R^2 = 0.03, Adj R^2 = 0.02, F(2,144)= 2.46, p = 0.09	R^2 = 0.02, Adj R^2 = 0.007, F(2,144)= 1.53, p = 0.22	**R^2 = 0.11, Adj R^2 = 0.101, F(2,144)= 9.23, p < 0.001**	**R^2 = 0.13, Adj R^2 = 0.121, F(2,144)= 11.06, p < 0.001**	**R^2 = 0.07, Adj R^2 = 0.056, F(2,143) = 5.27, p = 0.006**	**R^2 = 0.08, Adj R^2 = 0.068, F(2,143)= 6.30, p = 0.002**	**R^2 = 0.06, Adj R^2 = 0.048, F(2,144)= 4.67, p = 0.01**	R^2 = 0.02, Adj R^2 = 0.004, F(2,146)= 1.29, p = 0.28	**R^2 = 0.1, Adj R^2 = 0.082, F(2,144)= 7.55, p = 0.001**	**R^2 = 0.07, Adj R^2 = 0.053, F(2,143)= 5.09, p = 0.007**	**R^2 = 0.07, Adj R^2 = 0.061, F(2,145)= 5.80, p = 0.004**
Sex							✓	✓			✓	✓	✓	✓	✓		✓	✓	
Age							✓	✓			✓	✓	✓	✓	✓		✓	✓	✓
Model 2	AIC = 501.31	AIC = 516.62	AIC = 533.28	AIC = 541.29	R^2 = 0.15, Adj R^2 = 0.031, F(15,123)= 1.29, p = 0.22	R^2 = 0.11, Adj R^2 = 0.059, F(15,121) = 1.57, p = 0.093	**R^2 = 0.28, Adj R^2 = 0.188, F(16,130)= 3.12, p < 0.001**	**R^2 = 0.2, Adj R^2 = 0.097, F(16,130)= 1.98, p = 0.02**	R^2 = 0.16, Adj R^2 = 0.06, F(16,130)= 1.59, p = 0.08	R^2 = 0.14, Adj R^2 = 0.032, F(16,130)= 1.30, p = 0.21	R^2 = 0.15, Adj R^2 = 0.042, F(16,130)= 1.40, p = 0.15	**R^2 = 0.21, Adj R^2 = 0.11, F(16,130)= 2.13, p = 0.01**	R^2 = 0.16, Adj R^2 = 0.053, F(16,129)= 1.5, p = 0.11	R^2 = 0.13, Adj R^2 = 0.027, F(16,129)= 1.25, p = 0.24.	**R^2 = 0.28, Adj R^2 = 0.192, F(16,130)= 3.16, p < 0.001**	**R^2 = 0.14, Adj R^2 = 0.104, F(16,130)= 2.06, p = 0.014**	**R^2 = 0.33, Adj R^2 = 0.248, F(16,130)= 4.01, p < 0.001**	**R^2 = 0.27, Adj R^2 = 0.18, F(16,129)= 2.99, p < 0.001**	**R^2 = 0.30, Adj R^2 = 0.224, F(15,132)= 3.84, p < 0.001**
Sex																			
Age							✓	✓			✓	✓							
Social media																			
Smartphone / internet																			
Email			✓																✓
Media sharing																			

Anxiety and dependence on electronic device																	✓		✓
TV/ phone calling /texting																			
Technological friendships	✓														✓				
Video gaming																✓		✓	
FOPC	✓	✓	✓												✓	✓		✓	
HADS- anxiety	✓		✓														✓		
HADS- depression																			
BMI															✓		✓		✓
School start time																			✓
School end time																			

Note: $_s$ = weekday and $_w$ = weekend; SQ = sleep quality, Ref = Waking feeling refreshed, AOL = sleep onset latency, BT = bedtime, WT = wake time, TIB = time in bed, SD = sleep duration, SAS = sleepiness at school, SAW = sleepiness at the weekend, AAS = alertness at school, AAW = alertness at the weekend, SIE = sleepiness in the evening. Predictors for the significant models are identified with ✓ = significant predictor for the model. Models which were not significant ($p < 0.05$) do not have significant predictors. Boxes have been left blank to show that a variable is not a significant predictor. Significant models are in **bold**.

Frequent device usage may impact the time an adolescent goes to bed. Using electronic devices may directly displace adolescents' sleep as they end up going to bed later. This is particularly problematic on weekdays when their wake time is restricted by the school schedule. Device use may therefore impact the time that an adolescent goes to bed. As can be seen in Table 13, Model 1 was a significant model of weekday bedtime, explaining 20.4% of the variance observed in weekday bedtime $R^2 = 0.22$, Adj $R^2 = 0.204$, $F(2,144) = 19.68$, $p < 0.001$. Model 2 predicted 18.8% of the variance observed in weekday bedtime $R^2 = 0.28$, Adj $R^2 = 0.188$, $F(16,130)= 3.12$, $p < 0.001$. Older adolescents went to bed later on weekdays than younger adolescents. Table 14 indicates the unstandardized beta values, standard error, standardised beta values and p values for all of the predictors analysed.

Table 14 Hierarchical linear regression for the health risk factors predicting weekday bedtime (n = 146)

Model	Predictor	Unstandardised B	Std. Error	β	p value
1	(Constant)	18.22	0.68		0.00
	Sex	0.04	0.16	0.02	0.79
	Age	**0.27**	**0.04**	**0.46**	**< 0.001**
2	(Constant)	14.47	3.28		0.00
	Sex	0.05	0.20	0.02	0.80
	Age	**0.24**	**0.06**	**0.41**	**< 0.001**
	Social Media	0.05	0.09	0.05	0.55
	Smartphone / Internet	0.00	0.09	0.00	0.99
	Email	-0.01	0.11	-0.01	0.94
	Media Sharing	-0.01	0.08	-0.01	0.91
	Anxiety and Dependence on Technology	-0.14	0.09	-0.13	0.12
	TV/ Phone calling /Texting	0.08	0.09	0.07	0.40
	Technological Friendships	-0.12	0.09	-0.11	0.19
	Video Gaming	0.01	0.11	0.01	0.93
	FOPC	0.54	0.50	0.09	0.28
	HADS- Anxiety	-0.02	0.02	-0.09	0.47
	HADS- Depression	0.03	0.03	0.16	0.24
	BMI	-0.01	0.02	-0.03	0.73
	School Start Time	0.46	0.33	0.16	0.17
	School End Time	0.01	0.16	0.01	0.94

Note: FOPC: frequency of phone checking having awoken from sleep; significant predictors are in **bold**.

As can be seen in Table 13, model 1 (sex and age) was also a significant model of weekend bedtime. Sex and age explained 8.4% of the variance observed in weekend bedtime $R^2 = 0.1$**,** Adj $R^2 = 0.84$, $F(2,144)= 87.69$, $p = 0.001)$. Model 2 predicted 9.7% of the variance observed in weekend bedtime $R^2 = 0.2$**,** Adj $R^2 = 0.097$, $F(16,130)= 1.98$, $p = 0.02$. Older adolescents went to bed later on weekends. This finding shows that as adolescents get older, they go to bed later. Table 15 indicates the unstandardized beta values, standard error, standardised beta values and p values for all predictors analysed.

Table 15 Hierarchical linear regression for the health risk factors predicting weekend bedtime (n = 146)

Model	Predictor	Unstandardised B	Std. Error	β	p value
1	(Constant)	20.06	0.95		0.00
	Sex	-0.21	0.22	-0.08	0.35
	Age	**0.24**	**0.06**	**0.32**	**< 0.001**
2	(Constant)	14.20	4.47		0.00
	Sex	-0.30	0.27	-0.11	0.26
	Age	**0.19**	**0.08**	**0.25**	**0.02**
	Social media	-0.02	0.12	-0.01	0.86
	Smartphone / internet	0.03	0.12	0.02	0.79
	Email	0.22	0.15	0.15	0.13
	Media sharing	-0.14	0.11	-0.10	0.21
	Anxiety and dependence on electronic device	-0.15	0.12	-0.11	0.24
	TV/ phone calling /texting	-0.04	0.12	-0.03	0.74
	Technological friendships	-0.04	0.12	-0.02	0.78
	Video gaming	0.06	0.14	0.04	0.66
	FOPC	1.29	0.69	0.16	0.06
	HADS- anxiety	-0.02	0.03	-0.09	0.49
	HADS- depression	0.04	0.04	0.18	0.20
	BMI	0.02	0.03	0.05	0.55
	School start time	0.45	0.45	0.12	0.32
	School end time	0.14	0.22	0.07	0.54

Note: FOPC: frequency of phone checking having awoken from sleep; significant predictors are in **bold**.

Electronic device usage may also impact adolescents' sleep quality. Woods and Scott (2016) showed that adolescents who frequently used electronic devices in an evening had a poorer quality of sleep on weekdays. Thus, adolescents who use their devices more frequently may also have a poorer quality of sleep. As seen in Table 13, model 2 (AIC = 501.31) is a better model of adolescents' sleep quality on weekdays than model 1 (AIC = 1191.19) (sex and age). Additional variables were included in model 2 to examine the impact of electronic device usage, the school schedule and health risk factors on the quality of sleep individuals had on weekdays. Adolescents who frequently checked their mobile phone during the night were 2.66 times more likely to have a poorer quality of sleep on weekdays. Adolescents who were anxious were 1.12 times more likely to have a poorer quality of sleep on weekdays. Adolescents who had fewer technological friendships were more likely to have a poorer quality of sleep on weekdays. Log odds, exponentiated coefficients, standard error, t-values, p values and confidence intervals are shown in Table 16.

Table 16 Hierarchical linear regression for the health risk factors predicting weekday sleep quality (n = 146)

		Log odds	Exp coef	Std. Error	t value	p value	2.5 CI	97.5 CI
Model 1								
	Intercept (1:2)	-0.53		0.70	-0.76	0.45		
	Intercept (2:3)	0.98		0.68	1.44	0.15		
	Intercept (3:4)	2.12		0.69	3.08	0.00		
	Intercept (4:5)	3.35		0.70	4.77	0.00		
	Intercept (5:6)	4.71		0.72	6.52	0.00		
	Intercept (6:7)	6.17		0.78	7.87	0.00		
	Sex (1 = Male; 2 = Female)	-0.07	0.93	0.18	-0.37	0.71	- 0.42	0.29
	Age	**0.17**	**1.18**	**0.05**	**3.57**	**< 0.001**	**0.08**	**0.26**
Model 2	1|2	11.40		5.99	1.90	0.06		
	2|3	12.46		6.00	2.08	0.04		
	3|4	14.08		6.01	2.34	0.02		
	4|5	15.46		6.03	2.56	0.01		
	5|6	17.22		6.05	2.85	0.004		
	6|7	18.97		6.09	3.12	0.002		
	Sex	-0.30	0.75	0.36	-0.83	0.41	-1.0	0.40
	Age	0.14	1.15	0.11	1.34	0.18	-0.07	0.36
	Social media	0.09	1.09	0.15	0.56	0.57	-0.22	0.39
	Smartphone / internet	-0.07	0.93	0.17	-0.42	0.67	-0.41	0.26
	Email	0.07	1.08	0.19	0.392	0.70	-0.30	0.44
	Media sharing	-0.24	0.79	0.16	-1.55	0.12	-0.55	0.07
	Anxiety and dependence on electronic device	-0.11	0.90	0.17	-0.66	0.511	-0.43	0.21
	TV/ phone calling /texting	-0.01	0.99	0.16	-0.05	0.96	-0.33	0.31
	Technological friendships	**-0.33**	**0.72**	**0.16**	**-2.04**	**0.04**	**-0.65**	**-0.01**
	Video gaming	-0.22	0.80	0.20	-1.09	0.28	-0.62	0.18
	FOPC	**0.98**	**2.66**	**0.23**	**4.29**	**< 0.001**	**0.54**	**1.44**
	HADS- anxiety	**0.12**	**1.12**	**0.04**	**2.69**	**0.01**	**0.03**	**0.20**
	HADS- depression	0.003	1.00	0.05	0.06	0.96	-0.09	0.09
	BMI	0.06	1.06	0.04	1.42	0.16	-0.02	0.14
	School start time	0.50	1.64	0.60	0.83	0.41	-0.68	1.68
	School end time	0.30	1.35	0.29	1.04	0.30	-0.27	0.86

Note: FOPC: frequency of phone checking having awoken from sleep; significant predictors are in **bold**.

As seen in Table 13, model 2 (AIC = 516.62) was a better model of adolescents' sleep quality at the weekend than model 1 (AIC = 1173.56) (sex and age). Additional variables were included in model 2 to examine the impact of electronic device usage, the school schedule and health risk factors on the quality of sleep individuals had on the weekend. Adolescents who frequently checked their mobile phone during the night were 1.76 times more likely to have a poorer quality of sleep on weekends. Frequently checking their phone during the night leads to poorer weekday and weekend sleep quality. Log odds, exponentiated coefficients, standard error, t-values, p values and confidence intervals are shown in Table 17.

Table 17 Hierarchical linear regression for the health risk factors predicting weekend sleep quality (n = 146)

		Log odds	Exp coef	Std. Error	t value	p value	2.5 CI	97.5 CI
Model 1								
	Intercept (1:2)	1.0		0.69	1.44	0.15		
	Intercept (2:3)	2.28		0.71	3.23	0.001		
	Intercept (3:4)	3.14		0.72	4.40	< 0.001		
	Intercept (4:5)	4.08		0.73	5.62	< 0.001		
	Intercept (5:6)	4.95		0.74	6.65	< 0.001		
	Intercept (6:7)	6.99		0.92	7.63	< 0.001		
	Sex (1 = Male; 2 = Female)	0.18	1.19	0.18	0.97	0.33	-0.18	0.54
	Age	**0.13**	**1.14**	**0.05**	**2.81**	**0.01**	**0.04**	**0.23**
Model 2	1|2	-3.67		6.18	-0.59	0.55		
	2|3	-1.91		6.17	-0.31	0.76		
	3|4	-0.80		6.17	-0.13	0.80		
	4|5	0.28		6.17	0.05	0.96		
	5|6	1.33		6.18	0.22	0.83		
	6|7	3.76		6.26	0.60	0.55		
	Sex	-0.23	0.79	0.35	-0.65	0.51	-0.93	0.46
	Age	0.23	1.25	0.11	1.97	0.05	0.002	0.45
	Social media	-0.27	0.76	0.16	-1.71	0.09	-0.58	0.04
	Smartphone / internet	-0.06	0.94	0.17	-0.36	0.72	-0.39	0.26
	Email	0.04	1.04	0.22	0.19	0.85	-0.40	0.48
	Media sharing	0.12	1.12	0.16	0.73	0.46	-0.20	0.42
	Anxiety and dependence on electronic device	-0.19	0.83	0.17	-1.09	0.28	-0.53	0.15
	TV/ phone calling /texting	-0.10	0.90	0.17	-0.60	0.55	-0.43	0.23
	Technological friendships	-0.14	0.87	0.17	-0.87	0.39	-0.47	0.19
	Video gaming	0.32	1.37	0.19	1.65	0.10	-0.06	0.69
	FOPC	**0.56**	**1.76**	**0.23**	**2.42**	**0.02**	**0.11**	**1.03**
	HADS- anxiety	0.02	1.02	0.04	0.55	0.58	-0.06	0.11
	HADS- depression	0.02	1.02	0.05	0.32	0.75	-0.08	0.11
	BMI	-0.006	1.00	0.04	-0.15	0.88	-0.08	0.07
	School start time	< 0.001	1.00	0.62	< 0.001	1.00	-1.23	1.22
	School end time	-0.38	0.69	0.31	-1.23	0.22	-0.97	0.23

Note: FOPC: frequency of phone checking having awoken from sleep; significant predictors are in **bold**.

Device usage may also increase the number of times an adolescent wakes up during the night. Della Monica et al (2015) showed that the number of awakenings in a night was strongly correlated with how refreshed an individual felt in the morning. Adolescents who frequently check their phones during the night may therefore wake feeling less refreshed. Table 13 shows that model 2 (AIC = 533.38) was a better model of how refreshed adolescents felt upon waking on weekdays than model 1 (AIC = 1259.65). Additional variables were included in model 2 to examine the impact of electronic device usage, the school schedule and health risk factors on how refreshed adolescents felt upon waking on weekdays. Adolescents who frequently checked their mobile phone during the night were 1.73 times more likely to wake feeling less refreshed on weekdays. Adolescents who frequently emailed were 1.66 times more likely to wake feeling less refreshed on weekdays. Adolescents who were more anxious were 1.09 times more likely to wake feeling less refreshed on weekdays. Log odds, exponentiated coefficients, standard error, t-values, p values and confidence intervals are shown in Table 18.

Table 18 Hierarchical linear regression for the health risk factors predicting weekday waking feeling refreshed (n = 146)

		Log odds	Exp coef	Std. Error	t value	p value	2.5 CI	97.5 CI
Model 1								
	Intercept (1:2)	-0.32		0.70	-0.46	0.65		
	Intercept (2:3)	0.81		0.68	1.20	0.23		
	Intercept (3:4)	1.67		0.68	2.46	0.01		
	Intercept (4:5)	2.71		0.69	3.94	< 0.001		
	Intercept (5:6)	3.83		0.70	5.45	< 0.001		
	Intercept (6:7)	0.15		0.18	0.82	0.41		
	Sex (1 = Male; 2 = Female)	0.17	1.16	0.05	3.63	< 0.001	-0.21	0.50
	Age	-0.32	1.18	0.70	-0.46	0.65	0.08	0.26
Model 2	1|2	20.05		6.273	3.197	< 0.001		
	2|3	21.36		6.284	3.40	< 0.001		
	3|4	22.04		6.294	3.50	< 0.001		
	4|5	23.30		6.323	3.68	< 0.001		
	5|6	24.73		6.358	3.89	< 0.001		
	6|7	25.96		6.380	4.07	< 0.001		
	Sex	0.36	1.43	0.37	0.98	0.33	-0.36	1.08
	Age	0.04	1.04	0.11	0.39	0.70	-0.17	0.26
	Social media	0.06	1.07	0.16	0.41	0.68	-0.24	0.37
	Smartphone / internet	0.05	1.05	0.17	0.29	0.78	-0.28	0.38
	Email	0.51	1.66	0.20	2.55	0.01	0.12	0.90
	Media sharing	0.03	1.04	0.15	0.22	0.82	-0.27	0.33
	Anxiety and dependence on electronic device	-0.27	0.76	0.17	-1.64	0.10	-0.60	0.05
	TV/ phone calling /texting	0.05	1.06	0.17	0.32	0.75	-0.28	0.39
	Technological friendships	-0.16	0.85	0.17	-1.00	0.32	-0.49	0.16
	Video gaming	-0.19	0.82	0.19	-1.00	0.32	-0.57	0.19
	FOPC	**0.55**	**1.73**	**0.22**	**2.51**	**0.01**	**0.13**	**1.00**
	HADS- anxiety	**0.09**	**1.09**	**0.04**	**2.10**	**0.04**	**0.01**	**0.18**
	HADS- depression	0.06	1.06	0.05	1.20	0.23	-0.04	0.14
	BMI	0.05	1.05	0.04	1.23	0.22	-0.03	0.13
	School start time	0.15	3.17	0.61	1.88	0.06	-0.05	2.37

School end time	0.08	1.79	0.28	2.07	0.05	-0.03	0.12

Note: FOPC: frequency of phone checking having awoken from sleep; significant predictors are in **bold**.

There were no significant predictors of how refreshed adolescents felt upon waking at the weekend. This shows that how refreshed an adolescent feels upon waking on a weekend is dependent on other factors. Using electronic devices on a weekend night may not impact how refreshed the adolescent feels upon waking because they have the ability to self-determine their time they wake up at on a weekend and so they can sleep longer. These findings suggest that how refreshed an adolescent feels upon waking the following morning is, in part determined by the time they wake up at and length of time they spent asleep. Weekdays are restricted by the school schedule. Adolescents must still wake early for school the following morning despite not getting adequate sleep duration.

4.5. Discussion

The discussion of this study's results will be organised into six sections. Firstly, the purpose of the study will be re-described, secondly the study's results will be summarised, thirdly the results will be compared to previous research. Next, the strengths and weaknesses will be examined, followed by some improvements which will be made to the design of the study for study 2 and finally a conclusion will be reached about the findings of study 1.

4.5.1. The purpose of the study

This study had three main aims. The first aim of this study was to examine whether there were any quantitative differences in adolescents' sleep on weekdays and at the weekend. The study also aimed to examine whether the predictors for weekday sleep also explained weekend sleep. Thirdly, the study aimed to understand whether electronic device usage remained a predictor of poorer and shorter sleep even when other factors that are relevant to adolescents are examined simultaneously.

4.5.2. A summary of the study's results

The first purpose of this study was to understand whether weekday and weekend sleep differ from each other. Adolescents went to bed later, fell asleep quicker, woke up later, spent a longer time in bed, spent a longer time asleep, had a better quality of sleep, woke feeling more refreshed, felt sleepier and more felt more alert on weekends than on weekdays. Most of these findings were anticipated as they replicate findings from previous research (Allen and Mirable, 1989; Carskadon et al, 1998; Wahlstrom et al, 1997; Wahlstrom et al, 2014; Owens et al, 2010; Boergers et al, 2014; Chan et al, 2018). Their weekend wake time was over 2 hours later than their weekday wake time and they were getting almost 90 minutes more sleep at the weekend than during the week. These findings show that they were not getting enough sleep on weekdays and so repaid the sleep debt they had acquired by sleeping longer at the weekend. Adolescents also went to bed an hour later at the weekend than during the week. As discussed in the literature review (Chapter 1: An introduction to adolescents' sleep and device use) homeostatic sleep pressure increases whilst the individual is awake and dissipates as the individual sleeps. It is possible that adolescents fell asleep quicker on weekends because their homeostatic sleep pressure had risen. This has been observed in several sleep deprivation and sleep restriction studies (Jenni et al, 2005; Nelson et al, 2013). The findings also showed that adolescents were sleepier at the weekend than they were during the week. This finding was unexpected and appears to contradict the rest of the results. The findings show that adolescents went to bed later and woke up later at the weekend shows that they had irregular sleep/wake patterns. Adolescents who went to bed later at the weekend than they did during the week felt sleepier during the following day (Wolfson and Carskadon, 1998). Thus, the adolescents in the current study may have felt sleepier at the weekend than they did during the week because they had an irregular sleep/wake pattern. The current study's results have shown that adolescents' weekday and weekend sleep differ in quality, timing, and length. Therefore, both weekday and weekend sleep should be measured separately.

This study has also examined the extent to which electronic device usage predicted adverse sleep outcomes. Greater electronic device usage was correlated with adverse sleep outcomes. Adolescents who spent a longer time emailing, texting their friends, using their smartphone, surfing the web, sharing media, communicating with friends online went to bed later, spent a shorter time in bed and spent a shorter time asleep on weekdays than adolescents who did not spend as long on devices. Interestingly, weekend sleep was affected differently. Adolescents who spent a longer time texting their friends or on their smartphone went to bed later, spent a longer time in bed and spent a longer time asleep at the weekend. The biggest difference between adolescents' weekday and weekend sleep is that they have much more freedom to self-select the time they go to bed and, more importantly, wake up on weekends. This means that if they have used a device before going to sleep at the weekend then they are able to compensate for the sleep they have lost by waking later the following morning. This is not possible during the week as they must wake and rise for the school day. The hierarchical linear regressions, which incorporated other factors relevant to adolescents, showed that adolescents who frequently checked their mobile phone during the night woke feeling less refreshed on weekdays, had a poorer quality of sleep on weekdays and had a poorer quality of sleep on weekends. These findings support the previous argument that electronic device usage affects weekday sleep to a larger extent than weekend sleep. It also suggests that weekday and weekend sleep are explained differently too.

The hierarchical linear regressions also showed that weekday sleep quality was further predicted by adolescents feeling anxious and having fewer technological friendships. Adolescents who felt anxious, frequently checked their phone during the night and had fewer technological friendships had a poorer quality of sleep on weekdays. Similarly, adolescents who felt anxious, frequently checked their phones during the night and frequently used their emails woke feeling less refreshed on weekdays. There was no explanation as to why adolescents woke feeling less refreshed at the weekend. Anxious adolescents had a poorer weekday sleep quality and woke feeling less refreshed on weekdays, yet they did not have a poorer weekend sleep quality or wake feeling less refreshed at the weekend. This suggests that a factor which is specific to the weekday increased adolescents' anxieties. As weekday sleep quality was also predicted by fewer technological friendships, it is probable that adolescents were anxious of remaining in touch with their peers on school nights, which led to poorer weekday sleep quality. As weekday waking feeling refreshed was also predicted by greater email use, it is probable that adolescents were anxious of missing out on conversations which made them wake feeling less refreshed on weekdays. Adolescents may frequently check their phone during the night on weekends because they know they can delay the time they wake up at the following morning whereas adolescents seem to frequently check their phone during the night on weekdays because they feel anxious that they will miss out on conversations with their friends. This further supports the argument that adolescents' weekday and weekend sleep are explained by different factors.

Older adolescents went to bed later on weekdays and weekends. Whilst age predicted both weekday and weekend bedtimes, the true explanations behind these findings are likely to be substantially different to each other. Older adolescents may have later weekday bedtimes because they are less dependent on their parents putting them to bed. Carskadon (1990) showed that over 50% of 10-year-olds had their weekday bedtimes determined by their parents, in comparison to 19% of 13-year-olds. Moreover, older adolescents' homeostatic sleep pressure accumulates at a slower rate than younger adolescents (Jenni et al, 2005). This means that older adolescents will feel sleepy at a later time and so they are able to delay the time they go to bed. Older adolescents have the opportunity to use their devices for a longer period of time in the evening, which may further delay the time they go to bed. Older adolescents are given much more freedom to socialise with their friends and go to evening parties at the weekend. It is not uncommon for adolescents to drink alcohol or take other drugs at these parties too. Thus, it is possible that older adolescents went to bed later at the weekend because they stayed out later with their friends and consume substances. Both of these explanations would displace and disrupt their sleep and further support the argument that weekday and weekend sleep are explained by different predictors.

In summary, the results have shown that adolescents who used electronic devices more frequently woke feeling less refreshed on weekdays and they had a poorer quality of sleep on weekdays and at the weekend. It is unclear how or why older adolescents went to bed later on weekdays and at the weekend. This may be clearer by examining whether the time an individual puts their devices down impacts the time they go to bed. The measure of electronic device use will be improved upon for study 2 to establish whether older adolescents use their devices later in the evening.

4.5.3. How do the study's results fit with previous research?

This study has found that adolescents went to bed later, wake up later, spend a shorter period of time in bed, spend a shorter period of time asleep, have a better quality of sleep and wake feeling more refreshed on weekends than they do on weekdays. These results have replicated previous findings (Allen and Mirable, 1989; Carskadon et al, 1998; Wahlstrom et al, 1997; Wahlstrom et al, 2014; Owens et al, 2010; Boergers et al, 2014; Chan et al, 2018).

This study also found that adolescents who were more anxious and who used devices more frequently had a poorer quality of sleep on weekdays. This finding is consistent with Woods and Scott (2016). They reported that adolescents who were more anxious and who used devices later in the evening had a poorer quality of sleep. The current study's findings suggest that adolescents were frequently checking their phone during the night as they were anxious of staying in touch with their few friends at school. This was probably because they wanted to ensure they could join in with the conversations at school the following day. Woods and Scott's findings suggest that adolescents continued to use social media late in the evening because they too were anxious that they would miss out on conversations with their friends. Both of the study's findings show that adolescents feel anxious about keeping in touch with their friends in the evening and so they will either delay the time they go to sleep at, or they will frequently check their phone during the night to make sure they have not missed out on anything.

The current study also found that adolescents who were anxious, frequently checked their phone during the night and frequently used emails woke feeling less refreshed on weekdays. These findings support Shen et al (2018) findings which showed that adolescents who had a poorer quality of sleep had worse mood. Shen and colleagues devised their measure of sleep quality using several sleep parameters. One of these parameters was how refreshed the individual felt on the following morning. Taken together these findings show that anxious individuals wake feeling less refreshed the following morning. The current study's findings suggest that adolescents are reliant on using and checking their phone to stay in contact with their friends. These findings suggest that using devices frequently in the night induces a state of high arousal which leads to adverse sleep outcomes.

Older adolescents had later weekday and weekend bedtimes. This supports Carskadon and colleagues work, which has consistently shown that older adolescents went to bed later on both weekdays and at the weekend (Wolfson and Carskadon, 1998; Carskadon, 1990; Owens et al, 2010; Boergers et al, 2014). Older adolescents have a greater opportunity to expose themselves to the adverse effects of devices as their homeostatic sleep pressure increases at a slower rate than it does for younger adolescents (Jenni et al, 2005). The current study should have measured electronic device use by asking adolescents to report the time they began and finished using a device in an evening as this would have established whether older adolescents were using their devices later in the evening than the younger adolescents.

The current findings have shown that adolescents have a later sleep timing, sleep longer, have a better quality of sleep and wake feeling more refreshed at the weekend in comparison to during the week. Technology usage has been shown to negatively impact adolescents' sleep quality and how refreshed they feel upon waking the following morning.

4.5.4. Evaluation of the study

This study has examined whether electronic device usage predicts weekday and weekend sleep. Previous work has examined the impact of electronic device usage on sleep without considering the impact of other factors that are relevant to adolescents. This study has shown that electronic device usage remains a risk factor for adolescents' sleep and shows that device usage mainly affects weekday sleep. This is because weekday sleep is already restricted by the school schedule and so electronic device usage further restricts the adolescent's opportunity for sleep.

4.5.4.1. Limitations of the study

The findings of this study are restricted by some limitations. It is probable that the participants in the current study misunderstood the question which asked them to estimate how long it took them to fall asleep. As has been seen in the results section 37.5 % of weekday sleep onset latency responses and 31.2% of weekend sleep onset latency responses were above 30 minutes, which is one of the diagnostic and statistical manual 5 (DSM-5) (American Psychological Association, 2013) criteria for an insomnia diagnosis. To account for the possibility that adolescents misinterpreted the question, the wording of the question will be altered for study 2, which should aid participants' understanding of the question.

A further limitation of this study is that it did not account for multiple comparisons. The second model in this study examined how 16 variables predicted a variety of sleep variables. It is possible that some of the variables appeared to be significant when they are not significant predictors of sleep. Multiple comparisons would have reduced the possibility of factors appearing significant but not actually being significant predictors of adverse sleep outcomes.

Finally, as noted by Hirshkowitz et al (2015) and Paruthi et al (2016) the recommended amount of sleep that adolescents should get varies with age. The study did not benchmark how much sleep the participant said they got with the recommendation for a child of their respective age. An adolescent aged 18 years old getting 8 hours sleep may be adequate however this may not also be appropriate for a 12-year-old. Thus, the participant's reported sleep durations should have been compared to the recommended sleep duration for their age group to understand whether and how much sleep debt they had.

4.5.5. Improvements for study 2

As previously mentioned, the sleep onset latency question will be slightly altered to clarify the meaning to participants. The question will be changed to "How long does it take you to fall asleep once you start trying?". It is hypothesised that altering the wording of the question will allow participants to provide as accurate estimation of how long it takes them to fall asleep as self-reports allow.

Finally, electronic device usage will be measured using a different set of device questions. This is due to the Media, Technology and Attitudes scale structure having a poor fit with the data. The new questions will ask adolescents when they use a range of devices and how cognitively stimulated, they feel after using each device on both weekdays and at the weekends. Measuring different regularly used devices, the times they began and finished using devices and how much cognitive arousal each device gave to participants will improve our understanding of how and which aspect of electronic device affects sleep.

4.6. Conclusion

This study has found that adolescents went to bed later, woke later, spent a longer time in bed, spent a longer time asleep, had a better quality of sleep and woke feeling less refreshed on weekends than on weekdays. Secondly, the study has found that the predictors which explain weekday and weekend sleep are different to each other. Some of the factors which explain why adolescents report a poor quality of sleep on weekdays and weekends are the same. However, the underlying reason as to why adolescents report a poor quality of sleep must be different as the combination of factors which explain weekday and weekend sleep are different. Older adolescents report later weekday and weekend bedtimes. Whilst these two models appear to be explained by the same factor, it is probable that age is overexplaining the variance observed in this model and the true predictors which explain this variance will be uncovered by including other variables in study 2. The study also showed that more frequent electronic device usage, affected adolescents' sleep quality and how refreshed they felt upon waking the following day. Frequent electronic device usage impacted weekday sleep more so than weekend sleep. This difference is due to weekday sleep already being restricted by the school schedule and so electronic device usage further shortens the opportunity for good quality sleep, which results in the adolescent waking feeling less refreshed. There is more opportunity to extend sleep at the weekend and so using devices in the evening or during the night has less of an impact. Study 2 will build upon and further these findings by examining the relationship between electronic device timing and cognitive arousal and sleep, whilst incorporating other health risk factors such as sleep hygiene and substance use. This study will show *how* electronic device usage affects their adolescents' sleep.

5. Chapter 5: Study 2: Examining *how* device use affects adolescents' weekday and weekend sleep

5.1. Aims

1. To understand how adolescents' self-reported weekday and weekend sleep differ.
   1.1. To examine whether day and boarding students' sleep differ.
2. To establish how electronic device usage affects weekday and weekend sleep.
3. To establish how electronic device usage, sleep and health risk factors are related.

5.2. Introduction

The findings from study 1 showed that adolescents had a better quality of sleep, woke feeling more refreshed, went to bed later, woke up later, spent a longer time in bed, spent a longer time asleep and were more alert on weekend days. These findings all showed that adolescents were not getting enough sleep during the week and so they woke up later, slept for a longer period of time, had a better quality of sleep and woke feeling more refreshed at the weekend as they were repaying the sleep debt that they had acquired. This also meant that they had irregular sleep wake patterns. The findings also showed that adolescents were sleepier at the weekend, which coincides with the adolescents having irregular sleep/wake cycles.

Weekday and weekend sleep were predicted by different variables. Adolescents who frequently checked their phone in the night had a poorer quality of sleep on weekdays and weekend days. They woke feeling less refreshed on weekdays, but they did not wake feeling less refreshed on weekend days. These findings show that weekday and weekend sleep are affected differently based on the day's activities. The largest difference between weekdays and weekends is the presence or absence of the school schedule and so these adolescents were clearly anxious about some aspect relating to school.

In summary, study 1 found that adolescents had a better quality of sleep, woke feeling more refreshed and slept for a longer period of time on weekend days than on weekdays. This is consistent with Carskadon and colleagues (Allen and Mirable, 1989; Carskadon et al, 1998; Wahlstrom et al, 1997; Wahlstrom et al, 2014; Owens et al, 2010; Boergers et al, 2014; Chan et al, 2018), who all noted significant differences in the timing and duration of sleep during the week and at the weekend. The findings also showed that weekday and weekend sleep were affected by different predictors. The school schedule restricts the activities during the weekday for adolescents. The start of the school day restricts the time that adolescents must wake up at so that they arrive at school on time. The school day also restricts the time in which adolescents can use their devices. Most schools tell adolescents that they should not use their personal devices during the school day and so adolescents' device use predominately happens in the late afternoon and evening. Weekend schedules are not restricted in the same way. Adolescents have a greater opportunity to sleep for a longer period of time and repay the sleep debt that they have acquired over the previous week. They are also free to use their devices whenever they want at the weekend, thus device use is not necessarily concentrated in the evening.

Study 1 has shown that frequent electronic device usage affects adolescents' sleep. Study 2 will build upon the results from study 1 and will examine *how* adolescents' electronic device use affects their sleep.

5.2.1. Measure weekday and weekend electronic device usage

The model used in study 1 examined whether electronic device usage predicted weekday and weekend sleep whilst accounting for the participant's sex, age and health risk factors (anxiety, depression and BMI). The findings from study 1 showed that there were fewer significant models of weekend sleep. The data were collected on a single occasion on a weekday at school. It is possible that electronic device usage did not explain weekend sleep as their responses to these questions may have reflected their weekday electronic device usage more so than their weekend device usage. Study 2 will ask about both weekday and weekend electronic device use to account for the differences in adolescents' device use across the week.

5.2.2. Measure the timing of and cognitive stimulation from electronic device

Whilst study 1 has shown that adolescents who frequently use electronic devices have a poorer quality of sleep, wake feeling less refreshed and sleep for a shorter period of time, there are still questions which remain unanswered. Firstly, it is unclear *how* electronic device use impacts adolescents' sleep. There are three pathways which were put forward by Cain and Gradisar (2010) and are discussed in detail in the literature review (Chapter 1: An introduction to adolescents' sleep and device use). It is thought that electronic device usage impacts sleep via:

- The blue light which is emitted from the device suppresses melatonin secretion which delays sleep onset and thus reduces the time an individual sleeps for when there is a fixed wake time.

- The content that individuals view on their device increases cognitive arousal which make pre-sleep relaxation harder to achieve.
- The time that an individual spends on their device could be spent asleep and when there is a fixed wake time the following morning (e.g., on a school day) the individual sleeps for a shorter period of time.

There has been a wealth of literature which has shown that the blue light that is emitted from devices, the content which is viewed on the devices and spending a longer time on devices all impact sleep to some extent (Chang et al, 2015; Chinoy et al, 2018; Weaver et al, 2010; Gradisar et al, 2013; Higuchi et al, 2005; Gamble et al, 2013). The purpose of this study is to understand to what extent each pathway impacts sleep.

5.2.3. Investigating the impact of sleep hygiene

The core questionnaires used in the survey in study 1 were determined using a report published by the Royal College of Paediatric and Child Health (2017) which focused on adolescents' health risk factors. A variant of the survey used in study 1 (Core +2) included the Adolescent Sleep Hygiene Scale (ASHS) (LeBourgeois et al, 2005). The scale was not included in all variations of the survey as a larger sample size was anticipated and it was not a health risk factor identified by the Royal College of Paediatric and Child Health report. The number of the participants in study 1 who had completed ASHS was too small to include the subscales as predictors.

There are a number of additional reasons why a measure of sleep hygiene will be included in the model in study 2. The findings from study 1 showed that adolescents had irregular sleep/wake patterns. The ASHS includes a subscale which examines how regular adolescents' sleep timing is. It has been identified from the first study that adolescents' sleep/wake patterns are irregular.

Additionally, the Royal College of Paediatric and Child Health report also identified "alcohol and drug use" as an adolescent health risk factor. Alcohol use[146] has also been shown to predict how long an adolescent slept for on a weekday. Pasch et al (2012) showed that adolescents who consumed more alcohol slept for a shorter period of time at the weekend and did not sleep in as long at the weekend. Their findings also showed that adolescents who used more tobacco slept for a shorter period of time at the weekend and

[146] Substance use is the name of the subscale in the Adolescent Sleep Hygiene scale and refers to alcohol and drug use.

overall (weekday and weekend sleep combined). These findings suggest that adolescents who consume more alcohol and tobacco sleep for a shorter period of time on weekdays and at the weekend. As mentioned in the literature review (Chapter 1: An introduction to adolescents' sleep and device use), alcohol and tobacco affects sleep timing, how long it takes for an individual to fall asleep, sleep architecture, how long they spend asleep and the number of times they wake during the night (Williams et al, 1983; Zhang et al, 2006; Huang et al, 2013; Pasch et al, 2012). Adolescents also often consume alcohol and tobacco at the weekend when they are socialising with their friends (NHS England, 2019b). Thus, as alcohol and drug use are adolescent health risk factors, they should be included in the model to understand the relative importance amongst other adolescents' health risk factors.

Adolescents who are cognitively or emotionally aroused before going to sleep have been reported to go to bed later, struggle to fall asleep and sleep for a shorter period of time on weekdays (Bartel et al, 2016). The findings from study 1 showed that adolescents who frequently checked their mobile phone during the night, were anxious and had fewer technological friendships had a poorer quality of sleep on weekdays. The findings also showed that adolescents who frequently checked their phone during the night, were anxious and frequently used their emails woke feeling less refreshed on weekdays. Adolescents may have been anxious of missing out on conversations with their friends, which led them to frequently check their mobile phone during the night. If this is the case, then the sleep hygiene subscales such as "cognitive-emotional arousal" and "behavioural arousal" should explain more variance in weekday and weekend sleep.

Poor sleep hygiene has also been reported to affect sleep quality. Brown et al (2002) investigated the effect of sleep hygiene practices on college students' sleep quality. Adolescents who were disturbed by noises, had a variable sleep length, went to bed thirsty and worried about their ability to fall asleep at bedtime had a poorer quality of sleep. This shows that sleep hygiene needs to be incorporated to understand how an adolescents' pre-bedtime behaviours affect their sleep.

Poor sleep hygiene has been demonstrated to affect adolescents' sleep timing (their bedtime, the time it takes them to fall asleep and their wake time), sleep duration, sleep quality and daytime sleepiness (Bartel et al, 2016; Pasch et al, 2012; Brown et al, 2002). Study 2 will include a measure of sleep hygiene in all of the surveys to understand whether sleep hygiene factors are significant predictors of weekday and weekend sleep when incorporated into a model that accounts for the adolescents' sex, age, electronic device usage and health risk factors. It is only when sleep hygiene is incorporated into a comprehensive model with other predictors that the true predictiveness of sleep hygiene will be observed.

5.2.4. Investigating the differences between day school and boarding students

Post-hoc analysis[147] of study 1 showed that there was a significant difference between day school and boarding school adolescents' sleep. As the difference between day and boarding students' sleep was not specifically being investigated, the survey did not ask about whether they were a boarding or a day student. Study 1 showed that adolescents at boarding schools fell asleep quicker on weekdays and at the weekend, went to bed later on weekdays and at the weekend, woke up later on weekdays, spent a shorter period of time in bed on weekdays and at the weekend.

In addition to this interesting finding from study 1, there are a limited number of studies which have directly examined the differences between boarding students' and day students' sleep. Owens et al (2010) investigated the impact of delaying school start time in boarding schools on adolescents' sleep, mood and behaviour. Their findings showed that day and boarding students slept for a similar period of time on weekdays. However, boarding students went to bed later on weeknights and woke up later on weekdays than day students. Boarding students also went to bed later on weekend nights. Boarding students' may go to bed later because they share their bedroom (dormitory) with others. The lights may still be on and their friends may still be using their devices or chatting, which all further delay the time they all go to sleep and will reduce the amount of time they spend asleep. This means that an adolescent can only fall asleep when the rest of their dormitory also wants to fall asleep. Owens and colleagues' findings also showed that boarding and day students woke up at a similar time at the weekend. Thus, day students slept for a longer period of time at the weekend as boarding students went to bed later.

Boergers et al (2014) found similar findings. They investigated the impact of delaying school start time in a boarding school on adolescents' sleep and daytime functioning. Adolescents who started school at 8:25am rather than 8:00am, woke up later on weekdays and slept for a longer period of time on weekdays. Their findings also showed that adolescents who started school later were less depressed. It is probable that these adolescents also had more regular sleep/wake patterns as they will have acquired less sleep debt during the week and so they will not have need to sleep in as long at the weekend.

[147] Post-hoc analysis of study 1 is reported in the appendices.

These findings show that boarding students or adolescents whose school started later spent a longer time asleep on weekdays, spent a longer time in bed, had a better quality of sleep, were less depressed and less anxious. The current study will further these findings by examining whether being a boarding or day student affects weekday and weekend sleep and will ask adolescents whether they are a day or boarding student to make these comparisons.

5.2.5. The current study

Study 1 examined whether electronic device usage[148], frequency of phone checking and phone location (Rosen et al, 2016) affected weekday and weekend sleep. These measures of electronic device usage showed that adolescents who frequently used electronic devices had a poorer quality of sleep, woke feeling less refreshed and slept for a shorter period of time. The interpretation of these findings was limited as there was no measure of specific device use, cognitive arousal or timing of device use. Study 2 will examine the impact of a number of devices. These devices are televisions, mobile phones, tablets, e-readers and computers/ laptops. These devices have been chosen as they are the most commonly used devices by adolescents aged 12 – 15 years old (Ofcom, 2018). The measure will ask adolescents to declare the time they began and finished using each device and how cognitively arousing the devices were.

Study 1 showed that adolescents' electronic device use affected their sleep and health risk factors. These health risk factors were determined using the Royal College of Paediatric and Child Health report (2017). This report identified maintaining a healthy weight, wellbeing, smoking in young people and alcohol and drug use as adolescents' health risk factors. The sample of adolescents who completed the "substance use" subscale in study 1 was smaller than expected. The current study will ask all adolescents about their substance use to examine the relationship between adolescents' sleep and other health risk factors. This study will measure a combination of variables that have not yet been studied simultaneously to establish the influence of each variable whilst accounting for each other.

Post-hoc analysis from study 1 showed that boarding students went to bed later, fell asleep quicker and spent a shorter length of time in bed on both weekdays and at the weekend than day students. Boarding students also woke up later than day students did on weekdays. These findings are probably because they were sleeping in the same dormitory as their peers. This will have meant that the time they each went to sleep and the amount of sleep they each got

[148] Study 1 examined electronic device usage using the Media, Technology and Attitudes scale (Rosen et al, 2013)

was dependent on everyone in their dormitory being quiet and considerate. They fell asleep quicker than the day students because by the time they went to bed their homeostatic sleep pressure was higher, which made it easier to fall asleep. The current study will ask students to declare whether they are a boarding or day student, which will provide a clearer understanding as to how being a boarding or day student affects weekday and weekend sleep. This will also be incorporated into the model to understand whether being a boarding or day student impacts their sleep.

5.2.5.1. Hypotheses

- Participants will have a better quality of sleep, wake feeling more refreshed, go to bed later, wake up later, spend a longer time in bed, spend a longer time asleep, feel less sleepy and more alert at the weekend than during the week.
- Boarding students will have a poorer quality of sleep, wake feeling less refreshed, go to bed later, wake up later, spend less time in bed, spend less time asleep, feel sleepier and less alert in comparison to day students.
- Participants who use their devices later in the evening and are more cognitively aroused from their devices will go to bed later, have a poorer quality of sleep, wake up later and will wake feeling less refreshed.

5.3. Methods

The current study is multi-layered in that it will first seek to understand whether day and boarding students' sleep differ. It will then seek to understand whether weekday and weekend sleep differ and what the predictors are of weekday and weekend sleep. It will then explore the relationships between electronic device usage, sleep and health risk factors.

5.3.1. Sampling

This study used opportunity sampling to recruit the participants for the survey. Secondary schools and sixth forms across the country were contacted and asked if they would like to take part in the study. This study recruited 3 schools. The three schools which took part in this study were all boarding schools and were all from the South-West England. The schools opened the survey up to various year groups and so the age of participants from the schools has some variation. As there were fewer schools included and the schools were all private boarding schools which had both day and boarding students there are fewer extraneous variables that may have affected the findings in this study than in study 1.

5.3.2. Participants

Four hundred and eighty-nine adolescents began completing the survey. The participants were from three schools which had both day and boarding students. The participants were aged between 11.00 – 18.92 years (M ± SD = 14.94 ± 1.86), 17.59% were male, 78.73% were female and 3.68% did not disclose their sex. Two hundred and forty-eight adolescents completed the survey, aged between 11.92 – 18.92 (M ± SD = 15.29 ± 1.75), 16.4% were male, 70.5% were female and 13.1% did not disclose their sex.

5.3.3. Methods

This survey was organised into three variations; Core, Core +1 and Core + 2 and the components of these surveys can be seen in Table 19.

Table 19 Details of the contents of each variation of the survey used in study 2; named Core, Core +1, Core +2.

Core	Core +1	Core + 2
Demographics	Demographics	Demographics
Self-report sleep questions	Self-report sleep questions	Self-report sleep questions
Cleveland adolescent sleepiness scale-modified	Cleveland adolescent sleepiness scale-modified	Cleveland adolescent sleepiness scale-modified
Adolescent sleep hygiene scale	Adolescent sleep hygiene scale	Adolescent sleep hygiene scale
Media, Technology and Attitudes subscales (text messaging, tv viewing subscale, video gaming, facebook friendships, online friendships and preference for task switching)	Media, Technology and Attitudes subscales (text messaging, tv viewing subscale, video gaming, facebook friendships, online friendships and preference for task switching)	Media, Technology and Attitudes subscales (text messaging, tv viewing subscale, video gaming, facebook friendships, online friendships and preference for task switching)
Other Technology usage questions	Other Technology usage questions	Other Technology usage questions
Device use on weekdays and weekend days questions	Device use on weekdays and weekend days questions	Device use on weekdays and weekend days questions
Hospital anxiety and depression scale	Hospital anxiety and depression scale	Hospital anxiety and depression scale
	Munich chronotype questionnaire for children	Behavioural inhibition system-behavioural activation system

5.3.4. Materials

Many of the questionnaires that were used in this survey have been used in all of the studies in this thesis and so they are described in detail in Chapter 3: Methodology. This section will report the internal consistency values for each questionnaire used and will describe any aspects of the survey which are specific to this study.

5.3.4.1. Self-report sleep questions

The self-reported sleep questions are described in detail in the Chapter 3: Methodology chapter. The wording of the sleep onset latency question was altered as the results from study 1 indicated that participants had misunderstood the question. The question was changed to "How long does it take you to fall asleep on weekdays / weekends after you start trying?". The wording of this revised sleep onset latency question was influenced by (Monk, 2003).

Participants were asked to respond in hours and minutes. The measure can be seen in the appendices.

5.3.4.2. Cleveland Adolescent Sleepiness Questionnaire- modified (Spilsbury et al, 2007)

The scale is described in detail in Chapter 3: Methodology. All of the subscales within the Cleveland Adolescent Sleepiness Questionnaire- modified were checked for internal consistency. The values from this study are reported and compared against Spilsbury et al (2007) and the internal consistency values from study 1 in Table 20.

Table 20 Cronbach's α for Cleveland Adolescent Sleepiness Questionnaire according to Spilsbury et al (2007) and this study

Subscale	Spilsbury et al (2007)	Study 1 Cronbach's α	This study Cronbach's α (n = 286)
Sleepiness in school	-	0.9	0.9
Alertness in school	-	0.86	0.89
Sleepiness on weekday evenings	-	0.73	0.69*
Sleepiness at the weekend	-	0.78	0.8
Alertness at the weekend	-	0.81	0.89
Total CASQ score	0.89	0.9	0.9

Note: * = Cronbach's α does not meet 0.7. This is unsatisfactory according to Bland and Altman (1997).

The internal consistency value for "sleepiness on weekday evenings" subscale seen in Table 20 was marginally smaller than the 0.7 threshold, which could be due to individual differences in the samples of participants. On the whole, this study's internal consistency values are larger than those reported in study 1 showing that all of the participants in the current study responded in a similar way to each other.

5.3.4.3. Media, Technology and Attitudes Subscales- (Rosen et al, 2013)

The Media, Technology and Attitudes scale (Rosen et al, 2013) is described in detail in Chapter 4: Study 1 methods section. The confirmatory factor analysis, conducted in study 1, indicated that the Rosen et al (2013) proposed structure for Media, Technology and Attitudes scale was not present. Rosen et al (2013) reported that the subscales "can be used together or separately as they are internally reliable and externally valid" (p.2507).

Six subscales were retained for study 2 and these were: Text messaging, TV viewing, Video gaming, Facebook Friendships, Online Friendships and Preference for Task Switching. This measure of electronic device usage will not be used in the analyses as a more informative measure has been used to examine how adolescents' device use affects their sleep.

All of the subscales which were retained in study 2 were checked for internal consistency. The results can be seen in Table 21. The text messaging usage subscale did not meet 0.7 threshold described by Bland and Altman (1997), however the Cronbach's alpha obtained was slightly larger than that from study 1. On the whole, the internal consistency values were above the 0.7 threshold, and most are larger than the internal consistency values obtained in Study 1, indicating participants in Study 2 interpreted the questions in a similar manner to each other.

Table 21 Cronbach's α for Media and Technology and Attitudes subscales according to Rosen et al (2013) and this study

Subscale	Rosen et al (2013) Cronbach's α	Study 1 Cronbach's α	This study Cronbach's α (n = 429)
Text-messaging usage	0.84	0.64	0.67*
Television viewing	0.61	0.74	0.74
Video gaming usage	0.83	0.75	0.81
Online friendships	0.83	0.54	0.84
Facebook friendships	0.96	0.92	0.74
Multi-tasking preference	0.85	0.78	0.71

Note: * = Cronbach's α does not meet 0.7 and so, according to Bland and Altman (1997), is unsatisfactory.

5.3.4.4. Device use questions

Device use was measured using the questions detailed in Chapter 3: Methodology. Device duration was calculated as follows:

$$Device\ duration = device\ end\ time - device\ start\ time$$

5.3.4.5. Hospital Anxiety and Depression Scale - (Zigmond and Snaith, 1983)

The Hospital Anxiety and Depression scale is described in detail in "Chapter 3: Methodology". Both of the subscales were checked for internal consistency. Table 22Table 22 compares the current study's internal consistency values with Woods and Scott (2016) and those from study 1.

Table 22 Cronbach's α for Hospital Anxiety and Depression Subscales according to Woods and Scott (2016), study 1 and this study; n = 261

Subscale	Woods and Scott (2016) Cronbach's α	Study 1 Cronbach's α	This study Cronbach's α
Anxiety	0.8	0.88	0.84
Depression	0.72	0.85	0.76

This study's Cronbach's α values both meet the 0.7 threshold described by Bland and Altman (1997) and are higher than those reported by Woods and Scott (2016) but marginally smaller than study 1. This may be due to individual differences in the samples used in the studies.

5.3.4.6. Behavioural Inhibition System- Behavioural Activation System- (Carver and White, 1994)

Each of the subscales were checked for internal consistency and these values are reported and compared against Carver and White (1994) and the values from study 1 in Table 23.

Table 23 Cronbach's α for BIS/BAS subscales according to Carver and White (1994), study 1 and this study; n = 97

Subscale	Carver and White (1994) Cronbach's α	Study 1 Cronbach's α	This study Cronbach's α
Behavioural inhibition system	0.67	0.69	0.81
Behavioural activation system- drive	0.76	0.75	0.71
Behavioural activation system- reward responsiveness	0.73	0.64	0.61*
Behavioural activation system- fun seeking	0.66	0.60	0.60*

Note: * = Cronbach's α does not meet 0.7 and so, according to Bland and Altman (1997), is unsatisfactory.

The Cronbach's α values for BAS Reward Responsiveness and BAS Fun Seeking in Table 23 do not meet the 0.7 threshold described by Bland and Altman (1997) which may indicate that participants interpreted the questions differently to one another. Cronbach's alpha for Carver and White (1994), study 1 and study 2 are similar. BIS/ BAS will not be used in the analyses for this study and so the means and standard deviations can be found in the appendices.

5.3.4.1. Adolescent Sleep Hygiene Scale (Lebourgeois et al, 2005)

Adolescent sleep hygiene scale is described in detail in Chapter 3: Methodology. Each of the subscales were checked for internal consistency and these values are reported and compared against LeBourgeois et al (2005) and the values from study 1 in Table 24.

Table 24 Cronbach's α for Adolescent Sleep Hygiene Scale according to Lebourgeois et al (2005), study 1 and this study; n = 291

Subscale	Lebourgeois et al (2005) Cronbach's α	Study 1 Cronbach's α	Current study Cronbach's α
Physiological arousal	-	0.25	0.46*
Behavioural arousal	-	0.47	0.65*
Cognitive – emotional arousal	-	0.78	0.80
Sleep environment	-	0.46	0.67*
Sleep stability	-	0.59	0.73
Daytime sleepiness	-	0.64	0.82
Substance use	-	0.60	0.66*
Total ASHS score	0.8	0.74	0.84

Note : * = Cronbach's α does not meet 0.7, and so according to Bland and Altman (1997), is unsatisfactory

The Cronbach's α values for "Physiological arousal", "Behavioural arousal", "Sleep environment" and "Substance use" do not meet the 0.7 threshold, however on the whole the questionnaire has substantially higher internal consistency than study 1. The subscales have higher Cronbach's alpha values in study 2 than in study 1, indicating the participants in study 2 interpreted the questions similar to each other.

5.3.5. Procedure

Three schools, two of which were used in study 1, were contacted and asked if they would like to give their students the opportunity to take part in the study. The schools contacted and obtained parental consent. There were three surveys (Core, Core+1 and Core+2). Pupils answered one of the variations. Pupils from the same school answered the same variation. As there were only three schools that took part in this study, one school was assigned to each variation. There was a substantial amount of variation in the number of participants from each school and so there are unequal sample sizes in each variation of the survey. The schools were sent a link to the survey, and this was then circulated amongst the pupils who were taking part in the survey.

Before beginning the survey, the participant was given information regarding the survey and told that they did not need to take part in the survey. They were told they had the opportunity to withdraw at any point during the survey or afterwards and assigned themselves a unique identifier in case they wished to withdraw at any point. Participants then completed the survey and were provided with a full debrief at the end of the survey. Names of organisations and phone numbers were provided in case the survey had evoked feelings of distress or worry for the participant.

5.3.6. Data management

The responses were collected using an online platform, Qualtrics. The responses were downloaded, cleaned and reverse scored where appropriate in Microsoft Excel. In total there were 489 responses across 3 variations of the survey; 230 responses on Core (40% of these were complete) and 117 responses on Core + 1 (49% of these were complete) and 142 responses on Core + 2 (67% of these were complete).

The data were checked for linearity, normality, heteroscedasticity and multicollinearity. None of these variables were transformed as when the variables were transformed, other issues arose. For example, whilst the kurtosis or skewness value became more normal, the other (kurtosis or skewness value) became less normal. Neither the skewness or kurtosis values were large so the original data was used. The data were analysed in R studio (Version

3.6.1) and were analysed in the same way that the data from study 1 were analysed. using a variety of packages including “Tidyverse”, “Corrplot” and “Lavaan”. Bivariate correlations were conducted to examine the relationships between the sleep variables and device use variables. Hierarchical linear regressions and hierarchical ordinal regressions were conducted to examine which predictors explained the most variance within each sleep variable.

5.4. <u>Results</u>

This results section has been split into three sections similar to study 1. The first section will describe the characteristics of the participants. The second section will examine whether adolescents’ weekday and weekend sleep are different to one another. The final section will show how electronic device use and other health risk factors predicted sleep. The most important difference between study 1 and this study is that the measure of electronic device use was improved so that the findings would uncover which aspect of electronic device use (the time spent on devices, the content viewed, or the blue light emitted) affected adolescents’ sleep.

5.4.1. Adolescents frequently consumed substances and were sleepy during the day

This subsection will describe the participant’s characteristics on the demographic questions, Adolescent Sleep Hygiene Scale (LeBourgeois et al, 2005) and Hospital Anxiety and Depression scale (Zigmond & Snaith, 1983). The descriptive statistics for the subscales which were retained from the Media and Technology usage scale (Rosen et al, 2013) and Behavioural Inhibition System- Behavioural Activation System (Carver & White, 1994) can be found in the appendices as they were not used in the hierarchical linear regression model used in this study. The descriptive statistics for the Cleveland Adolescent Sleepiness Questionnaire- modified (Cleveland et al, 2007), subjective sleep questions and device use questions will be report in the following subsection as these questions asked specifically about weekday and weekend sleep schedules.

5.4.1.1. Demographics

The mean and standard deviation of day and boarding students’ age, time that school started and finished at, amount of time that they spent at school before and after classes and BMI can be seen in Table 25. The results show that participants had an average BMI of 21.59 (SD = 11.85), started school at 08:54 (SD = 00:26), finished school at 16:14 (SD = 01:13), spent 00:49 (SD = 02:30) at school before classes started and spent 01:17 (SD = 03:56) at school after classes had finished. There is very little difference between the day and boarding student means and standard deviations.

Table 25 Overall, day and boarding mean (M), standard deviation (SD) and n for participants' demographics

Variable	M ± SD (n) [hh:mm]	Complete participants M ± SD [hh:mm] (n = 248)	Incomplete participants M ± SD [hh:mm] (n = 241)	Day student M ± SD [hh:mm] (n)	Boarding student M ± SD [hh:mm] (n)
Age	14.94 ± 1.86 (489)	15.29 ± 1.75	14.85 ± 1.91	15.18 ± 1.96 (354)	14.35 ± 1.31 (117)
School start time	8.9 ± 0.43 (464) [08:54 ± 00:26]	8.52 ± 0.34 [08:31 ± 00:20]	9.1 ± 0.5 [09:06 ± 00:30]	8.93 ± 0.29 (348) [08:56 ± 00:17]	8.8 ± 0.68 (116) [08:48 ± 00:41]
School end time	16.23 ± 1.21 (464) [16:14 ± 01:13]	16.3 ± 1.3 [16:18 ± 01:18]	16.19 ± 1.1 [16:11 ± 01:06]	15.94 ± 1.12 (347) [15:56 ± 01:07]	17.09 ± 1.07 (117) [17:05 ± 01:04]
Time spent at school before classes	0.82 ± 2.5 (478) [00:49 ± 02:30]	0.76 ± 2.1 [00:46 ± 02:06]	1.13 ± 1.9 [01:08 ± 01:54]	0.56 ± 0.72 (349) [00:34 ± 00:43]	1.67 ± 4.82 (117) [01:40 ± 04:49]
Time spent at school after classes	1.28 ± 3.94 (477) [01:17 ± 03:56]	1.09 ± 4.32 [01:05 ± 04:19]	1.21 ± 3.1 [01:13 ± 03:06]	0.92 ± 3.35 (349) [00:55 ± 03:21]	2.49 ± 5.31 (116) [02:29 ± 05:19]
BMI	21.59 ± 11.85 (295)	20.45 ± 11.32	23.1 ± 8.93	21.81 ± 13.15 (230)	20.92 ± 5.05 (60)

5.4.1.2. Anxiety and Depression

The means, standard deviation, n and proportion of participants who were categorised as being "Normal", "Borderline" or "Abnormal" can be seen in

Table 26. As can be seen from the findings, participants had an average anxiety score of 10.02 (SD = 3.86) and an average depression score of 9.59 (SD = 7.11) which indicated that participants were borderline anxious and borderline depressed. Participants are categorised as 'normal' if their score = 0 – 7, 'borderline' if their score = 8 – 10, and 'abnormal' if their score = 11 – 21.

Variable	M ± SD (n)	Day student M ± SD (n)	Boarding student M ± SD (n)	Normal	Borderline	Abnormal
Anxiety	10.02 ± 3.86 (261)	10.26 ± 3.69 (203)	9.16 ± 4.33 (58)	24.1 %	28.8%	47.1%
Depression	9.59 ± 7.11 (261)	10.99 ± 7.27 (203)	4.72 ± 3.47 (58)	49.4%	9.6%	41%

Table 26 Overall, day and boarding student mean (M), standard deviations (SD), n and proportion of participants categorised as "Normal", "Borderline" and "Abnormal" for the Hospital Anxiety and Depression subscales

Variable	M ± SD (n)	Day student M ± SD (n)	Boarding student M ± SD (n)	Normal	Borderline	Abnormal
Anxiety	10.02 ± 3.86 (261)	10.26 ± 3.69 (203)	9.16 ± 4.33 (58)	24.1 %	28.8%	47.1%
Depression	9.59 ± 7.11 (261)	10.99 ± 7.27 (203)	4.72 ± 3.47 (58)	49.4%	9.6%	41%

5.4.1.3. Sleep Hygiene

The mean, standard deviation, standardised mean, standardised standard deviation, and n for both boarding and day students for the scale are shown in Table 27. The table shows that day students were more behaviourally aroused before going to bed, were sleepier during the day, had less stable sleep and used more substances than boarding students. Adolescents' bed and wake times which were collected as part of the Adolescent Sleep Hygiene scale can be seen in the appendices as these values have not been used in the analyses as other questions were used.

Table 27 Mean (M), standard deviation (SD), standardised mean (Std. M), standardised standard deviation (Std. SD), n and ANOVA for day and boarding students' scores on ASHS

Variable	M ± SD (n)	Std M ± Std SD	Day student M ± SD (n)	Boarding student M ± SD (n)	ANOVA
Physiological arousal	22.94 ± 4.45 (291)	4.59 ± 0.89	22.66 ± 4.42 (224)	23.88 ± 4.45 (67)	F(1,270) = 3.31, p = 0.07
Behavioural arousal	**10.3 ± 3.69 (291)**	**3.43 ± 1.23**	**9.78 ± 3.61 (224)**	**12.03 ± 3.44 (67)**	**F(1,270) = 16.13, p < 0.001**
Cognitive emotional arousal	23.12 ± 6.24 (291)	3.85 ± 1.04	22.76 ± 6.05 (224)	24.33 ± 6.73 (67)	F(1,270) = 1.40, p = 0.24
Daytime sleepiness	**10.67 ± 2.15 (300)**	**5.34 ± 1.07**	**10.46 ± 2.31 (228)**	**11.36 1.31 (72)**	**F(1,270) = 9.02, p = 0.003**
Sleep environment	26.07 ± 2.99 (282)	5.21 ± 0.8	25.87 ± 4.18 (219)	26.76 ± 3.18 (63)	F(1,270) = 2.1, p = 0.15
Sleep stability	**10.04 ± 3.85 (280)**	**3.35 ±1.28**	**9.74 ± 3.69 (218)**	**11.10 ± 4.2 (62)**	**F(1,270) = 6.31, p = 0.013**
Substance use	**11.38 ± 1.51 (300)**	**5.69 ± 0.75**	**11.21 ± 1.66 (228)**	**11.92 ± 0.6 (72)**	**F(1,270) = 15.29, p < 0.001**
Bedtime routine	4.96 ± 1.7 (282)	4.96 ± 1.7	5.03 ± 1.67 (219)	4.70 ± 1.78 (63)	F(1,270) = 0, p = 0.22
Total ASHS score	**119.09 ± 16.61 (280)**		**117.20 ± 16.33 (218)**	**125.74 ± 15.99 (62)**	**F(1,270) = 11.47, p = 0.001**

Note: Results which are significant at p < 0 .05 are in **bold.**

5.4.2. Adolescents sleep later, longer and have a better quality of sleep at the weekend

5.4.2.1. Weekday and weekend sleep

As can be seen in Table 28, adolescents had a better quality of sleep (Figure 5A), woke feeling more refreshed (Figure 5B), went to bed later (Figure 5C), woke up later (Figure 5D), spent a longer time in bed and spent a longer time asleep (Figure 5E) at the weekend than they did on weekdays. As can be seen in Table 29, adolescents were less alert at school than they were at the weekend. Interestingly, they were also sleepier at the weekend than they were on weekdays. This finding supports what was found in the first study and is probably due to adolescents having irregular sleep/wake patterns (Chapter 4: Study 1: Identifying the predictors of adolescents' weekday and weekend sleep.). Table 28 shows that the adolescents had irregular sleep/wake patterns and slept for a longer period of time at the weekend than they did on weeknights.

Table 28 Overall, day and boarding students' weekday and weekend mean (M), standard deviations (SD), n, paired sample t-tests and ANOVAs for sleep variables

Variable	Weekday M ± SD (n) [hh:mm]	Weekend M ± SD (n) [hh:mm]	Paired sample t-test	Day student weekday M ± SD (n) [hh:mm]	Boarding student weekday M ± SD (n) [hh:mm]	ANOVA	Day student weekend M ± SD (n) [hh:mm]	Boarding student weekend M ± SD (n) [hh:mm]	ANOVA
Sleep quality	**4.13 ± 1.41 (462)**	**3.18 ± 1.58 (450)**	**t(448)=13.88, p < 0.001**	**4.23 ± 1.34 (346)**	**3.81 ± 1.57 (116)**	**F(1,425) = 5.02, p = 0.03**	3.24 ± 1.6 (340)	3.01 ± 1.49 (110)	F(1,425) = 1.88, p = 0.17
Waking feeling refreshed	**4.77 ±1.48 (463)**	**3.47 ± 1.57 (452)**	**t(451) = 17.14, p < 0.001**	4.77 ± 1.49 (347)	4.78 ± 1.44 (116)	F(1,425) = 0, p = 0.99	3.56 ± 1.56 (340)	3.22 ± 1.58 (112)	F(1,425) = 3.15, p = 0.08
Sleep onset latency	0.51 ± 0.62 (466) [00:31 ± 00:37]	0.47 ± 0.63 (465) [00:28 ± 00:38]	t(462) = 1.57, p = 0.12	0.53 ± 0.65 (347) [00:32 ± 00:39]	0.46 ± 0.52 (116) [00:28 ± 00:31]	F(1,425) = 1.88, p = 0.17	0.49 ± 0.69 (347) [00:29 ± 00:41]	0.41 ± 0.39 (115) [00:25 ± 00:23]	F(1,425) = 1.83, p = 0.18
Bedtime	**22.72 ±1.3 (463) [22:43 ± 01:18]**	**23.77 ±2.48 [23:46 ± 02:29] (450)**	**t(449) = -10.36, p < 0.001**	22.68 ± 1.29 (347) [22:41 ± 01:17]	22.83 ± 1.33 (114) [22:50 ± 01:20]	F(1,425) = 2.43, p = 0.23	23.7 ± 2.09 (339) [23:42 ± 02:05]	23.98 ± 3.45 (109) [23:59 ± 03:27]	F(1,425) = 1.03, p = 0.31
Wake time	**30.9 ± 0.82 (456) [06:54 ± 00:49]**	**33.2 ± 1.64 [09:12 ± 01:38] (445)**	**t(441)= - 30.13, p < 0.001**	30.87 ± 0.86 (343) [06:52 ± 00:52]	30.98 ± 0.7 (113) [06:59 ± 00:42]	F(1,425) = 0.92, p = 0.24	**33.29 ± 1.73 (336) [09:17 ±01:44]**	**32.93 ± 1.29 (109) [08:56 ± 01:17]**	**F(1,425) = 11.91, p = 0.04**
Time in bed	**8.18 ± 1.36 (457) [08:11 ± 01:22]**	**9.59 ± 1.76 (445) [09:35 ± 01:46]**	**t(442)= - 15.94, p < 0.001**	8.18 ± 1.35 (344) [08:11 ± 01:21]	8.17 ± 1.43 (113) [08:10 ± 01:26]	F(1,425) = 0.36, p = 0.65	9.66 ± 1.86 (334) [09:40 ± 01:52]	9.39 ± 1.42 (111) [09:23 ± 01:25]	F(1,425) = 2.16, p = 0.15
Sleep duration	**7.67 ± 1.45 (456) [07:40 ± 01:27]**	**9.13 ± 1.78 (444) [09:08 ± 01:47]**	**t(441) = - 16.30, p < 0.001**	7.66 ± 1.44 (343) [07:40 ± 01:26]	7.71 ± 1.48 (113) [07:43 ± 01:29]	F(1,425) = 0.07, p = 0.86	9.17 ± 1.88 (333) [09:10 ± 01:53]	8.98 ± 1.42 (111) [08:59 ± 01:52]	F(1,425) = 0.90, p = 0.34

Note: Results which are significant at p < 0.05 are in **bold**

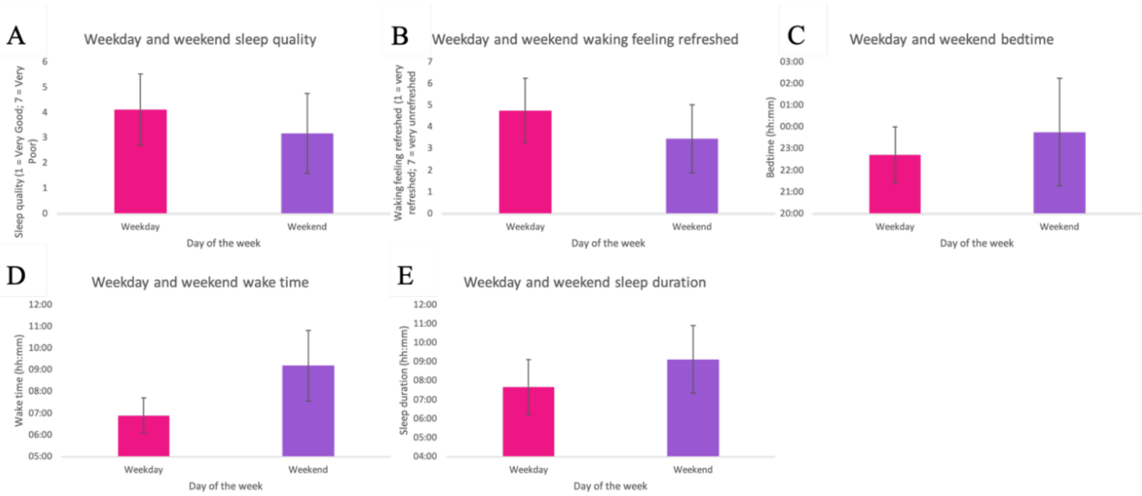

Figure 5 (A) Mean weekday and weekend sleep quality; (B) Mean weekday and weekend waking feeling refreshed scores; (C) Mean weekday and weekend bedtime; (D) Mean weekday and weekend wake time; (E) Mean weekday and weekend sleep duration. Error bars ± SD

The results in Table 28 also show that boarding students had a better quality of sleep on weekdays and woke up earlier at the weekend. These findings show that boarding students had more consistent sleep/wake patterns than the day students. Moreover, the findings in Table 29 show that the day students were sleepier than the boarding students at the weekend. There was a smaller difference between the time that boarding students went to bed, woke up at and the amount of time they spent asleep on weekdays and at the weekend.

Table 29 Mean (M), Standard Deviation (SD), standardised means (Std. M), standardised standard deviations (Std. SD), n, paired sample t-tests and ANOVAs for day and boarding students' weekday and weekend sleepiness and alertness

Variable	Weekday M ± SD (n)	Std. weekday M ± Std SD (n)	Weekend M ± SD (n)	Std. weekend M ± Std. SD (n)	Paired sample t-test	Day student weekday M ± SD (n)	Boarding student weekday M ± SD (n)	ANOVA	Day student weekend M ± SD (n)	Boarding student weekend M ± SD (n)	ANOVA
Sleepiness	**7.22 ± 3.61 (295)**	**1.44 ± 0.72 (295)**	**8.34 ± 3.72 (286)**	**1.67 ± 0.74 (286)**	**t(283)= - 5.02, p < 0.001**	7.26 ± 3.68 (224)	7.11 ± 3.39 (71)	F(1,282) = 0.23, p = 0.63	**8.63 ± 3.95 (217)**	**7.42 ± 2.73 (69)**	**F(1,282) = 5.67, p = 0.02**
Alertness	**17.09 ± 5.01 (295)**	**3.42 ± 1.00 (295)**	**13.97 ± 5.07 (286)**	**2.79 ± 1.01 (286)**	**t(283) = 12.24, p < 0.001**	17.32 ± 4.71 (224)	16.37 ± 5.83 (71)	F(1,282) = 2.00, p = 0.16	14.07 ± 4.87 (217)	13.65 ± 5.68 (69)	F(1,282) = 0.28, p = 0.60
Sleepiness on weekday evenings	8.46 ± 2.78 (295)	2.82 ± 0.93 (295)				**8.88 ± 2.71 (224)**	**7.14 ± 2.57 (71)**	**F(1,282) = 22.25, p < 0.001**			

Note: Results which are significant at p < 0.05 are in **bold**.

5.4.2.2. Device use

Table 30 shows the means, standard deviations, paired sample t-tests and ANOVAs for weekday and weekend device use and device duration for both boarding and day students. The findings show that participants finished using TVs and mobile phones later on weekend evenings than they did on weekday evenings. The findings also show that participants watched TV and used their mobile phone for a longer period of time at the weekend than they did during the week.

Table 31 shows the means, standard deviations, paired sample t-tests and ANOVAs for weekday and weekend device cognitive arousal for both boarding and day students. These findings show that participants felt more cognitively aroused after watching TV at the weekend than they did during the week.

Table 30 Overall, day and boarding student mean (M), standard deviations (SD), n and paired sample t-tests for weekday and weekend device use end time and duration

Variable	Weekday M ± SD (n) [hh:mm]	Weekend M ± SD (n) [hh:mm]	Paired sample t-test	Day student Weekday M ± SD (n) [hh:mm]	Boarding student Weekday M ± SD (n) [hh:mm]	ANOVA	Day student Weekend M ± SD (n) [hh:mm]	Boarding student Weekend M ± SD (n) [hh:mm]	ANOVA
TV End	**20.66 ± 1.92 (178) [20:40 ± 01:55]**	**21.2 ± 1.98 (191) [21:12 ± 01:59]**	**t(154) = -4.83, p < 0.001**	20.82 ± 1.87 (160) [20:49 ± 01:52]	19.22 ± 1.79 (18) [19:13 ± 01:47]	F(1,22)= 2.85, p = 0.50	21.36 ± 1.91 (173) [21:22]	19.69 ± 2.07 (18) [19:41 ± 02:04]	F(1,22) = 11.10, p = 0.15
MP End	**22.13 ± 1.82 (304) [22:08 ± 01:49]**	**22.63 ± 2.13 (288) [22:38 ± 02:08]**	**t(281) = - 5.15, p < 0.001**	22.14 ± 1.97 (229) [22:08 ± 01:58]	22.09 ± 1.27 (75) [22:05 ± 01:16]	F(1,22) = 5.42, p = 0.34	22.69 ± 2.21 (217) [22:41 ± 02:13]	22.46 ± 1.86 (71) [22:28 ± 01:52]	F(1,22) = 0.75, p = 0.76
Tablet End	20.31 ± 2.25 (109) [20:19 ± 02:15]	20.52 ± 2.42 (100) [20:31 ± 02:25]	t(87) = - 1.36, p = 0.18	20.22 ± 2.24 (86) [20:13 ± 02:14]	20.65 ± 2.33 (23) [20:39 ± 02:20]	F(1,22) = 1.1, p = 0.67	20.48 ± 2.46 (80) [20:29 ± 02:28]	20.7 ± 2.3 (20) [20:52 ± 02:18]	F(1,22) = 4.22, p = 0.42
E Reader End	19.84 ± 2.47 (57) [19:50 ± 02:28]	20.76 ± 2.52 (45) [20:46 ± 02:31]	t(33) = - 0.98, p = 0.33	**19.44 ± 2.32 (41) [19:26 ± 02:19]**	**20.88 ± 2.6 (16) [20:53 ± 02:36]**	**F(1,22) = 35.21, p = 0.03**	20.44 ± 2.61 (32) [20:26 ± 02:37]	21.54 ± 2.16 (13) [21:32 ± 02:10]	F(1,22) = 8.53, p = 0.28
Comp End	20.78 ± 1.94 (246) [20:47 ± 01:56]	21.08 ± 2.35 (220) [21:05 ± 02:21]	t(207) = - 1.80, p = 0.07	20.58 ± 2.06 (177) [20:35 ± 02:04]	21.3 ± 1.49 (69) [21:18 ± 01:29]	F(1,22) = 1.2, p = 0.69	20.99 ± 2.45 (154) [20:59 ± 02:27]	21.27 ± 2.11 (66) [21:16 ± 02:07]	F(1,22) = 1.88, p = 0.64
TV Duration	**1.98 ± 1.69 (177) [01:59 ± 01:41]**	**2.53 ± 1.92 (191) [02:32 ± 01:55]**	**t(154)= -4.67, p < 0.001**	2.1 ± 1.7 (159) [02:06 ± 01:42]	0.97 ± 1.17 (18) [00:58 ± 01:10]	F(1,20) = 0.09, p = 0.87	2.65 ± 1.95 (173) [02:39 ± 01:57]	1.36 ± 1.16 (18) [01:22 ± 01:10]	F(1,20) = 5.63, p = 0.19
MP Duration	**4.34 ± 2.21 (304) [04:20 ± 02:13]**	**4.79 ± 2.47 (288) [04:47 ± 02:28]**	**t(281) = -3.67, p < 0.001**	4.42 ± 2.29 (229) [04:25 ± 02:17]	4.07 ± 1.92 (75) [04:04 ± 01:55]	F(1,20) = 5.23, p = 0.41	4.84 ± 2.54 (217) [04:50 ± 02:32]	4.64 ± 2.28 (71) [04:38 ± 02:17]	F(1,20) = 0.74, p = 0.79
Tablet Duration	2.11 ± 1.92 (109) [02:07 ± 01:55]	2 ± 1.98 (102) [02:00 ± 01:59]	t(92) = 0.17, p = 0.87	1.92 ± 1.84 (86) [01:55 ± 01:50]	2.78 ± 2.13 (23) [02:47 ± 02:08]	F(1,20) = 0.87, p = 0.58	1.9 ± 1.9 (82) [01:54 ± 01:54]	2.42 ± 2.27 (20) [02:25 ± 02:16]	F(1,20) = 8.63, p = 0.16
E Reader Duration	1.45 ± 1.94 (57) [01:27 ± 01:56]	1.86 ± 2.05 (43) [01:36 ± 02:03]	t(31) = - 0.19, p = 0.85	**1.28 ± 1.6 (41) [01:17 ± 01:36]**	**1.88 ± 2.64 (16) [01:53 ± 02:38]**	**F(1,20) = 25.55, p = 0.04**	**1.81 ± 1.96 (31) [01:49 ± 01:58]**	**2 ± 2.35 (12) [02:00 ± 02:21]**	**F(1,20) = 21.32, p = 0.04**
Comp Duration	2.83 ± 1.99 (246) [02:50 ± 01:59]	2.95 ± 2.23 (220) [02:57 ± 02:14]	t(207)= -0.70, p = 0.49.	2.57 ± 2.02 (177) [02:34 ± 02:01]	3.49 ± 1.76 (69) [03:29 ± 01:46]	F(1,20) = 6.60, p = 0.34	2.7 ± 2.17 (154) [02:42 ± 02:10]	3.54 ± 2.28 (66) [03:32 ± 02:17]	F(1,20) = 3.37, p = 0.43

*Note: TV = Television, MP = Mobile Phone, Comp = Computer; results which are significant at p < 0 .05 are in **bold.***

Table 31 Weekday and weekend mean (M), standard deviations (SD), paired sample t-tests and ANOVAs for day and boarding students' cognitive arousal from devices.

Variable	Weekday M ± SD (n)	Weekend M ± SD (n)	Paired sample t-test	Day student Weekday M ± SD (n)	Boarding student Weekday M ± SD (n)	ANOVA	Day student Weekend M ± SD (n)	Boarding student Weekend M ± SD (n)	ANOVA
TV CA	**2.99 ± 1.53 (158)**	**3.42 ± 1.73 (177)**	**t(138) = -4.14, p < 0.001**	3.02 ± 1.53 (160)	2.29 ± 1.6 (18)	F(1,156) = 1.54, p = 0.22	3.41 ± 1.69 (173)	3.55 ± 2.38 (18)	F(1,175) = 0.06, p = 0.80
MP CA	4.18 ± 1.76 (299)	4.27 ± 1.87 (284)	t(276) = -1.24, p = 0.22	4.22 ± 1.76 (229)	4.07 ± 1.78 (75)	F(1,298) = 0.40, p = 0.53	4.29 ± 1.86 (217)	4.2 ± 1.9 (71)	F(1,282) = 0.13, p = 0.71
Tablet CA	3.17 ± 1.92 (90)	3.42 ± 1.98 (84)	t(69) = - 1.83, p = 0.07	3.25 ± 1.9 (86)	2.82 ± 2.01 (23)	F(1,88) = 2.47, p = 0.42	3.52 ± 1.99 (80)	2.93 ± 1.91 (20)	F(1, 82) = 1.09, p = 0.30
E-reader CA	2.5 ± 1.93 (34)	2.75 ± 1.98 (36)	t(23) = - 0.34, p = 0.07	2.54 ± 1.84 (41)	2.4 ± 2.22 (16)	F(1,32) = 0.04, p = 0.85	2.96 ± 2.08 (32)	2.0 ± 1.41 (13)	F(,34) = 1.50, p = 0.23
Comp CA	3.41 ± 1.72 (227)	3.39 ± 1.87 (205)	t(187) = -0.08, p = 0.94	3.5 ± 1.76 (177)	3.19 ± 1.61 (69)	F(1,225) = 1.40, p = 0.24	3.47 ± 1.91 (154)	3.2 ± 1.79 (66)	F(1,203) = 0.93, p = 0.34

Note: TV = Television, MP = Mobile Phone, Comp = Computer, CA = Cognitive Arousal; results which are significant at p < 0 .05 are in **bold.**

This section has shown that that adolescents go to bed later, wake up later, spend a longer time in bed, spend a longer time asleep, have a better quality of sleep, wake feeling more refreshed, are more alert and are sleepier at the weekend than on weekdays. They also show that adolescents use watch TV and use their mobile phones later in the evening at the weekend than they do during the week. As this is the case, it is expected that weekday and weekend sleep will be predicted by different variables.

5.4.3. Adolescents who use their devices later in the evening had a poorer quality of sleep and went to bed later

Bivariate correlations were conducted to understand the relationships between device timing, duration, sleep, sleep hygiene and health risk factors. As seen in Figure 6, participants who finished watching TV later on weekday evenings went to bed later on weekdays, spent a shorter time in bed on weekdays and spent a shorter time asleep on weekdays. Adolescents who finished using their phone later on weekday evenings had a poorer quality of sleep on weekdays, went to bed later on weekdays, spent a shorter time in bed on weekdays and spent a shorter time asleep on weekdays. Adolescents who finished using their tablets later on weekday evenings spent a shorter time asleep on weekdays. Adolescents who finished using their computer later on weekdays went to bed later on weekdays, spent a shorter time in bed on weekdays and they spent a shorter time asleep on weekdays. Adolescents who were more cognitively stimulated from their tablet on weekdays woke feeling more refreshed on weekday mornings. Adolescents who were more cognitively stimulated from their e-reader on weekday evenings woke feeling more refreshed on weekday mornings and took a longer time to fall asleep on weekday evenings. There were fewer adolescents who used a tablet or an e-reader and so this may explain the unexpected result.

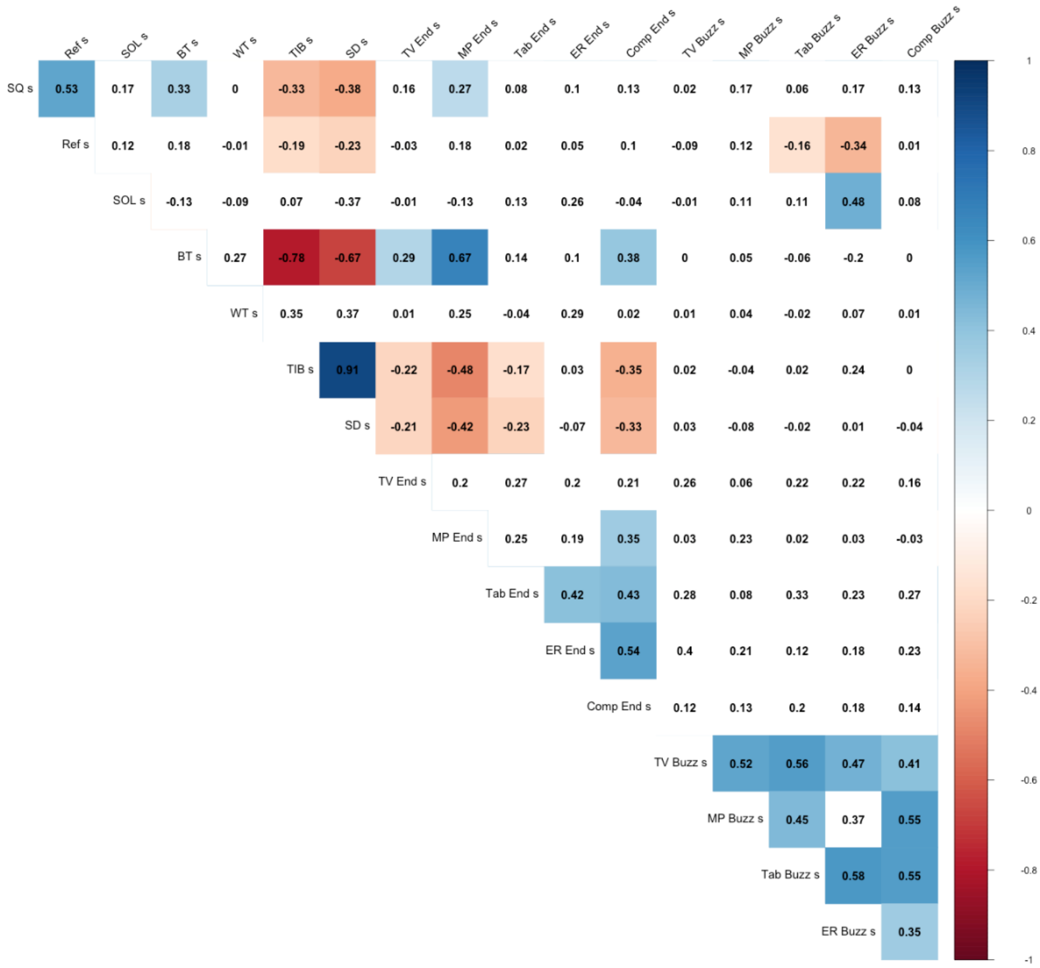

Figure 6 Correlation matrix for weekday sleep variables, weekday device end time and weekday device buzz.

Note: s indicates weekday, SQ = sleep quality, Ref = waking feeling refreshed, SOL = sleep onset latency, BT = bedtime, WT = wake time, TV End s = TV weekday end time, MP End s = Mobile Phone weekday end time, Tab End s = Tablet weekday end time, ER End s = E-reader weekday time, Comp End s = Computer weekday end time, TV Buzz s = TV weekday buzz, MP Buzz s = Mobile Phone weekday buzz, Tab Buzz s = Tablet weekday buzz, ER Buzz s = E-reader weekday buzz; Comp Buzz s = Computer weekday buzz; pairwise deletion used; n = 466 – 46. Devices such as E-readers and tablets were used least frequently hence the n range; 178 participants used TV; 304 used mobile phone; 109 used tablets; 57 used e-readers; 246 used computers. Significant values (p < 0.05) are shaded blue or red. Values which are shaded blue are positive correlations, values which are shaded red are negative correlations. The depth of colour indicates the strength of the correlation.

As can be seen in Figure 7 adolescents who finished watching TV later on weekend evenings went to bed later at the weekend. Adolescents who used their mobile phone later on weekend evenings had a poorer quality of sleep at the weekend, went to bed later on weekends, spent a shorter time in bed on weekends and spent a shorter time asleep at the weekend. Adolescents who used their tablet later on weekend evenings spent a shorter time asleep on weekends. Adolescents who used their computers later on weekend evenings went to bed later on weekends, spent a shorter time in bed on weekends and spent a shorter time asleep on weekends.

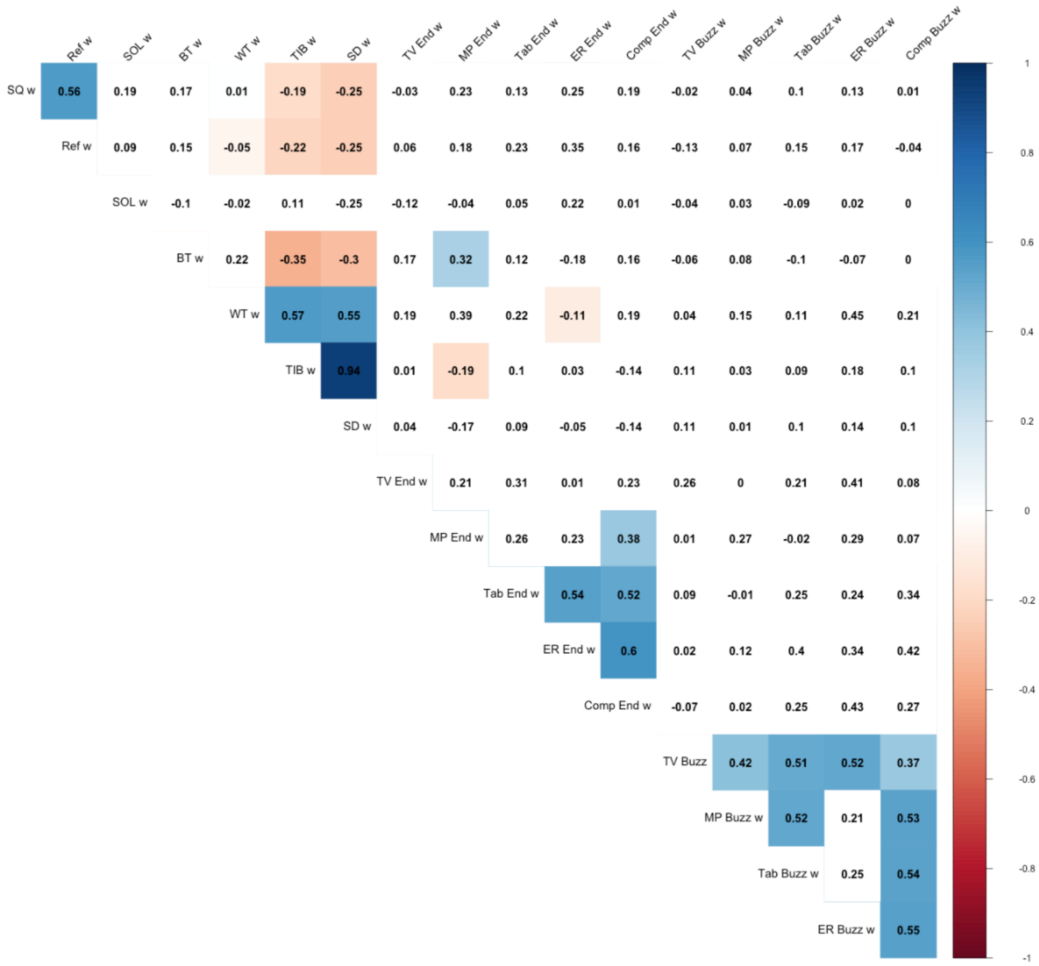

Figure 7 Correlation matrix for weekend sleep variables, weekend electronic device usage end time, weekend electronic device buzz.

Note: w indicates weekend, SQ = sleep quality, Ref = waking feeling refreshed, SOL = sleep onset latency, BT = bedtime, WT = wake time, TV End w = TV weekend end time, MP End w = Mobile Phone weekend end time, Tab End w = Tablet weekend end time, ER End w = E-reader weekend time, Comp End w = Computer weekend end time, TV Dur w = TV weekend buzz, MP Buzz w = Mobile Phone weekend buzz, Tab Buzz w = Tablet weekend end time, ER Buzz w = E-reader weekend buzz, Comp Buzz w = Computer weekend buzz; pairwise deletion used; n = 31 - 465. Devices such as E-readers and tablets were used least frequently hence the n range. 191 used TV; 288 used mobile phone; 100 used tablets; 45 used e-readers; 220 used computers. Significant values (p < 0.05) are shaded blue or red. Values which are shaded blue are positive correlations, values which are shaded red are negative correlations. The depth of colour indicates the strength of the correlation.

The correlations matrices both show that adolescents who used devices later in the evening had poorer sleep, later sleep timing and spent a shorter period of time asleep. Hierarchical linear regressions were then conducted to understand whether the timing and content that adolescents were viewing on their devices explained any unique variance within weekday and weekend sleep when it was combined with sleep hygiene and health risk factors. Table 32 provides an overview of all of the models which were examined and whether the model explained a significant proportion of variance. Any models which were not significant can be found in the appendices.

Table 32 Overview of hierarchical linear regressions models, R^2, Adjusted R^2, F statistics and p – values for model 1 and model 2 with significant predictors indicated.

	SQs	SQw	Refs	Refw	SOLs	SOLw	BTs	BTw	WTs	WTw	TIBs	TIBw	SDs	SDw	SAS	SAW	AAS	AAW	SIE
Model 1	AIC = 1544.28	AIC = 1563.01	AIC = 1569.68	AIC = 1563.01	R^2 = 0.01, Adj R^2 = -0.003, F(2,138) = 0.81, p = 0.45	R^2 = 0.005, Adj R^2 = -0.001, F(2,138) = 0.32, p = 0.73	**R^2 = 0.21, Adj R^2 = 0.20, F(2,138)= 18.35, p < 0.001**	**R^2 = 0.21, Adj R^2 = 0.20, F(2,138) = 18.35, p < 0.001**	**R^2 = 0.13, Adj R^2 = 0.11, F(2,138) = 9.95, p < 0.001**	**R^2 = 0.097, Adj R^2 = 0.084, F(2,138) = 7.42, p = 0.0009**	**R^2 = 0.06, Adj R^2 = 0.04, F(18, 138) = 4.22, p = 0.02**	R^2 = 0.0411, Adj R^2 = 0.0272, F(2,138) = 2.95, p = 0.0554	**R^2 = 0.05, Adj R^2 = 0.04, F(2,138) = 3.79, p = 0.02**	R^2 = 0.0410, Adj R^2 = 0.0271, F(2,138) = 2.948, p = 0.0558	R^2 = 0.013, Adj R^2 = -0.001, F(2,138) = 0.91, p = 0.41	**R^2 = 0.0439, Adj R^2 = 0.0301, F(2,138) = 3.17, p = 0.045**	R^2 = 0.039, Adj R^2 = 0.025, F(2,138) = 2.81, p = 0.064	**R^2 = 0.084, Adj R^2 = 0.0709, F(2,138) = 6.339, p = 0.002**	**R^2 = 0.07, Adj R^2 = 0.06, F(2,138) = 5.52, p = 0.005**
Sex (1 = Male; 2 = Female)																			
Age										✓	✓	✓	✓					✓	✓
Model 2	**AIC = 545.79**	**AIC = 577.78**	**AIC = 594.09**	**AIC = 577.78**	R^2 = 0.16, Adj R^2 = 0.03, F(18,122)= 1.25, p = 0.23	R^2 = 0.18, Adj R^2 = 0.06, F(18,122) = 1.5, p = 0.1	**R^2 = 0.54, Adj R^2 = 0.48, F(18,122) = 8.07, p < 0.001**	**R^2 = 0.54, Adj R^2 = 0.48, F(18,122) = 8.07, p < 0.001**	**R^2 = 0.26, Adj R^2 = 0.15, F(18, 122) = 2.38, p = 0.003**	**R^2 = 0.315 Adj R^2 = 0.214, F(18,122) = 3.123, p = 0.0001**	**R^2 = 0.36, Adj R^2 = 0.27, F(2,122) = 3.83, p < 0.001**	**R^2 = 0.2207, Adj R^2 = 0.1058, F(18,122) = 1.92, p = 0.0199**	**R^2 = 0.39, Adj R^2 = 0.30, F(18, 122) = 4.27, p < 0.001**	R^2 = 0.1837, Adj R^2 = 0.0633, F(18,122) = 1.53, p = 0.0922	**R^2 = 0.38, Adj R^2 = 0.28, F(18,122) = 4.07, p < 0.001**	**R^2 = 0.3296, Adj R^2 = 0.2307, F(18,122) = 3.33, p < 0.001**	**R^2 = 0.32, Adj R^2 = 0.22, F(18,122) = 3.22, p < 0.001**	**R^2 = 0.2394, Adj R^2 = 0.1271, F(18,122) = 2.133, p = 0.0082**	**R^2 = 0.40, Adj R^2 = 0.31, F(18,122) = 4.44, p < 0.001**
Sex (1 = Male; 2 = Female)														✓	✓				
Age																			
Type of student (1 = Day, 2 =									✓	✓	✓		✓						

Boarding student)																					
School start time																✓	✓		✓		✓
School end time																✓	✓				
Anxiety[a]				✓												✓	✓		✓		✓
Depression[a]																✓	✓				
Physiological arousal[b]		✓						✓	✓												
Behavioural arousal[b]			✓																		
Cognitive emotional arousal[b]			✓		✓																
Sleep environment[b]								✓	✓	✓	✓	✓	✓	✓	✓			✓		✓	
Sleep stability[b] (sleep/wake pattern regularity)	✓		✓			✓	✓							✓	✓						
Daytime sleepiness[b]														✓	✓			✓		✓	
Substance use[b] (alcohol and tobacco)			✓		✓	✓	✓							✓	✓						
Bedtime routine[b]	✓																				
Time that mobile phone was put down						✓	✓	✓	✓	✓	✓	✓	✓					✓		✓	

Time that computer was put down																		✓	✓
Mobile phone cognitive arousal																			
Computer cognitive arousal																		✓	✓

Note: $_s$ = weekday and $_w$ = weekend; SQ = sleep quality, Ref = waking feeling refreshed, SOL = sleep onset latency, BT = bedtime, WT = wake time, TIB = Time in bed, SD = Sleep duration, SAS = Sleepiness at school, SAW = Sleepiness at the weekend, AAS = Alertness at school, AAW = Alertness at the weekend, SIE = Sleepiness in the evening; [a] = Hospital Anxiety and Depression subscale; [b] = Adolescent Sleep Hygiene subscale; predictors for the significant models are identified with ✓ = significant predictor for the model. Models which were not significant ($p < 0.05$) do not have significant predictors. Boxes have been left blank to show that a variable is not a significant predictor. Significant models are in **bold.**

5.4.3.1. Bedtime

Study 1 showed that older adolescents went to bed later on both weekdays and at the weekend. As Carskadon (2011) argued, older adolescents are more independent than younger adolescents and so they can go to bed when they chose rather than relying on their parents putting them to bed. Carskadon also argued that as older adolescents have more freedom to choose their bedtime, they have a greater opportunity to use their devices in the evening before going to sleep which may then delay the time they go to sleep. This is supported by the findings in Table 32. Model 1 (sex and age) was a significant model of weekday bedtime explaining 21% of the variance in weekday bedtime ($R^2 = 0.21$, Adj $R^2 = 0.20$, $F(2,138) = 18.35$, $p < 0.001$). This model replicated the findings from study 1 by showing that older adolescents went to bed significantly later. Additional variables were included in Model 2 to understand whether age was still a significant predictor of weekday bedtime. Model 2 was also a significant model of weekday bedtime explaining 62% of the variance ($R^2 = 0.62$, Adj $R^2 = 0.55$, $F(19,107) = 9.25$, $p < 0.001$). This model showed that adolescents who used their mobile phone and their computer later in the evening went to bed later on weekdays. These findings support the idea that older adolescents had a greater opportunity to use devices later in the evening which further delayed the time they went to bed. Table 33 indicates the unstandardized beta values, standard error, standardised beta values and p -values for all predictors analysed.

Table 33 Hierarchical linear regression for the health risk factors predicting weekday bedtime

		Unstandardised B	Std. Error	β	t value	p value
Model 1	Intercept	2.95	0.05		61.71	< 0.001
	Sex (1 = Male; 2 = Female)	-0.003	0.01	-0.02	-0.22	0.83
	Age	**0.02**	**0.003**	**0.46**	**6.06**	**< 0.001**
Model 2	(Intercept)	2.80	0.17	< 0.001	16.64	< 0.001
	Sex (1 = Male; 2 = Female)	0.01	0.01	0.05	0.71	0.48
	Age	0.003	0.003	0.11	1.03	0.31
	Type of student (1 = Day, 2 = Boarder)	< 0.001	0.008	0.003	0.04	0.97
	School start time	-0.02	0.01	-0.09	-1.12	0.27
	School end time	0.003	0.004	0.08	0.76	0.45
	Anxiety[a]	-0.001	0.001	-0.08	-0.89	0.37
	Depression[a]	0.002	0.001	0.22	1.56	0.12
	Physiological arousal[b]	0.000	0.001	0.01	0.07	0.94
	Behavioural arousal[b]	0.001	0.001	0.060	0.713	0.477
	Cognitive emotional arousal[b]	< 0.001	0.001	0.003	0.04	0.97
	Sleep environment[b]	-0.002	0.001	-0.14	-1.83	0.07
	Sleep stability[b] (sleep/wake pattern regularity)	-0.001	0.001	-0.09	-1.27	0.21

Daytime sleepiness[b]	< 0.001	0.002	-0.003	-0.04	0.97
Substance use[b] (alcohol and tobacco)	0.001	0.003	0.02	0.21	0.83
Bedtime routine[b]	0.001	0.002	0.03	0.52	0.61
Time that mobile phone was put down on weekdays	**0.01**	**0.002**	**0.53**	**6.19**	**< 0.001**
Time that computer was put down on weekdays	**0.01**	**0.002**	**0.21**	**2.75**	**0.01**
Mobile phone cognitive arousal on weekdays	-0.001	0.002	-0.02	-0.26	0.79
Computer cognitive arousal on weekdays	-0.001	0.002	-0.04	-0.57	0.57

Note: [a] = Hospital Anxiety and Depression subscale; [b] = Adolescent Sleep Hygiene subscale; significant predictors are in **bold.**

As described above, study 1 showed that older adolescents went to bed later at the weekend too. Older adolescents are often allowed greater freedom to socialise with their friends in an evening or go to night-time parties which generally occur at the weekend. Older adolescents are also allowed to begin experimenting with substances such as alcohol and these are often consumed at these night-time parties. Additionally, approximately 67% of adolescents who had drank alcohol in the previous week had drunk on Saturday and 38% had drank alcohol on Friday (NHS England, 2019b). This is supported by the findings in Table 32. Model 1 (sex and age) was a significant model of weekend bedtime explaining 21% of the variance in weekend bedtimes ($R^2 = 0.21$, Adj $R^2 = 0.20$, $F(2,138) = 18.35$, $p < 0.001$). This model replicated the findings from study 1 by showing that older adolescents had later weekend bedtimes. Additional variables were included in Model 2 to understand whether age was still a significant predictor of weekend bedtime. Model 2 was also a significant model explaining 54% of the variance in weekend bedtimes ($R^2 = 0.54$, Adj $R^2 = 0.47$, $F(19,121) = 7.58$, $p < 0.001$). Adolescents who used their mobile phones later on a weekend evening, had less stable sleep and consumed more substances went to bed later on weekends. Table 34 indicates the unstandardized beta values, standard error, standardised beta values and p - values for all predictors analysed.

Table 34 Hierarchical linear regression for the health risk factors predicting weekend bedtime

		Unstandardised B	Std. Error	β	t value	p value
Model1	Intercept	2.95	0.05		61.71	
	Sex (1 = Male; 2 = Female)	-0.003	0.01	-0.02	-0.22	0.83
	Age	**0.02**	**0.003**	**0.46**	**6.06**	**< 0.001**
Model 2	(Intercept)	3.15	0.23	< 0.001	13.93	
	Sex (1 = Male; 2 = Female)	0.002	0.01	0.01	0.20	0.85
	Age	0.01	0.004	0.18	1.59	0.11
	Type of student (1 = Day, 2 = Boarder)	-0.002	0.011	-0.011	-0.14	0.89
	School start time	-0.02	0.02	-0.09	-1.16	0.25
	School end time	-0.001	0.01	-0.03	-0.26	0.80
	Anxiety[a]	-0.001	0.001	-0.06	-0.68	0.50
	Depression[a]	0.001	0.001	0.08	0.52	0.60
	Physiological arousal[b]	-0.002	0.001	-0.14	-1.68	0.10
	Behavioural arousal[b]	0.001	0.001	0.07	0.84	0.41
	Cognitive emotional arousal[b]	0.001	0.001	0.08	0.99	0.32
	Sleep environment[b]	-0.001	0.001	-0.04	-0.59	0.56
	Sleep stability[b] (sleep/wake pattern regularity)	**-0.003**	**0.001**	**-0.21**	**-2.91**	**0.004**
	Daytime sleepiness[b]	0.002	0.002	0.057	0.79	0.43
	Substance use[b] (alcohol and tobacco)	**-0.010**	**0.004**	**-0.19**	**-2.48**	**0.02**
	Bedtime routine[b]	-0.002	0.003	-0.05	-0.67	0.50
	Time that mobile phone was put down on weekdays	**0.01**	**0.003**	**0.47**	**5.07**	**< 0.001**
	Time that computer was put down on weekdays	0.002	0.002	0.07	0.89	0.37
	Mobile phone cognitive arousal on weekdays	-0.004	0.003	-0.11	-1.27	0.21
	Computer cognitive arousal on weekdays	0.003	0.003	0.09	1.07	0.29

Note: [a] = Hospital Anxiety and Depression subscale; [b] = Adolescent Sleep Hygiene subscale; significant predictors are in **bold**.

5.4.3.2. Sleep quality

The findings from study 1 suggested that adolescents who were anxious of staying in touch with their few friends frequently checked their phone during the night so that they could contribute to the conversations at school the following day. As seen in Table 32, model 2 was a better model of adolescents' quality of sleep on weekdays (AIC = 545.79) than model 1 (sex and age) (AIC = 1544.28). Additional variables were included in model 2 to examine the impact of electronic device usage, the school schedule, sleep hygiene and health risk factors on the quality of sleep individuals had on weekdays. Adolescents who were more physiologically aroused before going to bed were 1.02 times more likely to have a poorer quality of sleep. Adolescents who had less stable sleep were 1.00 times more likely to have a poorer quality of sleep on weekdays. Adolescents who had a poorer bedtime routine were 0.89 times more likely to have a poorer quality of sleep on weekdays. These findings show that the activities an adolescent engaged with just before going to bed affected the quality of their sleep that night and that those who went to bed and woke up later at the weekend than they did during the week had a poorer quality of sleep on weekdays. Log odds, exponentiated coefficients, standard error, t-values, p values and confidence intervals are shown in Table 35.

Table 35 Hierarchical linear regression for the health risk factors predicting weekday sleep quality

		Log Odds	Exp coef	Std. Error	t value	p value	2.5 CI	97.5 CI
Model 1	Intercept (1:2)	-0.68		0.81	-0.84	0.40		
	Intercept (2:3)	0.38		0.79	0.48	0.63		
	Intercept (3:4)	1.52		0.79	1.92	0.05		
	Intercept (4:5)	2.68		0.80	3.35	0.00		
	Intercept (5:6)	4.03		0.81	4.95	0.00		
	Intercept (6:7)	5.83		0.85	6.86	0.00		
	Sex (1 = Male; 2 = Female)	-0.01	0.99	0.22	-0.05	0.96	- 0.44	0.42
	Age	**0.16**	**1.17**	**0.05**	**3.42**	**< 0.001**	**0.07**	**0.25**
Model 2	Intercept (1:2)	-13.15		7.74	-1.70	0.09		
	Intercept (2:3)	-11.91		7.73	-1.54	0.12		
	Intercept (3:4)	-10.45		7.72	-1.35	0.18		
	Intercept (4:5)	-8.97		7.72	-1.16	0.24		
	Intercept (5:6)	-7.41		7.71	-0.96	0.34		
	Intercept (6:7)	-4.80		7.68	-0.62	0.53		
	Sex (1 = Male; 2 = Female)	-0.31	0.73	0.41	-0.75	0.45	-1.13	0.50
	Age	-0.15	0.86	0.16	-0.95	0.34	-0.47	0.16
	Type of student (1 = Day, 2 = Boarder)	0.30	1.35	0.40	0.76	0.45	-0.48	1.08
	School start time	-0.57	0.57	0.63	-0.91	0.37	-1.81	0.66
	School end time	-0.12	0.88	0.2	-0.61	0.54	-0.51	0.27
	Anxiety[a]	-0.57	0.90	0.63	-0.91	0.37	-1.81	0.66
	Depression[a]	-0.12	1.16	0.20	-0.61	0.54	-0.51	0.27
	Physiological arousal[b]	**0.15**	**1.02**	**0.05**	**2.90**	**< 0.001**	**0.05**	**0.25**
	Behavioural arousal[b]	0.02	1.04	0.05	0.53	0.60	-0.07	0.12
	Cognitive emotional arousal[b]	0.05	1.07	0.05	1.01	0.31	-0.04	0.14
	Sleep environment[b]	0.06	0.91	0.05	1.19	0.23	-0.04	0.17
	Sleep stability[b] (sleep/wake pattern regularity)	**-0.09**	**1.00**	**0.04**	**-2.66**	**0.01**	**-0.17**	**-0.03**
	Daytime sleepiness[b]	0.00	0.97	0.05	0.05	0.96	-0.10	0.10

	Substance use[b] (alcohol and tobacco)	-0.03	0.78	0.05	-0.64	0.52	-0.13	0.06
	Bedtime routine[b]	**-0.25**	**0.89**	**0.08**	**-3.11**	**< 0.001**	**-0.41**	**-0.09**
	Time that mobile phone was put down on weekdays	-0.12	0.98	0.11	-1.06	0.29	-0.35	0.10
	Time that computer was put down on weekdays	-0.02	1.15	0.10	-0.18	0.86	-0.21	0.17
	Mobile phone cognitive arousal on weekdays	0.12	0.99	0.11	1.02	0.31	-0.11	0.34
	Computer cognitive arousal on weekdays	-0.02	1.18	0.09	-0.20	0.84	-0.20	0.16

Note: [a] = Hospital Anxiety and Depression subscale; [b] = Adolescent Sleep Hygiene subscale; significant predictors are in **bold.**

The findings from study 1 suggested that adolescents who frequently checked their phone during the night had a poorer quality of sleep at the weekend. As seen in Table 32, model 2 was a better model of adolescents' quality of sleep at the weekend (AIC = 577.78) than model 1 (sex and age) (AIC = 1563.01). Additional variables were included in model 2 to examine the impact of electronic device usage, the school schedule, sleep hygiene and health risk factors on the quality of sleep individuals had at the weekend. Adolescents who were more behaviourally aroused were 1.11 times more likely to have a poorer quality of sleep at the weekend. Adolescents who were more physiologically aroused before going to bed were 1.02 times more likely to have a poorer quality of sleep. Adolescents who were more cognitively aroused were 0.92 times more likely to have a poorer quality of sleep at the weekend. Adolescents who had less stable sleep were 0.91 times more likely to have a poorer quality of sleep at the weekend. Adolescents who used more substances were 0.68 times more likely to have a poorer quality of sleep at the weekend. These findings show adolescents who engaged with devices, worried, or used substances before going to sleep had a poorer quality of sleep and that those who went to bed and woke up later at the weekend than they did during the week had a poorer quality of sleep on weekends. Log odds, exponentiated coefficients, standard error, t-values, p values and confidence intervals are shown in Table 36.

Table 36 Hierarchical linear regression for the health risk factors predicting weekend sleep quality

		Log Odds	Exp coef	Std. Error	t value	p value	2.5 CI	97.5 CI
Model 1	Intercept (1:2)	0.58		0.81	0.72	0.47		
	Intercept (2:3)	1.80		0.82	2.20	0.03		
	Intercept (3:4)	2.64		0.82	3.20	0.001		
	Intercept (4:5)	3.63		0.83	4.37	< 0.001		
	Intercept (5:6)	4.59		0.84	5.47	< 0.001		
	Intercept (6:7)	6.16		0.89	6.93	< 0.001		
	Sex (1 = Male; 2 = Female)	0.18	1.2	0.23	0.80	0.421	-0.26	0.63
	Age	**0.13**	**1.14**	**0.05**	**2.76**	**0.01**	**0.04**	**0.22**
Model 2	Intercept (1:2)	-14.92		7.79	-1.92	0.06		
	Intercept (2:3)	-13.42		7.78	-1.72	0.09		
	Intercept (3:4)	-12.23		7.77	-1.57	0.12		
	Intercept (4:5)	-11.32		7.77	-1.46	0.15		
	Intercept (5:6)	-10.21		7.76	-1.32	0.19		
	Intercept (6:7)	-7.72		7.72	-1.000	0.32		
	Sex (1 = Male; 2 = Female)	-0.76	0.47	0.41	-1.85	0.07	-1.57	0.05
	Age	0.04	1.04	0.15	0.26	0.79	-0.26	0.34
	Type of student (1 = Day, 2 = Boarder)	0.77	2.15	0.41	1.87	0.06	-0.04	1.57
	School start time	-0.73	0.48	0.63	-1.17	0.24	-1.97	0.51
	School end time	-0.02	0.98	0.20	-0.08	0.93	-0.41	0.37
	Anxiety[a]	0.08	1.08	0.05	1.56	0.12	-0.02	0.18
	Depression[a]	0.004	1.00	0.05	0.09	0.93	-0.08	0.09
	Physiological arousal[b]	-0.03	0.97	0.05	-0.64	0.52	-0.12	0.06
	Behavioural arousal[b]	**0.10**	**1.11**	**0.05**	**2.00**	**0.05**	**0.002**	**0.20**
	Cognitive emotional arousal[b]	**-0.08**	**0.92**	**0.03**	**-2.32**	**0.02**	**-0.15**	**-0.01**
	Sleep environment[b]	0.06	1.06	0.05	1.19	0.23	-0.04	0.15
	Sleep stability[b] (sleep/wake pattern regularity)	**-0.09**	**0.91**	**0.05**	**-1.98**	**0.05**	**-0.18**	**-0.001**
	Daytime sleepiness[b]	0.03	1.03	0.07	0.46	0.64	-0.11	0.18
	Substance use[b] (alcohol and tobacco)	**-0.39**	**0.68**	**0.12**	**-3.23**	**0.001**	**-0.63**	**-0.16**
	Bedtime routine[b]	0.004	1.00	0.09	0.04	0.97	-0.18	0.19
	Time that mobile phone was put down on weekdays	-0.05	0.95	0.12	-0.44	0.66	-0.28	0.17
	Time that computer was put down on weekdays	-0.08	0.92	0.09	-0.91	0.36	-0.25	0.09
	Mobile phone cognitive arousal on weekdays	0.15	1.17	0.11	1.44	0.15	-0.06	0.37
	Computer cognitive arousal on weekdays	-0.02	0.98	0.10	-0.23	0.82	-0.23	0.18

Note: [a] = Hospital Anxiety and Depression subscale; [b] = Adolescent Sleep Hygiene subscale; significant predictors are in **bold.**

5.4.3.3. Waking feeling refreshed

As can be seen in Table 32, model 2 was a better model of how refreshed adolescents felt upon waking on weekdays (AIC = 594.09) than model 1 (sex and age) (AIC = 1569.68). Additional variables were included in model 2 to examine the impact of electronic device usage, the school schedule, sleep hygiene and health risk factors on how refreshed the individual felt upon waking. Anxious adolescents were 1.15 times more likely to wake up feeling less refreshed on weekdays. Log odds, exponentiated coefficients, standard error, t-values, p values and confidence intervals are shown in Table 37.

Table 37 Hierarchical linear regression for the health risk factors predicting weekday waking feeling refreshed

		Log odds	Exp coef	Std. Error	t value	p value	2.5 CI	97.5 CI
Model 1	Intercept 1:2	-1.79		0.79	-2.28	0.02		
	Intercept 2:3	-0.33		0.74	-0.45	0.65		
	Intercept 3:4	0.70		0.73	0.96	0.34		
	Intercept 4:5	1.64		0.73	2.25	0.02		
	Intercept 5:6	2.82		0.74	3.81	0.00		
	Intercept 6:7	4.14		0.75	5.51	0.00		
	Sex	0.46	1.58	0.23	2.03	0.04	0.02	0.90
	Age	**0.12**	**1.12**	**0.05**	**2.50**	**0.01**	**0.03**	**0.21**
Model 2	Intercept 1:2	-7.77		7.80	-1.00	0.32		
	Intercept 2:3	-6.41		7.78	-0.82	0.41		
	Intercept 3:4	-5.33		7.77	-0.69	0.49		
	Intercept 4:5	-4.08		7.77	-0.53	0.60		
	Intercept 5:6	-2.91		7.77	-0.37	0.71		
	Intercept 6:7	-1.42		7.77	-0.18	0.86		
	Sex (1 = Male; 2 = Female)	0.19	1.21	0.41	0.47	0.64	-0.62	1.01
	Age	-0.09	0.91	0.15	-0.62	0.53	-0.38	0.20
	Type of student (1 = Day, 2 = Boarder)	0.22	1.24	0.38	0.58	0.56	-0.53	0.97
	School start time	-0.19	0.83	0.65	-0.29	0.77	-1.48	1.08
	School end time	-0.17	0.84	0.19	-0.89	0.37	-0.56	0.21
	Anxiety[a]	**0.14**	**1.15**	**0.05**	**2.69**	**0.01**	**0.04**	**0.25**
	Depression[a]	-0.01	0.99	0.05	-0.21	0.84	-0.10	0.08
	Physiological arousal[b]	-0.01	0.99	0.05	-0.26	0.80	-0.10	0.08
	Behavioural arousal[b]	-0.08	0.92	0.05	-1.55	0.12	-0.18	0.02
	Cognitive emotional arousal[b]	-0.05	0.95	0.03	-1.40	0.16	-0.12	0.02
	Sleep environment[b]	0.05	1.05	0.05	0.95	0.34	-0.05	0.14
	Sleep stability[b] (sleep/wake pattern regularity)	0.03	1.03	0.05	0.59	0.56	-0.06	0.12
	Daytime sleepiness[b]	0.01	1.01	0.07	0.17	0.86	-0.13	0.16
	Substance use[b] (alcohol and tobacco)	-0.01	0.99	0.12	-0.11	0.92	-0.25	0.22
	Bedtime routine[b]	-0.10	0.90	0.09	-1.09	0.28	-0.29	0.08

	Time that mobile phone was put down on weekdays	0.12	1.13	0.11	1.11	0.27	-0.10	0.34
	Time that computer was put down on weekdays	-0.04	0.96	0.09	-0.50	0.62	-0.22	0.13
	Mobile phone cognitive arousal on weekdays	0.00	1.00	0.11	-0.01	0.99	-0.22	0.22
	Computer cognitive arousal on weekdays	-0.03	0.97	0.11	-0.29	0.77	-0.25	0.18

Note: [a] = Hospital Anxiety and Depression subscale; [b] = Adolescent Sleep Hygiene subscale; significant predictors are in **bold.**

As can be seen in Table 32, model 2 was a better model of how refreshed individuals felt upon waking on weekends (AIC = 577.78) than model 1 (sex and age) (AIC = 1563.01). Additional variables were included in model 2 to examine the impact of electronic device usage, the school schedule, sleep hygiene and health risk factors on how refreshed individuals felt upon waking on weekends. Adolescents who were more cognitively aroused before going to sleep were 0.92 times more likely to wake up feeling less refreshed at the weekend. Adolescents who consumed more substances were 0.68 times more likely to wake up feeling less refreshed at the weekend. Log odds, exponentiated coefficients, standard error, t-values, p values and confidence intervals are shown in Table 38.

Table 38 Hierarchical linear regression for the health risk factors predicting weekend waking feeling refreshed

		Log Odds	Exp coef	Std. Error	t value	p value	2.5 CI	97.5 CI
Model 1	Intercept (1:2)	0.40		0.73	0.55	0.58		
	Intercept (2:3)	1.62		0.73	2.21	0.03		
	Intercept (3:4	2.45		0.74	3.32	0.00		
	Intercept (4:5)	3.44		0.75	4.62	0.00		
	Intercept (5:6)	4.41		0.76	5.83	0.00		
	Intercept (6:7)	5.97		0.81	7.37	0.00		
	Sex	0.18	1.2	0.23	0.80	0.42	-0.26	0.63
	Age	**0.13**	**1.14**	**0.05**	**2.76**	**0.01**	**0.04**	**0.22**
Model 2	Intercept (1:2)	-14.16		7.73	-1.83	0.07		
	Intercept (2:3)	-12.66		7.72	-1.64	0.10		
	Intercept (3:4	-11.47		7.71	-1.49	0.14		
	Intercept (4:5)	-10.57		7.70	-1.37	0.17		
	Intercept (5:6)	-9.46		7.69	-1.23	0.22		
	Intercept (6:7)	-6.96		7.65	-0.91	0.36		
	Sex (1 = Male; 2 = Female)	-0.76	0.47	0.41	-1.84	0.07	-1.57	0.05
	Age	0.04	1.04	0.15	0.26	0.79	-0.26	0.34
	Type of student (1 = Day, 2 = Boarder)	0.77	2.15	0.41	1.87	0.06	-0.04	1.57
	School start time	-0.73	0.48	0.63	-1.17	0.24	-1.97	0.51
	School end time	-0.02	0.98	0.20	-0.08	0.93	-0.41	0.37
	Anxiety[a]	0.08	1.08	0.05	1.56	0.12	-0.02	0.18
	Depression[a]	0.00	1.00	0.05	0.09	0.93	-0.08	0.09

Physiological arousal[b]	-0.03	0.97	0.05	-0.64	0.52	-0.12	0.06
Behavioural arousal[b]	**0.10**	**1.11**	**0.05**	**2.00**	**0.05**	**0.00**	**0.20**
Cognitive emotional arousal[b]	**-0.08**	**0.92**	**0.03**	**-2.32**	**0.02**	**-0.15**	**-0.01**
Sleep environment[b]	0.06	1.06	0.05	1.19	0.23	-0.04	0.15
Sleep stability[b] (sleep/wake pattern regularity)	-0.09	0.91	0.05	-1.98	0.05	-0.18	0.00
Daytime sleepiness[b]	0.03	1.03	0.07	0.46	0.64	-0.11	0.18
Substance use[b] (alcohol and tobacco)	**-0.39**	**0.68**	**0.12**	**-3.23**	**< 0.001**	**-0.63**	**-0.16**
Bedtime routine[b]	0.00	1.00	0.09	0.04	0.97	-0.18	0.19
Time that mobile phone was put down on weekdays	-0.05	0.95	0.11	-0.44	0.66	-0.28	0.17
Time that computer was put down on weekdays	-0.08	0.92	0.09	-0.91	0.36	-0.25	0.09
Mobile phone cognitive arousal on weekdays	0.15	1.17	0.11	1.44	0.15	-0.05	0.37
Computer cognitive arousal on weekdays	-0.02	0.98	0.10	-0.23	0.82	-0.23	0.18

Note: [a] = Hospital Anxiety and Depression subscale; [b] = Adolescent Sleep Hygiene subscale; significant predictors are in **bold.**

5.4.3.4. Wake Time

As can be seen in Table 32, model 1 (sex and age) was a significant model of weekday wake time explaining 13% of the variance ($R^2 = 0.13$, Adj $R^2 = 0.11$, $F(2,138) = 9.95$, $p < 0.001$). Older individuals woke up later on weekdays. Additional variables were included in Model 2 to examine the impact of electronic device usage, the school schedule, sleep hygiene and health risk factors on the time individuals woke up at on weekdays. Model 2 explained 40% of the variance in weekday wake time ($R^2 = 0.40$, Adj $R^2 = 0.29$, $F(19,107) = 3.7$, $p < 0.001$). Adolescents who boarded at school, used their computer earlier in the evening, had less stable sleep and were more depressed woke up later on weekdays. Table 39 indicates the unstandardized beta values, standard error, standardised beta values and p -values for all predictors analysed.

Table 39 Hierarchical linear regression for the health risk factors predicting weekday wake time

		Unstandardised B	Std. Error	β	t value	p value
Model1	Intercept	28.73	0.54		53.03	
	Sex (1 = Male; 2 = Female)	-0.05	0.14	-0.03	-0.36	0.72
	Age	**0.14**	**0.03**	**0.36**	**4.46**	**< 0.001**
Model 2	(Intercept)	29.74	3.02	< 0.001	9.84	
	Sex (1 = Male; 2 = Female)	-0.24	0.15	-0.14	-1.63	0.11
	Age	0.04	0.06	0.11	0.77	0.44
	Type of student (1 = Day, 2 = Boarder)	**0.50**	**0.14**	**0.33**	**3.55**	**0.001**
	School start time	-0.04	0.24	-0.02	-0.15	0.88
	School end time	0.03	0.07	0.05	0.36	0.72
	Anxiety[a]	-0.003	0.02	-0.02	-0.17	0.86

Depression[a]	**0.04**	**0.02**	**0.38**	**2.07**	**0.04**
Physiological arousal[b]	-0.02	0.02	-0.13	-1.26	0.21
Behavioural arousal[b]	-0.01	0.02	-0.07	-0.65	0.51
Cognitive emotional arousal[b]	-0.002	0.01	-0.02	-0.16	0.87
Sleep environment[b]	0.04	0.02	0.17	1.76	0.08
Sleep stability[b] (sleep/wake pattern regularity)	**-0.04**	**0.02**	**-0.22**	**-2.48**	**0.02**
Daytime sleepiness[b]	0.04	0.03	0.12	1.33	0.19
Substance use[b] (alcohol and tobacco)	-0.07	0.05	-0.12	-1.33	0.19
Bedtime routine[b]	0.04	0.04	0.09	1.10	0.27
Time that mobile phone was put down on weekdays	0.08	0.04	0.20	1.89	0.06
Time that computer was put down on weekdays	**-0.08**	**0.04**	**-0.20**	**-2.11**	**0.04**
Mobile phone cognitive arousal on weekdays	-0.04	0.04	-0.10	-0.94	0.35
Computer cognitive arousal on weekdays	0.06	0.04	0.15	1.46	0.15

Note: *a* = Hospital Anxiety and Depression subscale; b = Adolescent Sleep Hygiene subscale; significant predictors are in **bold.**

As can be seen in Table 32, model 1 (sex and age) was a significant model of weekend wake time explaining 9.7% of the variance ($R^2 = 0.097$, Adj $R^2 = 0.084$, $F(2,138) = 7.42$, $p = 0.0009$). Older adolescents woke up later at the weekend. Carskadon et al (1993; 1998) showed that the circadian rhythm becomes naturally delayed during adolescence. This means that older adolescents go to bed and sleep later, and they will also wake later, especially when their sleep is not restricted by the school schedule. Additional variables were included in Model 2 to examine the impact of electronic device usage, the school schedule, sleep hygiene and health risk factors on the time individuals woke up at on weekends. Model 2 was also a significant model of weekend waketime explaining 35% of the variance ($R^2 = 0.35$, Adj $R^2 = 0.24$, $F(19,121) = 3.36$, $p < 0.001$). Adolescents were day students, who used their mobile phone later on weekend evenings, had less stable sleep and were more cognitively aroused woke up later on weekends. Table 40 indicates the unstandardized beta values, standard error, standardised beta values and p -values for all predictors analysed.

Table 40 Hierarchical linear regression for the health risk factors predicting weekend wake time

		Unstandardised B	Std. Error	β	t value	p value
Model1	Intercept	29.85	1.12		26.76	< 0.001
	Sex (1 = Male; 2 = Female)	-0.25	0.28	-0.07	-0.88	0.38
	Age	0.25	0.07	0.31	3.78	< 0.001
Model 2	(Intercept)	3.54	0.17	< 0.001	20.58	< 0.001
	Sex (1 = Male; 2 = Female)	-0.01	0.01	-0.06	-0.75	0.45
	Age	0.003	0.003	0.14	1.03	0.30
	Type of student (1 = Day, 2 = Boarder)	-0.02	0.01	-0.201	-2.24	0.03

School start time	-0.01	0.01	-0.05	-0.56	0.58
School end time	-0.001	0.004	-0.04	-0.29	0.77
Anxiety[a]	-0.002	0.001	-0.15	-1.49	0.14
Depression[a]	0.0002	0.001	0.03	0.15	0.88
Physiological arousal[b]	-0.001	0.001	-0.07	-0.74	0.46
Behavioural arousal[b]	0.001	0.001	0.12	1.15	0.25
Cognitive emotional arousal[b]	**-0.002**	**0.001**	**-0.24**	**-2.36**	**0.02**
Sleep environment[b]	0.001	0.001	0.05	0.55	0.58
Sleep stability[b] (sleep/wake pattern regularity)	**-0.003**	**0.001**	**-0.27**	**-3.12**	**0.002**
Daytime sleepiness[b]	-0.001	0.002	-0.06	-0.67	0.50
Substance use[b] (alcohol and tobacco)	0.002	0.003	0.07	0.79	0.43
Bedtime routine[b]	-0.001	0.002	-0.03	-0.31	0.76
Time that mobile phone was put down on weekdays	**0.006**	**0.002**	**0.331**	**2.98**	**0.003**
Time that computer was put down on weekdays	-0.001	0.002	-0.08	-0.86	0.39
Mobile phone cognitive arousal on weekdays	-0.002	0.002	-0.09	-0.87	0.39
Computer cognitive arousal on weekdays	0.004	0.002	0.18	1.73	0.09

Note: [a] = Hospital Anxiety and Depression subscale; [b] = Adolescent Sleep Hygiene subscale; significant predictors are in **bold.**

5.5. <u>Discussion</u>

5.5.1. The purpose of the study

The current study was similar to study 1 in that the purpose was to establish how weekday and weekend sleep were different to each other, how electronic device use affected sleep and how adolescents' health risk factors affected their weekday and weekend sleep. The findings from study 1 showed that more frequent electronic device usage impacted adolescents' sleep, however it was unclear *how* electronic devices affected sleep. The current study used better measures of electronic device use which asked adolescents to declare the time they began and finished using each device and how cognitively aroused adolescents felt. The current study also included the Adolescent Sleep Hygiene scale which measured substance use[149], cognitive – emotional arousal and sleep stability across weekdays and at the weekend, which have been reported to affect adolescents' sleep (Royal College of Paediatric and Child Health, 2017; Bartel et al, 2016). Study 1 also showed that adolescents who went to boarding schools went to bed later, fell asleep quicker, spent a longer time in bed and woke up later than adolescents who went to day schools. The current study asked students whether they

[149] The substance use measure from Adolescent Sleep Hygiene scale measures alcohol and tobacco use.

were a boarding or day student to ascertain the true impact of living at school. The purpose of the current study was to understand whether weekday and weekend sleep differed to each other, how health risk factors, electronic device use and sleep hygiene explained weekday and weekend sleep, how device use was related to sleep and how being a boarding student further impacted their sleep.

5.5.2. The study's results

Study 1 found that there were significant differences between weekday and weekend sleep. The current study also examined whether weekday and weekend sleep were different to each other, and the findings exactly replicated the findings from study 1. Adolescents had a better quality of sleep, woke feeling more refreshed, went to bed later, woke up later, spent a longer time in bed and spent a longer time asleep on weekends than on weekdays. These findings were expected, supported the first hypothesis and supported the rationale for investigating weekday and weekend sleep separately.

There were also significant differences in boarding and day students' sleep. Boarding students had a better quality of sleep on weekdays, woke up earlier at the weekend and were less sleepy at the weekend. Boarding students had more consistent sleep/wake schedules than day students. Wolfson and Carskadon (1998) noted that adolescents who had irregular sleep/wake schedules were sleepier than adolescents who had more consistent sleep/wake schedules. Whilst the aim was to recruit similar numbers of day: boarding students, here were considerably more day students than boarding students who took part in the survey and this may have influenced the finding. Thus, the current study's findings show that adolescents who have more regular or consistent sleep/wake schedules report a better quality of sleep and feeling more refreshed the following morning.

The correlational findings from the current study show that the adolescents who used their devices later in the evening and used their devices for longer periods of time on both weekdays and at the weekend had a poorer quality of sleep and slept for a shorter length of time. Adolescents who watched TV later in the evening, used their mobile phone later in the evening, used their tablets later in the evening, used their computers later in the evening, spent a longer time watching TV, spent a longer time on their mobile phones and spent a longer time on their computers went to bed later, spent a shorter time in bed, spent a shorter time asleep and had a poorer quality of sleep. These findings show that adolescents who used their devices later in the evening spent a shorter time asleep and had a poorer quality of sleep. These findings may show that the devices delayed the onset of sleep.

Hierarchical linear regressions were also conducted in the current study. When only sex and age were included in the model, age was a significant predictor of weekday and weekend bedtime. This shows that older adolescents went to bed later on weekdays. Once other factors had been included in the model, age was no longer a significant predictor of weekday bedtime. Adolescents who used their mobile phone and computer later in the evening went to bed later on weekdays. These findings show that age was explaining the variance attributable to the time adolescents put their mobile phone and computer down. Older adolescents may have gone to bed later because their homeostatic sleep pressure accumulated at a slower rate and their circadian rhythm was delayed, which meant that the older adolescents felt sleepy later in the evening. Older adolescents may have further delayed their naturally delayed circadian rhythm by using devices in the evening which may have increased how alert they feel (Carskadon, 2011). This supports the current study's findings and shows that older adolescents use their mobile phones and computers later in the evening which further delayed the time they went to bed.

Adolescents who used their mobile phones later in the evening also woke up later and woke up feeling less refreshed at the weekend. As previously mentioned, adolescents who used their devices later in the evening also went to bed later on weekdays and at the weekend. These findings support one another. Adolescents who used their devices later on either weekday or weekend evenings went to bed later. The school schedule restricts the time that adolescents can wake up at on weekdays and so they do not get enough sleep during the week. This means that the adolescents acquired sleep debt, which needed repaying at the weekend. Adolescents who used their devices later on a weekend evening also went to bed later. Weekend sleep is not restricted in the same way that weekday sleep is. They were able to wake up later at the weekend to repay the sleep debt that they had acquired during the week.

Sleep quality and waking feeling refreshed were both predicted by states of high arousal. Adolescents who were more physiologically aroused had a poorer weekday sleep quality, adolescents who were more cognitively aroused before going to sleep had a poorer weekend sleep quality. Similarly, adolescents who were more anxious woke feeling less refreshed during the week and adolescents who were more cognitively aroused before going to sleep woke feeling less refreshed on weekends. These findings suggest that being in a state of high arousal or anxiousness before going to sleep may affect sleep quality or how refreshed the adolescent felt upon waking the following morning because the individual found it harder to fall or stay asleep.

5.5.3. How do the results fit with previous research?

Several research studies, including the first study of this doctoral thesis, have shown that weekday and weekend sleep are different. Carskadon and colleagues (Anders et al, 1980; Carskadon et al, 1998) were amongst the first to observe a difference between weekday and weekend sleep. The school schedule is, at least in part, responsible for the differences in when adolescents go to bed, wake up and how long they sleep for on weekdays and at the weekend. The current study has shown that adolescents went to bed later, woke up later, spent a longer time in bed, spent a longer time asleep, had a better quality of sleep, woke feeling more refreshed, were more alert and were sleepier at the weekend. These findings replicate the findings from study 1 and previous studies' findings (Allen and Mirable, 1989; Carskadon, 1990; Carskadon et al, 1998; Wahlstrom et al, 1997; Wahlstrom et al, 2014; Owens et al, 2010; Boergers et al, 2014; Chan et al, 2018). These findings also further support the argument that weekday and weekend sleep should be examined separately.

The current study also found that adolescents who boarded at school woke up later on weekdays. This finding was expected as boarding students have a shorter commute to school than day students do. A longer commute means that an adolescent must wake up earlier than a student with a shorter commute. This finding supports Owens et al (2010) who also reported that boarding students woke up later than day students did. The model also showed that adolescents who were more depressed woke up later. Interestingly, Owens et al (2010) reported that adolescents who woke up later on weekdays were less depressed. It is possible that the different findings are due to the studies being conducted in different countries where the school day begins at slightly different times. Owens and colleagues' study was conducted in America where the typical high school/ secondary school start time (07:30am) is earlier than that in the UK (08:30 – 09:00am). Thus, the relationship between wake time and depression may not be linear, the relationship may be U-shaped. The final study will build upon these findings and will examine whether boarding and day students' sleep and their mood differ as function of their electronic device use.

Understanding how adolescents' health risk factors affect their sleep is important in being able to provide accurate advice on how to improve sleep quality and duration. Sleep hygiene has been reported to be an important predictor of weekday and weekend sleep by several researchers and so it was included in the hierarchical linear regression model. Brown et al (2002) showed that sleep hygiene practices, including worrying whilst falling asleep and sleep stability, contributed to poor sleep quality. This supports the current study's findings that adolescents who were more physiologically aroused, had a less stable sleep/wake pattern and had a poorer bedtime routine had a poorer quality of sleep and that adolescents who were more anxious woke feeling less refreshed at the weekend.

The current study has also shown that adolescents who used their mobile phone and computer later in the evening went to bed later on weekdays. This finding supports previous work by Bartel et al (2016) who investigated the impact of health risk and protective factors on Australian, Dutch and Canadian adolescents. Their findings showed that weekday bedtime was predicted by the time that adolescents finished using their mobile phone and the internet. Taken together the two findings suggest that adolescents use their mobile phones and computers up until they go to bed and so they may delay the time they go to bed to use their devices. Bartel and colleagues also showed that weekday sleep duration was predicted by the time adolescents stopped using the internet, how much alcohol they consumed and how worried they felt before going to sleep. In comparison, the current study found that weekday sleep duration was predicted by the time an adolescent finished using their mobile phone or computer, how comfortable their sleep environment was and whether they were a boarding or day student. The differences in these predictors between the two studies may reflect the sample of adolescents who were recruited for the studies. The current study used boarding and day students, the majority of which were < 18 years old and so are unlikely to have access to alcohol, especially during the week. However, Bartel et al (2016) used adolescents who were not part of a boarding school and so they may have had greater access to substances during the week.

Adolescents who consumed more alcohol and tobacco went to bed later at the weekend. Moreover, adolescents who consumed more alcohol and tobacco woke feeling less refreshed at the weekend. These findings were anticipated as recent statistics show that approximately 67% of adolescents who had drank alcohol in the previous week had drunk on Saturday and 38% had drank alcohol on Friday (NHS England, 2019b). This is presumably because adolescents use alcohol and tobacco whilst they are socialising with their friends which often happens on weekend evenings. These findings also partially support Pasch et al (2012) who found that adolescents who consumed alcohol slept for a shorter period of time at the weekend and did not extend their weekend sleep as much. Alcohol is known to reduce sleep onset latency, increase slow wave sleep in the first half of the night, disrupt sleep and increase wakefulness or stage 1 sleep in the second half of the night (Williams et al, 1983; Van Reen et al 2006). Furthermore, della Monica et al (2014) showed that the variable “waking feeling refreshed” was correlated with the number of awakenings during the night. Thus, it was not surprising to find that adolescents who consumed alcohol woke feeling less refreshed as alcohol is known to increase wakefulness especially in the second half of the night.

Adolescents who used their mobile phone later in the evening went to bed later at the weekend. This finding is in contrast to Gradisar et al (2013) finding that device use did not predict later bedtimes. The differences between the current study's findings and Gradisar and colleagues study findings may be due to the sample each study used. Whilst Gradisar and colleagues' study had a large overall sample, only 171 participants were aged 13 – 18 years old, whereas the current study recruited 489 adolescents. In addition, the results are based on the entire sample (aged 13 – 64 years) and it is unlikely that a sample in which approximately 70% of participants are 30+ years will reflect the same behaviours of a sample aged 11 – 18-year-olds.

5.5.4. Evaluation of the study

The current study was designed based on the findings from study 1. The study examined how the timing, the duration of device use and how cognitively aroused adolescents feel after using their devices affects their sleep and mood. The current study also compared day and boarding students' sleep. This is important as boarding schools provide an opportunity to examine how their sleep differs to adolescents who commute to school. Boarding and day students will be compared again in study 3 as this is an under-researched area.

5.5.4.1. Limitations

The findings from the current study are restricted by its limitations. It is possible that weekend sleep models do not explain as much variance as the models of weekday sleep as participants answered the questions about their weekend sleep during the school week. Participants were required to answer the questions about their weekend sleep retrospectively and so their answers may have been influenced by their previous night's sleep.

In addition, a larger sample was anticipated and would have improved the generalisability of the findings. The survey data was collected during the Covid-19 pandemic. Data could not be collected whilst adolescents were not attending school as sleep during lockdown, across all age groups, was very different to sleep during a typical week (Blume et al, 2020). It was challenging to recruit schools in September 2020 when they returned as schools were less interested in taking part as students and teachers needed to concentrate on catching up on their curriculum.

The measure of substance use was taken from ASHS. The items which were used to measure adolescents' substance intake did not indicate whether the question referred to either weekday or weekend use. According to recent findings, 67% of adolescents who had consumed alcohol in the week prior consumed alcohol on Saturday night and 38% consumed alcohol on Friday night (weekend night) (NHS England, 2019b). As the questions measuring substance use did not specify the day of the week, the findings regarding substance use should be interpreted with caution.

The device use measure used in this study was designed to understand how electronic devices affected weekday and weekend sleep. There was no measure of whether adolescents were using a blue light screen filter on their devices. Van der Lely et al (2015) showed that adolescents who used blue blocker glasses whilst using a light emitting device reported feeling less alert and sleepier than adolescents who wore clear goggles whilst using a light emitting device. It would have been helpful to know whether participants responses were based on them using a blue light screen filter on their device. This will be rectified in the final study.

5.5.5. Improvements for study 3

This study has shown that using devices later in the evening and using devices for a longer period of time predict weekday and weekend sleep. The third and final study of this doctoral thesis will measure sleep using daily diaries. As noted in study 1 and again in study 2, the models were able to explain weekday sleep much better than weekend sleep. This is probably because the participants answered the survey during the school week and so their responses will have been influenced by the previous night's sleep. Study 3 will measure sleep using daily diaries.

Study 3 will also use a combination of subjective and objective measures of sleep and electronic device usage. Study 1 and study 2 have both relied upon subjective reports of sleep, electronic device usage and measures of wellbeing and so the findings from both of these studies are somewhat limited in their accuracy. Study 3 will use actimetry to objectively measure sleep and smartphone screen time apps to objectively measure electronic device usage. Daily diaries will be used to subjectively measure sleep and electronic device usage.

The ASHS has a subscale which measures substance use. It was decided that this subscale would be used as a measure of substance use to avoid lengthening the survey. The questions on the substance use subscale asked about general substance use. They do not pertain to either weekdays or the weekend. Questions which specifically asked about weekday and weekend substance use would have allowed for more accurate conclusions to be made about how substance use affected adolescents' sleep patterns.

Finally, study 3 will also assess the impact of electronic device usage on sleep and the effect this then has on state mood. Whilst study 1 and study 2 have shown that electronic device usage predicts poorer sleep and wellbeing it is important to examine the impact of poor sleep on state mood. Thus, study 3 will examine the impact of electronic device use on sleep and state mood as this will show how device usage affects sleep on a daily basis.

5.6. Conclusion

The current study has found that adolescents who used their devices later in the evening and for a longer period of time went to bed later and had a poorer quality of sleep. This supports previous research studies which have also shown that frequent device usage has a negative impact on adolescents' sleep.

Interestingly, adolescents' electronic device use affected their weekday sleep to a larger extent than their weekend sleep, which may be due to adolescents having the opportunity to extend their sleep at the weekend. This may also be due to adolescents completing the survey on a weekday. Adolescents who use their devices later on a weekend evening went to bed at a later time, they also woke up later on the following morning. This is because there are fewer restrictions on when the adolescent must wake up at the weekend. Study 3 will use daily diaries, smartphone screen time applications and actimetry to establish whether electronic device use predicted more variance in weekday sleep because weekdays are heavily restricted by the school schedule.

Differences were also noted between weekday and weekend sleep and boarding and day students' sleep. This not only supports the rationale for examining weekday and weekend sleep separately but also strengthens the rationale for investigating the differences between boarders and day students. Study 3 will build upon this by examining both boarding and day students.

Study 3 will draw upon these findings to establish how electronic device use (whether the blue light that devices emit, the content viewed on the devices or the time that the devices are used) affects weekday and weekend sleep and state mood.

6. Chapter 6: Study 3: To what extent does actual electronic device usage impact adolescents' actual sleep and following day mood?

6.1. Aims

1. To examine how device use affects sleep across a 14-day period.
    a. To examine how day and boarding students' sleep differ to each other.
2. To examine how poorer, ill-timed and shorter sleep affects positive and negative mood.

6.2. Introduction

The findings from study 2 showed that there were some differences between boarding and day students' sleep. Day students had a poorer quality of sleep on weekdays, woke up later at the weekend and felt sleepier at the weekend than boarding students did. The findings also showed that adolescents who used their mobile phone or computer later in the evening or used their mobile phones and computers for a longer period of time in the evening went to bed and woke up later. There are still a number of questions which remain unanswered.

Whilst the findings from study 2 showed that the adolescents who used their devices for a longer period of time and later in the evening delayed the time they went to bed and the time that they woke up at the following morning, the results are based on subjective reports rather than objective measures. These measures enabled us to assess relatively large numbers of adolescents, however the third and final study of this thesis will use a combination of methods to measure the impact of device use over a two-week period on state mood.

Secondly, study 1 and study 2 both asked participants to complete the survey on a single occasion. Often, participants completed the survey on a weekday at school. There were fewer significant models of weekend sleep, and this was probably because participants' responses were influenced by their most recent night's sleep and so the data which was collected was a better reflection of adolescents' weekday sleep. Study 3 will resolve this issue by collecting data using daily diaries over a 14-day period.

Thirdly, whilst study 2 asked adolescents whether they used a variety of devices, there was no real measure of blue light. Study 3 will resolve this issue by asking adolescents whether they had enabled a blue blocker screen on their device. Under normal circumstances[150] the

[150] Normal circumstances refers to a time when there are no social distancing restrictions for a global pandemic.

spectral characteristics of each device would have been measured; however, this study was conducted during the global Covid-19 pandemic and so the study was severely restricted.

6.2.1. Technology usage and sleep

The research referred to in this section has been discussed in the literature review. Study 1, 2 and other previous research have measured electronic device usage and sleep using surveys. Bartel et al (2016) examined the impact of protective and risk factors on adolescents' weekday sleep. Adolescents who used their mobile phones and the internet later on a weekday evening went to bed later and slept for a shorter period of time on weekdays. These findings show that device and network use were directly related to the time adolescents went to bed and the amount of time that adolescents slept for. Bartel and colleague's findings have improved knowledge of how device use affects weekday sleep patterns, however the study did not examine how device use affected weekend sleep. It is likely that device and network use are directly related to the amount of time adolescents spend asleep as the time adolescents woke up at will have been restricted due to the start of the school day. Adolescents have little, if any, opportunity to extend their sleep during the school week. A larger array of devices could also have been examined which would have shown how different devices such as laptops, televisions and tablets affected adolescents' sleep.

Gamble and colleagues (2014) showed that adolescents who watched television, used a mobile phone or computer "every/almost every night" went to sleep later and woke up later on weekdays and at the weekend. These findings show that frequent device use before bed delays the onset of sleep. Adolescents tried to overcompensate for going to sleep later by delaying the time they woke up at the following morning. Both Bartel et al (2016) and Gamble et al (2014) both used surveys to measure the effect of device use on sleep. Daily diaries provide a more accurate measure of sleep as surveys cannot capture sleep and electronic device use over longer periods of time. Single self-reports of sleep and device use rely on participant's retrospective memory. Thus, their responses may have been influenced by their recent nights' sleep. Study 3 will avoid this issue by using daily diaries to collect responses on participant's sleep, electronic device use and mood.

6.2.1.1. How does the interactivity of an activity affect sleep?

Interestingly, Gamble and colleagues' (2014) findings showed that watching television in bed before sleep resulted in fewer adverse sleep outcomes than frequently using computers and mobile phones before going to sleep. This may be due to the devices requiring different amounts of interactivity from the adolescent. The interactivity of devices is a relatively under-investigated pathway in which electronic devices may affect sleep. Weaver et al (2010) investigated the impact of participants playing an interactive video game[151] vs watching a DVD[152] on their sleep. Their findings showed that adolescents who played an interactive video game felt less sleepy, took longer to fall asleep and felt more alert before going to sleep[153]. Weaver and colleagues concluded that devices such as computers led to adverse sleep outcomes as they demand more interaction from the participant. Devices such as televisions did not lead to adverse sleep outcomes as they do not require the same amount of interaction from participants. The two tasks that were given to participants differed in the amount of interaction that was required from participants. Watching a DVD is a passive activity in that the individual does not need to engage with the content to the same extent, or in the same way, as when they are playing an interactive video game.

Gradisar et al (2013) furthered this by investigating whether interactive and passive devices predicted adverse sleep outcomes in participants who were aged 13 – 64 years. Their findings showed that participants who used interactive devices[154] before going to bed struggled to fall asleep, struggled to stay asleep and woke up feeling less refreshed. Passive devices[155] did not predict adverse sleep outcomes. Gradisar and colleagues' work has been supported by a systematic review (67 studies were reviewed) which found that interactive devices were more consistently related to adverse sleep outcomes. Computer use was related to adverse sleep outcomes in 94% of studies they reviewed, followed by video games (86%) and mobile phones (83%). Television usage was least related to adverse sleep outcomes (76% of studies they reviewed) (Hale and Guan, 2015).

Whilst Weaver, Gradisar, Hale and Guan's findings appear to suggest that interactive devices led to adverse sleep outcomes, this thesis argues that a device is not inherently interactive or passive. It is the activity that an individual engages with which is interactive or passive. This is supported by Jones et al (2018) who examined the impact of completing paper puzzles or reading print materials. Their findings showed that participants who completed paper puzzles were more alert before going to sleep than the participants who read print materials. These findings suggest that the amount of stimulation activities require is related to how alert the individual feels. Gradisar and colleagues argued that a smartphone is interactive no matter what activity the individual engages with. A smartphone can be used

[151] The interactive video game was Call of Duty: Modern Warfare
[152] The DVD was March of the Penguins.
[153] Cognitive alertness was measured using alpha power from polysomnography [PSG]).
[154] Interactive devices were computers, mobile phones and video gaming consoles.
[155] Passive devices were MP3 players, TVs and music players.

to communicate with peers (interactive), or it can be used to stream television programmes (passive). It has also been shown that individuals who were more cognitively aroused before going to bed had a poorer quality of sleep (Brown et al, 2002). Thus, the degree of interaction that the device requires from the individual with may predict adverse sleep outcomes instead and this may shed further light on how cognitive arousal from electronic devices affects sleep. The current study will collect information on the applications adolescents' use and will categorise applications into passive or interactive depending on the level of interaction the activity demands from the adolescent.

6.2.2. Measuring mood as a state

The findings from study 1 and study 2 showed that adolescents who had poorer mental health had a poorer quality of sleep, woke feeling less refreshed and had poorer daytime functioning. It is equally important to investigate how device use predicts sleep and state mood as this may contribute to a reduction in the prevalence of poor mental health.

Measuring state mood (mood which is liable to frequent fluctuations) allows researchers to examine how the relationship between mood fluctuations and the most recent night's sleep. This is particularly important for adolescents as their prefrontal cortex does not reach full maturity until after adolescence (Giedd, 2004). The prefrontal cortex is involved in processing affect and emotion and so poorer or shorter sleep is likely to affect adolescents' mood and wellbeing (Davidson, 2002).

Subjective methods such as self-reports are often used within sleep research as they allow for large amounts of data to be collected from participants with relative ease, however they are limited by their accuracy and their generalisability. Shen et al (2018) investigated the relationships between positive and negative affect and sleep duration and sleep quality in adolescents. Affect was measured using Positive and Negative Affect schedule [PANAS][156] (Watson et al, 1988). Their findings showed that adolescents who had a poorer quality of sleep had a more negative mood and adolescents who slept for a shorter period of time had a less positive mood. The study is not only limited by using self-reports to measure sleep, which have weak correlations with objective methods of measuring sleep ($r = 0.02$; Arora et al, 2013), but the questions that participants were given are also questionable. Sleep duration

[156] Whilst positive and negative affect appear to be polar opposites of the same construct, they are in fact distinct dimensions. Positive affect is characterised by enthusiasm, activeness and alertness. High positive affect reflects high energy and concentration; low positive affect reflects sadness and lethargy. Negative affect is characterised by distress. High negative affect reflects anger, contempt, guilt and fear; low negative affect reflects a state of calmness and peace (Watson et al, 1988).

was measured by asking participants to categorise themselves into one of 7 categories ("less than 6 hours" to "more than 10 hours"). It is unlikely that many participants slept for whole hours. The categories provided were "6 hours", "7 hours", "8 hours" etc. and there was no guidance on how participants who slept for parts of an hour should categorise themselves. For example, a participant who slept for 06:30 hours could respond with either "6 hours" or "7 hours". Whichever category they chose would be inaccurate and would either be an underestimation or an overestimation of how long they slept for. Self-reported sleep duration should be measured by asking the participant to estimate how long they slept for, or by calculating the difference between the time they fell asleep and the time that they woke up at.

Studies that have used more objective sleep methods (such as Polysomnography [PSG] or actigraphy) to understand the impact of sleep restriction or deprivation on positive and negative mood have reported conflicting results. Franzen et al (2008) investigated the impact of a single night of sleep deprivation on adults'[157] positive and negative affect. Their findings showed that participants who underwent total sleep deprivation had a lower positive mood. Negative affect was not impacted. Similar findings have been found by Lo et al (2016; 2017), who investigated the impact of restricting[158] adolescents' sleep for a week on sleep and mood. Their findings showed that adolescents who were sleep restricted had a lower positive mood. There was no difference in their negative affect. Dinges et al (1997) also investigated the impact of 7 days of sleep restriction[159] on adults' mood. Their findings showed that individuals became more fatigued, more anxious, more confused and more tense as they became more sleep restricted. Baum et al (2014) argued that one night of sleep deprivation was not enough to elevate negative affect. Baum and colleagues investigated the impact of 5 days of sleep restriction[160] on young adolescents' sleep and negative affect. Their findings showed that after 5 nights of sleep restriction participants were more tense, more anxious, more angry, more confused and more fatigued. Lo and colleagues' findings contradicts Baum et al and Dinges et al findings, whilst the latter support one another. The differences in the findings may have been because there were substantial differences between Lo and colleagues and Dinges and colleagues and Baum and colleagues pre-study protocols. Lo and colleagues asked participants to sleep for 9 hours per night for the week prior to the study

[157] Participants were aged (M ± SD) 24.4 ± 2.76 years.
[158] Sleep restriction was ~ 5 hours.
[159] Sleep restriction was defined as 33% reduction in their normal total sleep time. On average participants had 4.98 ± 0.57 hours sleep per night.
[160] Sleep restriction was ~ 6.5 hours.

and for the first three days of the study (baseline measure). Dinges and colleagues and Baum and colleagues asked participants to maintain their normal nocturnal sleep/wake patterns that they would have had at home or to change their bedtimes to prepare for the study, respectively. Thus, Lo and colleagues' participants would have been well rested and had little, if any, sleep debt when they began the study whereas Dinges et al (1997) or Baum et al (2014) participants may not have been well rested and would probably have already had sleep debt. In the real world, adolescents are rarely well rested, other than the week directly after school holidays, and thus the research above suggests that adolescents will only have a worse mood when the amount of sleep they have lost exceeds a threshold. The current study will not ask adolescents to change their sleep patterns in the weeks prior to beginning the current study so as to replicate real life as closely as possible.

6.2.3. Using objective measures of device use

The relationship between electronic device use and sleep has often been measured using self-reports as was done in study 1 and study 2. Studies have recently shown that these estimates are inaccurate and unacceptable measures of device use (Kaye et al, 2020). Participants often underestimate the number of times they check social networking sites yet overestimate the time they spend on these sites (Ernala et al, 2020). New smartphone models now measure the amount of time individuals spend on their device and applications. As this is a recent development there are only a handful of studies that have used this objective measure of device use.

Bartel et al (2019) recently investigated the effect of altering adolescents' pre-bedtime electronic device use to achieve better sleep health (n = 63). They used the application "Screen On / Off Logger Lite" to provide an objective measure of device use. Bartel and colleagues were unable to use the data from these screenshots as only two participants sent their screenshots to the researchers. Moreover, "Screen On/ Off Logger Lite" only measures when the phone screen was turned on. The application did not record the time spent an individual sent on individual applications. This is a new feature of the inbuilt screen time applications on iPhones and Android smartphones.

Similarly, Lin et al (2019) investigated whether they could identify the time in which adults[161] went to sleep based on their smartphone behaviours. They used the application "Know Addiction" (Lin et al, 2015) which records when notifications were received and

[161] Participants were aged (mean ± SD) 26.7 ± 9.4 years).

screen on/ off timing. However, this method of measuring device use only measured whether the screen was switched on/ off.

These applications are available on all newer smartphone models. There are applications which can be downloaded for older smartphone models. This makes this objective measure of electronic device use accessible. This measure of device use could revolutionise how researchers who are interested in how device use affects sleep. Study 3 will use this objective measure of device use to understand how activities which require more interaction from adolescents affects their sleep.

6.2.4. Using objective measures of sleep parameters

Study 1 and study 2 both asked adolescents to complete a survey to measure their weekday and weekend sleep. Adolescents were asked to report on their sleep quality, how refreshed they felt upon awaking, how long it took them to fall asleep, the time they went to bed and the time they woke up at and how alert/sleepy they felt the following morning. The amount of time in bed and the amount of time spent asleep were derived from the time adolescents reported going to bed, the time they reported waking up at and how long it took them to fall asleep. The gold standard method of measuring sleep, PSG, is expensive and time consuming, which has led many researchers to use self-report measures despite it being less accurate and reliable than other measures of sleep.

Wolfson et al (2003) investigated the relationships between self-reported sleep collected using a survey, sleep diary reported sleep and actigraphy. They reported moderate to strong correlations for weekday sleep measured using a survey and actigraphy. Weaker correlations were observed between the measures for weekend sleep with coefficients ranging between 0.31 – 0.52. These findings are surprising as a wealth of literature has shown that self-reported sleep collected using a survey and actigraphy are different (Kushida et al, 2001). Stronger correlations may have been observed between weekday self-report and weekday actigraphy data due to individuals being more aware of the time they go to bed and wake up at on weekdays due to the school schedule restricting their sleep patterns.

A similar examination of the agreement between adolescents'[162] self-reported sleep and actigraphy data was conducted. Arora et al (2013) found self-reported and actigraphy measured weekday and weekend sleep were weakly correlated. Arora and colleagues found moderate correlations between daily diary and actigraphy measured weekday and weekend

[162] Participants were aged (range; M ± SD was not provided) 11-13 years.

sleep. There will always be a difference between self-reported and actigraphy measured sleep as self-reported sleep is, at best, an estimate and will always be limited by their retrospective memory and how sleepy they feel upon waking.

After examining the agreement rates between actigraphy measured sleep, PSG measured sleep and daily reported sleep Kushida et al (2001) recommended combining actigraphy and daily reports to obtain data which were not significantly different to PSG. The current study intends to build upon these findings by; using both actigraphy and daily diaries to measure sleep and asking participants to signal when they intend to fall asleep and when they woke up.

6.2.5. The current study

The current study will draw upon all aspects of the literature reported above to understand how adolescents' device use affects their sleep and mood. Firstly, the study will build upon the findings from study 2 and will compare and contrast day and boarding students' sleep. The study will use a combination of daily diaries and actigraphy to account for possible under or overestimation of sleep patterns. An objective measure of device use will be used to provide accurate measures of smartphone use. Individual applications will be categorised to compare how activities which demand more or less interaction affect sleep. This will be the first study to examine the impact of electronic device use[163] on adolescents' sleep. Finally, mood will be measured as a state rather than as a trait to understand whether poor sleep predicts poor mood (a precursor to poor mental health). This study will aid our understanding of how adolescents' device use affects their sleep and mood. It is important to understand the relationship between device use, sleep and mood to know how to best advise adolescents on how and when they should avoid using their devices and to reduce the prevalence of poor mental health.

6.2.5.1. Hypotheses

1. Boarding students will have a better quality of sleep, wake feeling more refreshed, go to bed and sleep later, wake and rise later, spend a longer time in bed and spend a longer time asleep than day students.
2. Participants who use electronic devices later in the evening will have a poorer quality of sleep, wake feeling less refreshed, go to bed and sleep later and spend a shorter time asleep.

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[163] Objective device use will be measured using "Screen Time" and "Digital Balance".

3. Participants who engage with more interactive activities will have a poorer quality of sleep, wake feeling less refreshed, go to bed and sleep later and spend a shorter period of time asleep.
4. Participants who have a poorer quality of sleep, wake feeling less refreshed, go to bed and sleep later and spend a shorter period of time asleep will have a lower positive mood and have a more negative mood.

6.3. Methods

6.3.1. Sampling

All the participants in this study came from one boarding school which provided for both boarding and day students. This school had expressed interest in completing this study as the school already knew about the thesis project by participating in study 2 with their younger year groups.

6.3.2. Participants

Thirty-four adolescents completed the screening survey. Adolescents were selected to take part if they met the following inclusion criteria:

- Were male or if they were female, they had natural menstrual cycles (i.e., not using oral contraception).
- Reported using some form of electronic device.
- Complied with the survey instructions (e.g., when a question asked for a number, they responded with a number).

Twenty-six adolescents were selected to take part and began the study. One participant left during the first week of the study. One participant lost his watch during the first week of the study and one watch was not returned at the end of the study. The data from twenty-three participants were examined. Four participants were removed from the analysis due to them removing their actigraph and failing to complete their daily diaries. Nineteen participants (M ± SD age : 16.75 ± 0.37 years) and their data were analysed; 26% were day students (M ± SD age: 16.78 ± 0.34 years) and 74% were boarding students (M ± SD age: 16.73 ± 0.39 years), 16% were male and 84% were female.

The participants were all recruited from one school, which had both boarding and day students. The boarding students had a strict routine which consisted of them having their temperature taken at 07:00 (covid-19 precaution), breakfast between 07:15 – 07:45. In the evening, participants had to be back in the boarding house by 22:00 and their lights were switched off at 22:30. On weekends, participants had their breakfast at 08:00 and their lights were switched off at 22:45.

6.3.3. Materials

6.3.3.1. Screening survey

The survey that was used in study 2 was used to screen and assess whether participants were eligible to take part in the study. The survey has been described in detail in Chapter 3: Methodology.

The screening survey asked participants to answer: questions about their demographic, questions about their weekday and weekend sleep, questions about their weekday and weekend electronic device usage, Media, Technology usage and Attitudes subscales (Rosen et al, 2013), report where they leave their phone overnight and how often they check their phone during the night (Rosen et al 2016), Adolescent Sleep Hygiene Scale (LeBourgeois et al, 2005), Cleveland Adolescent Sleepiness Questionnaire- modified (Spilsbury et al, 2007) and Hospital Anxiety and Depression Scale (Zigmond and Snaith, 1983). The descriptive results from the screening survey can be found in the appendices.

6.3.3.2. The study

This section will describe the measures used in the 14-day study. Participants were asked to wear an actigraph for the entire study, complete daily diaries and complete a cognitive test battery on 5 specified days. These measures will be described in detail in the following section.

6.3.3.2.1. Actigraphy

Condor Instruments ActTrust watches were used (Model AT0503). These watches measured movement across three dimensions, temperature (external temperature and skin temperature) and light (intensity [Lux], blue light [µw/cm], red light [µw/cm], green light [µw/cm], ambient light [µw/cm] and infrared light [µw/cm]). Data were collected in 60-second epochs. The actigraph was worn on participants' non-dominant wrist. Participants were asked to press the "event" button when they were going to try to fall asleep and when they had woken up in the morning.

Once all actigraph watches had been imported into ActStudio (version 1.0.13), the times that participants reported going to bed and rising out of bed the following morning in the daily diaries were input into the "Sleep Diary" function on ActStudio. ActStudio estimated the time that participants went to sleep and rose out of bed in the morning, how long it took them to fall asleep, how long they spent in bed, how long they spent asleep and how long they spent awake after falling asleep using the Kole-Kripke algorithm.

6.3.3.2.2. Daily sleep diary

The sleep diary consisted of three measures: sleep, device use and mood. The following subsections will describe the items used in these three measures.

6.3.3.2.2.1. Sleep

Participants were asked to rate their previous night's quality of sleep and how refreshed they felt upon waking that morning. They were also asked to report the time that they went to bed the previous night, the time that they went to sleep the previous night, how long it took them to fall asleep, the time they woke up at that morning, the time that they got out of bed at that morning, the number of times they woke up during the night and how long they spent awake during the night. The quality of sleep and how refreshed they felt upon waking were scored on a 7-point Likert scale (1 = very good/ very refreshed; 7 = very poor/ very unrefreshed). The number of times a participant woke up during the night was measured on a 5-point Likert scale (1 = did not wake; 2 = one or more brief awakenings; 3 = one or more long awakenings; 4 = some short and some long awakenings; 5 = many short and long awakenings). The time that participants went to bed, went to sleep, woke up at, got out of bed and the amount of time it took them to fall asleep were all measured in 24-hour clock. Time in bed and sleep duration were calculated as follows:

$$Time\ in\ bed = rise\ time - bedtime$$

$$Sleep\ duration = wake\ time - sleep\ time$$

6.3.3.2.2.2. Technology use

The electronic device use questions asked participants when they began and finished using the following devices: TV, Mobile Phone, Tablet, E-Reader and Computer / Laptop (Figure 8A). Participants were also asked how cognitively aroused they felt after using each of these devices and whether they had enabled a blue blocker screen on any of the devices (Figure 8B).

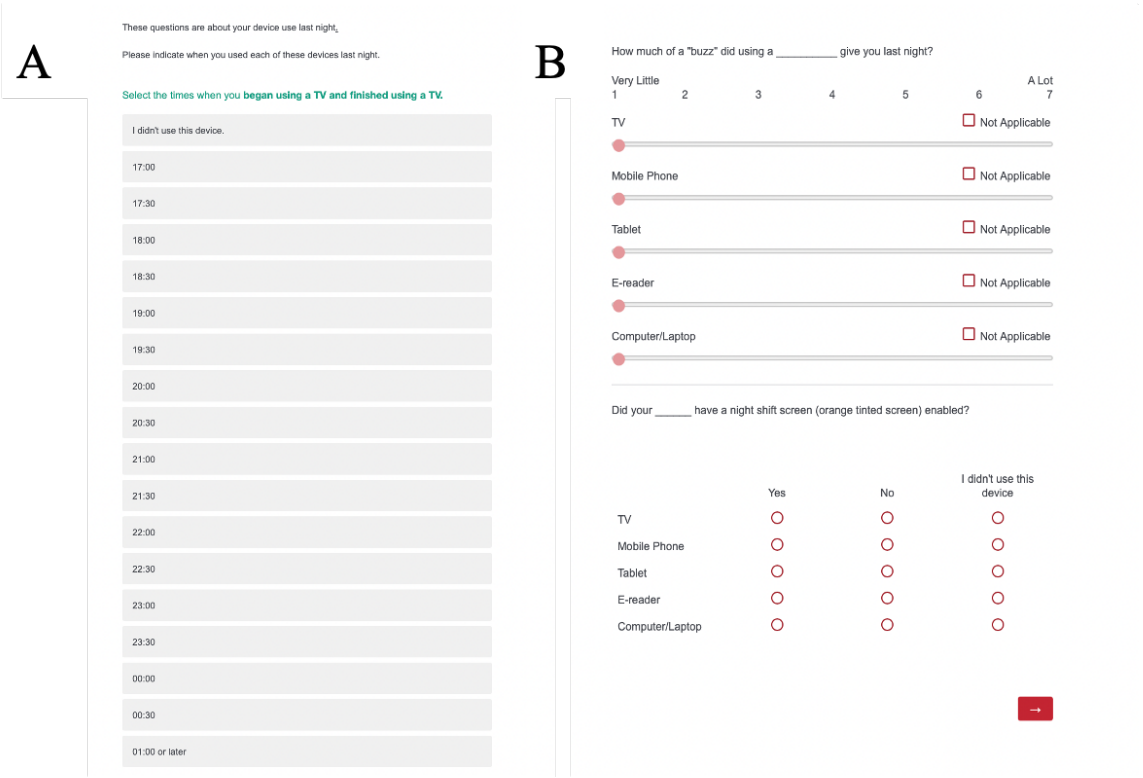

Figure 8 (A) Questions which measured the time adolescents began and finished using each device; (B) How cognitively aroused they felt after using each device and whether they had enabled a blue blocker screen on each device.

6.3.3.2.2.3. Mood

Mood was measured using the International Short Form Positive and Negative Affect schedule (Thompson, 2007). The scale measured positive and negative affect at the current moment in time on a 5-point Likert scale (1 = not at all, 5 = extremely) (Watson et al, 1988). The items included in this scale were: upset, hostile, alert, ashamed, inspired, nervous, determined, attentive, afraid and active. Higher scores indicated greater agreement with the items.

6.3.3.2.3. Screen Time and Digital Balance applications

The inbuilt applications, "Screen Time" (Apple) and "Digital Balance" (Android) were used to objectively measure how long participants spent on their smartphone (Figure 9A) and which smartphone applications participants used the most (Figure 9B). Participants were asked to send screenshots every morning showing how long they had spent on their smartphone and their most used applications on the previous day. Figure 9 shows example screenshots from a participant.

Following data collection, the applications were categorised based on their interactivity. The categorisation of applications can be seen in the appendices.

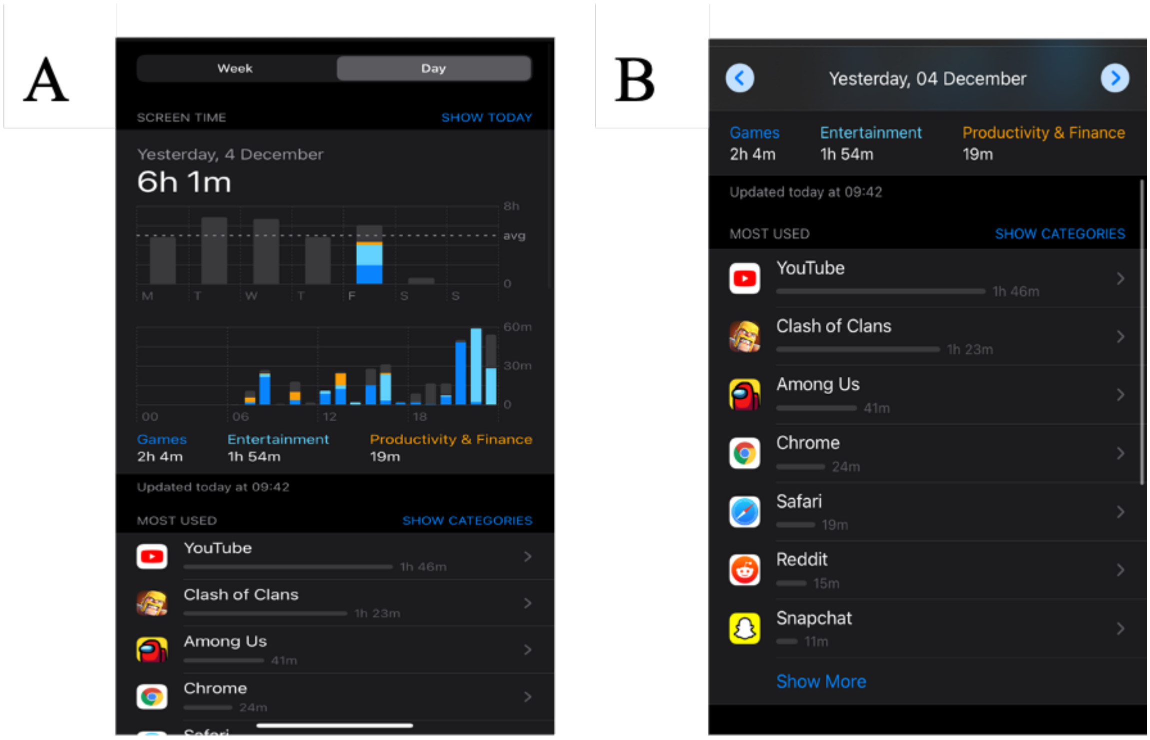

Figure 9 Example screenshots from a participant. (A) The participant's overall daily smartphone usage;(B) The participant's most used applications

6.3.3.2.4. Cognitive Test Battery

The cognitive test battery consisted of six tasks. These were administered using the online platform, Labvanced (Finger et al, 2017), in the following order: Karolinska Sleepiness Scale [KSS] (Akerstdt and Gillberg, 1990), Sustained Attention to Response Task [SART] (Robertson et al, 1997), International Short Form Positive and Negative Affect schedule (Thompson, 2007), N-back [1,2,3 back] (Kirchner, 1958) and finished with a second measurement of KSS. The cognitive tasks have *not* been included in any of the analysis due to human error. The time in which participants could respond to each of the tasks was set incorrectly and so the data were inaccurate estimates of cognition. This was only noticed once data collection had finished. Whilst the data has not been used, an account of how the measures *should* have been configured is provided below.

6.3.3.2.4.1. Karolinska sleepiness scale (Akerstdt and Gillberg, 1990)

Karolinska sleepiness scale is a single question which measures sleepiness at a particular time. Responses were scored on a 9-point Likert scale (1 = extremely alert, 2 = very alert, 3 = alert, 4 = rather alert, 5 = neither alert nor sleepy, 6 = some signs of sleepiness, 7 = sleepy, but no effort to keep awake, 8 = sleepy, but some effort to keep awake, 9 = very sleepy, great effort to keep awake, fighting sleep). The KSS has been shown to have good concurrent validity as it correlated with a visual analogue scale for sleepiness and with alpha and theta power using the Karolinska Drowsiness Test (Kaida, et al, 2006). It is difficult to examine the test-retest reliability of KSS as the scores change depending on the time of day measured. The data have not been reported due to human error.

6.3.3.2.4.2. Sustained Attention to Response Task (Robertson et al, 1997)

The Sustained Attention to Response Task (SART) measures sustained attention. A series of digits were shown in the middle of the screen (225 digits, each of the nine digits were shown 25 times). The digits were presented in 72-point symbol font and measured 499.77 * 242.42 in Labvanced units[164]. Figure 10 shows a schematic of SART. Participants were asked to respond to each digit with “Y” key and to inhibit this response when the digit “3” was shown. The digit “3” was the target and so participants were required to inhibit this response. The inter-stimulus[165] interval is 900ms. This was followed by a mask (a ring with a diagonal cross in the centre) which measured 52.66 * 36.46 in Labvanced units. The digits were shown in a random order. Participants were told to give equal importance to accuracy and speed whilst completing the task. Digits and masks were presented in black on a white screen.

Prior to beginning the task, participants completed a practice session. They received feedback on whether they had responded correctly or incorrectly. There were 18 trials in the practice session and the target was shown on two of these trials. The data have not been reported due to human error.

The hit rate and false alarm rate were first calculated:

$$Hit\ rate = \frac{Number\ of\ correct\ match\ trials\ x\ 100}{Number\ of\ match\ trials}$$

$$False\ alarm\ rate = \frac{Number\ of\ incorrect\ mismatch\ trials\ x\ 100}{Number\ of\ mismatch\ trials}$$

Non parametric measures of sensitivity (A’) and response bias (B''_D) were then calculated. These measures were first introduced by Pollack and Norman (1964) and further used by Macmillan and Creelman (1991; 1996).

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[164] The measurements are given in Labvanced units as the task was conducted using an online experimental platform and so screen size will have differed between participants. Labvanced corrects for this difference by showing the stimuli in proportion to the screen size.

[165] The inter-stimulus interval was set to 250ms in the current study, which was incorrect.

$$Hit > FA, A' = \frac{1}{2} + \frac{(Hit - FA) * (1 + Hit - FA)}{4 * Hit * (1 - FA)}$$

$$FA > Hit, A' = \frac{1}{2} + \frac{(FA - Hit) * (1 + FA - Hit)}{4 * FA * (1 - Hit)}$$

$$B"_D = \frac{(1 - Hit) * (1 - FA) - (Hit * FA)}{(1 - Hit) * (1 - fa) + (Hit * FA)}$$

A' is a discriminability measure from signal detection theory. A' ranges from 0 – 1; 0.5 suggests chance performance. $B"_D$ indicates whether participants tended to respond "Yes" to indicate the stimuli matched (they were more likely to detect matches when the stimuli matched) ($B"_D < 0$) ; respond "No" to indicate the stimuli did not match (they were less likely to detect matches when the stimuli matched) ($B"_D > 0$); neutral in likelihood of providing "Yes" and "No" responses ($B"_D = 0$).

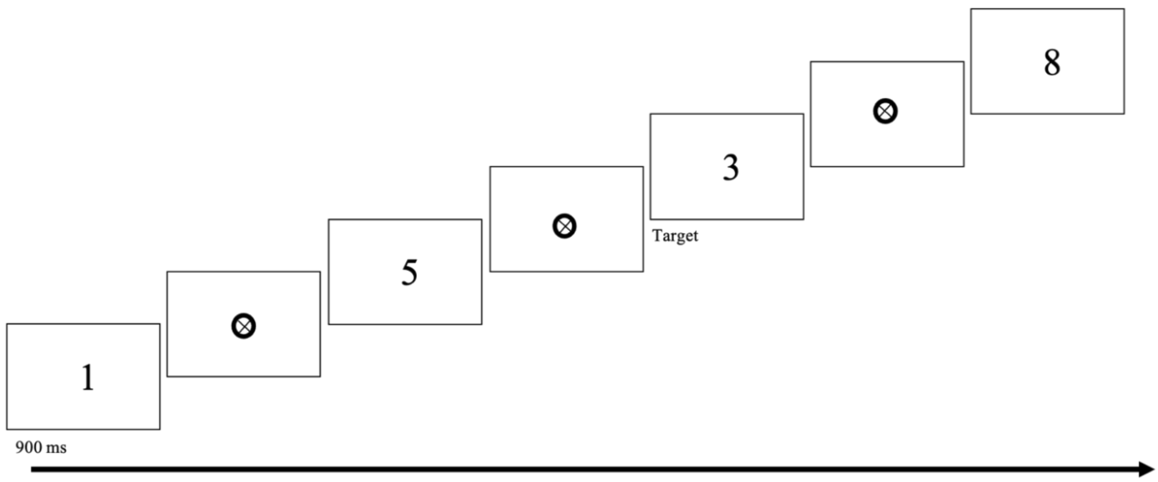

Figure 10 Schematic of Sustained Attention to Response Task. The digit "3" is a target, all other digits are non-targets and should be responded to.

6.3.3.2.4.3. N – Back (Kirchner, 1958)

N-back is a task which measures working memory performance. A single letter appeared on the screen and participants were asked whether the current letter matched the letter that was shown 1,2 or 3 trials before. The nine letters that were used were: "B", "C", "D", "F", "G", "H", "J", "K" and "M". The letters were centred in the middle of the screen and measured

300 * 200 Labvanced units[166]. Each trial was separated with an interstimulus interval which lasts for 1500ms. A black cross (236.59 * 98.25) was shown in the centre of the screen to re-align the eyes to the centre of the screen for 1500ms. The inter-stimulus interval is 2,000ms[167]. When participants had not responded in the time allocated their data was recorded as missing. The match: mismatch ratio was 18:18. The data were not reported due to human error.

Prior to beginning the task, participants completed a practice session. They received feedback on whether they had responded correctly or incorrectly. There were 11 trials in the practice session and all nine letters were featured.

Figure 11 shows a schematic of 1-back. The data were not analysed as the tasks were set up incorrectly.

The hit rate and false alarm rate were both calculated. A' was then calculated using the formula reported above. Hit rate and false alarm were measured as:

$$Hit\ rate = \frac{Number\ of\ correct\ match\ trials\ x\ 100}{Number\ of\ match\ trials}$$

$$False\ alarm\ rate = \frac{Number\ of\ incorrect\ mismatch\ trials\ x\ 100}{Number\ of\ mismatch\ trials}$$

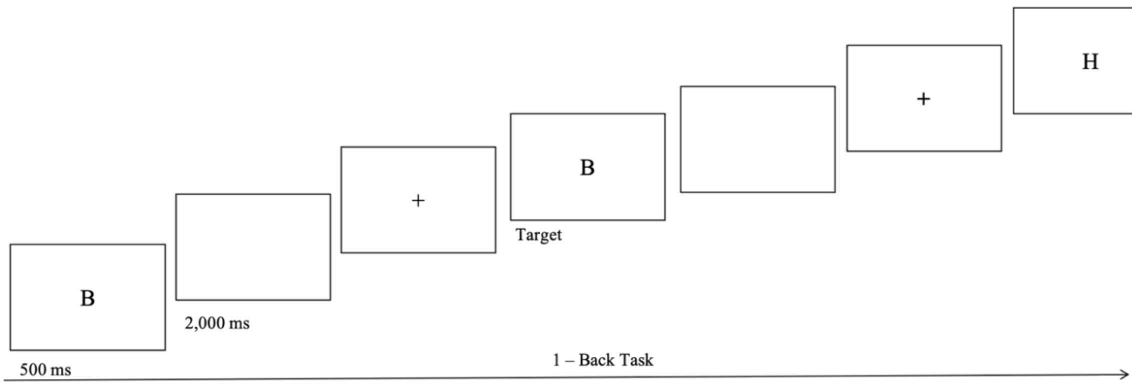

Figure 11 Schematic of 1-back task.

[166] Labvanced measures stimuli in arbitrary units to correct for participants having different sized screens.
[167] The interstimulus interval was set to 500ms in the current study, which is incorrect.

6.3.3.2.4.4. International short form positive and negative affect schedule (Thompson, 2007)

Positive and negative affect were measured using the International Short Form Positive and Negative affect schedule [I-PANAS-SF]. The scale is described in detail in the daily diary section for Mood. The scores for I-PANAS-SF on the cognitive test battery have not been reported due to human error.

6.3.4. Procedure

Participants were given an information sheet which detailed what would be required of them. They were asked to complete the consent form if they wanted to take part. Participants were asked to complete the screening survey which assessed whether they were suitable to take part in the study. Those who were eligible to take part in the study were contacted.

The study ran for 2 weeks (23/11/2020 – 07/12/2020) and participants were asked to wear the wrist actigraphy for the entire duration. They were told to remove their actigraph when they were bathing to avoid submerging the watch in water. Most of the participants also preferred to remove their watch whilst they exercised but put their actigraph back on as soon as possible. An email was sent everyday which asked them to complete their daily diary. A reminder to complete the daily diary was sent at 17:00, 19:00 and 21:00. Participants completed the cognitive test battery on six occasions. They were asked to complete the familiarisation session between 20/11/2020 – 22/11/2020, baseline on 23/11/2020 and the cognitive sessions on 25/11/2020, 29/11/2020, 02/12/2020 and 06/12/2020. They returned their actigraphy watches to school on 07/12/2020 where they were kept in a secure location until the lead investigator collected them. As a token of gratitude, participants were offered a £30 Amazon voucher and the research team offered to talk to students and teachers about sleep hygiene.

6.3.5. Data management

The responses were initially checked in Microsoft Excel. Twenty-six adolescents began the study. One student left the study within the first week, one student lost their watch in the first week and one student did not return their watch. Twenty-three participants finished the study, however four of these participants removed their watches on several occasions during the study and failed to complete the daily diaries and so they were removed from the analysis. Nineteen participants' data were analysed.

The data were analysed in R 4.0.3 using a variety of packages including "tidyverse" to obtain descriptive statistics and independent and paired samples t-tests; "ordinal", "broom", “ggfortify”, “nlme” and “MuMIn” to conduct mixed effects linear models and mixed effects ordinal models.

6.3.5.1. Statistical analysis

This section will describe the statistical analysis used in this study. The means, standard deviations, standardised means, standardised standard deviations and paired samples t-tests have been reported for the screening data in “Participants”. Standardised means and standardised standard deviations have been calculated for Adolescent Sleep Hygiene Scale as the subscales have different numbers of items and the means cannot be compared against one another. Standardised means and standardised standard deviations have been calculated by dividing the subscale score by the number of items on that subscale.

Mixed effects models have been used to show how mobile phone use affects sleep. Mixed effect models include both fixed and random effects. The fixed effects used in these models are how long an adolescent spent on interactive activities, how long an adolescent spent on passive activities, the time an adolescent used their mobile phone in an evening, how cognitively aroused they felt after using a mobile phone and whether there was a blue blocker screen enabled on the mobile phone. The participant’s number was included as a random effect. Mixed effects models were used to analyse the data as they allow for random effects such as the participant to be included in the analysis. This meant that individual variation within the participants was accounted for. The only variables which were included in the models related to mobile phone use as every participant used their mobile phone on weekdays and on weekend evenings. If any of the other devices had been included in the model, then the power of the analyses would have reduced further.

Mixed effects models were then conducted to show how sleep affected mood. The fixed effects used in these models were: participant’s quality of sleep, how long it took participants to fall asleep (actigraphy), the time that participants went to bed (actigraphy), the time that participants got out of bed (actigraphy) and the amount of time participants spent awake after sleep (actigraphy). The participant’s number was included as a random effect.

6.4. <u>Ethics</u>

All individual components of this study received ethical clearance from Nottingham Trent University’s ethics committee.

Parents and guardians were contacted and informed of the study once the school had agreed to take part. As the participants were all 16 + years old parental consent was not needed but parents were told to keep them informed. Participants received an information sheet and were asked to provide informed consent if they wanted to take part. They were told they could withdraw at any point during the study if they wanted to. They were told that they would be contacted by the research team if they had been chosen to take part.

Before beginning the 14-day study, participants were reminded of what the study required of them. When participants were completing every daily diary, they were reminded that they did not need to take part and that they had the right to withdraw. At the end of the 14-day period participants were given an Amazon voucher (£30) to compensate them for their time. They were given a full debrief about the aims of the study and the thesis. They were reminded that they could withdraw their data for a further 2 weeks if they wanted to. They were also provided with contacts if they felt their wellbeing had suffered as a consequence of taking part in the study.

6.5. Results

This section has been split into three sections. The first section will examine how adolescents' weekday and weekend sleep differ and how being a day or boarding student affects this. The second section will examine how adolescents' electronic device usage affects their sleep. The final section will examine how sleep affects state mood.

6.5.1. Adolescents woke up later and spent a longer period of time asleep at the weekend

As can be seen in Table 41, adolescents woke up later (Figure 12A), rose out of bed later (Figure 12B and Figure 13A), spent a longer time in bed (Figure 12C) and spent a longer time asleep (Figure 12D and Figure 13B) on weekend nights than on weekday nights.

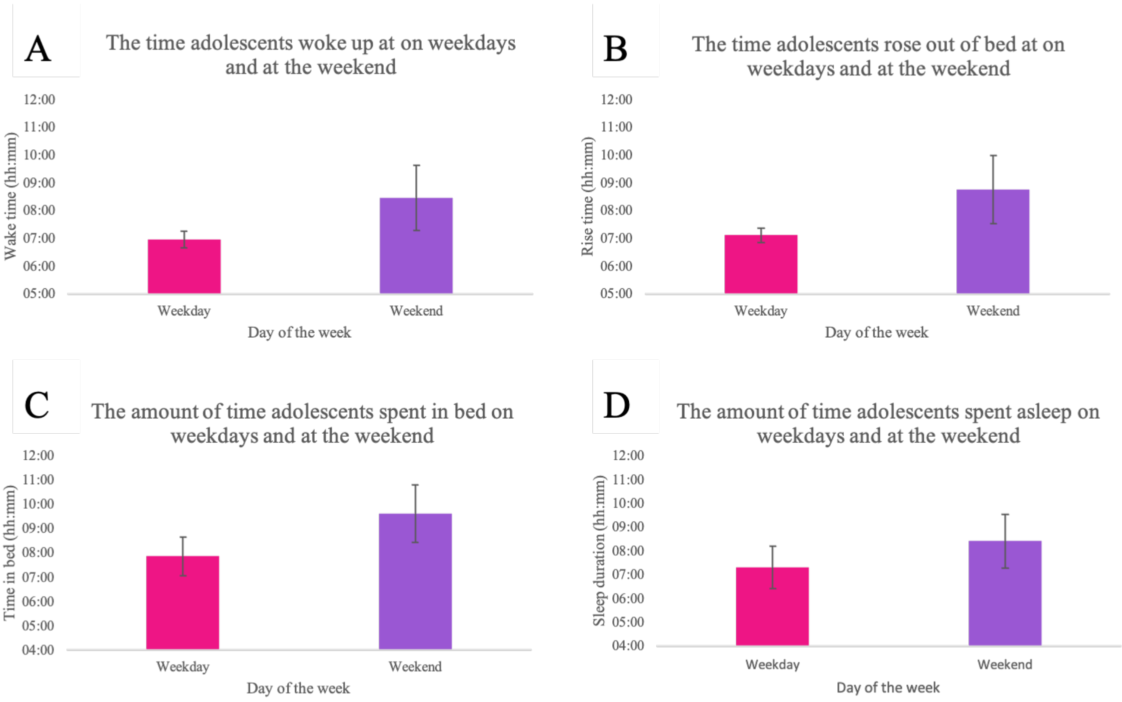

Figure 12(A) Mean weekday and weekend wake time; (B) Mean weekday and weekend rise time; (C) Mean weekday and weekend time in bed; (C) Mean weekday and weekend sleep duration using daily diaries. Error bars ± SD

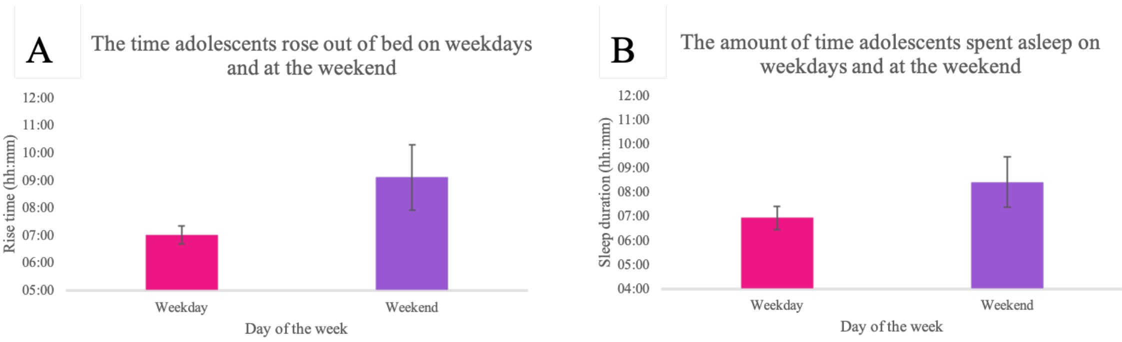

Figure 13: (A) Mean weekday and weekend rise time; (B) Mean weekday and weekend sleep duration using actimetry. Error bars ± SD

Table 41 Mean (M), standard deviation (SD), t-tests and ANOVAs for weekday vs weekend and day (n = 5) and boarding students'(n = 14) sleep as measured using daily diaries and actigraphy; n = 19.

Sleep Variable	Weekday M ± SD [hh:mm]	Weekend M ± SD [hh:mm]	t-test	Day student weekday M ± SD [hh:mm]	Boarding student weekday M ± SD [hh:mm]	ANOVA	Day student weekend M ± SD [hh:mm]	Boarding student weekend M ± SD [hh:mm]	ANOVA
Daily Diary Variables									
SQ	3.22 ± 0.87	2.68 ± 0.78	t(35.56)= 1.98, p = 0.06	3.66 ± 0.61	3.06 ± 0.92	*F*(1,17) = 1.79, p = 0.20	2.55 ± 0.48	2.73 ± 0.87	*F*(1,17) = 0.19, p = 0.67
Ref	3.31 ± 0.89	2.91 ± 0.95	t(35.88)= 1.33, p = 0.19	3.82 ± 0.66	3.12 ± 0.92	*F*(1,17) = 2.37, p = 0.14	3.1 ± 0.7	2.84 ± 1.04	*F*(1,17) = 0.27, p = 0.61
SOL	0.39 ± 0.56 [00:23 ± 00:34]	0.23 ± 0.13 00:14 ± 00:08]	t(19.89)= 1.24, p = 0.23	0.29 ± 0.09 [00:17 ± 05]	0.43 ± 0.65 [00:26 ± 00:39]	*F*(1,17) = 0.22, p = 0.65	0.25 ± 0.11 [00:15 ± 00:07]	0.22 ± 0.14 [00:13 ± 00:08]	*F*(1,17)= 0.15, p = 0.70
BT	23.15 ± 0.88 [23:09 ± 00:53]	23.49 ± 1.11 [23:29 ± 01:07]	t(34.21)= -1.04, p = 0.31	22.56 ± 0.99 [22:34 ± 00:59]	23.37 ± 0.77 [23:22 ± 00:46]	*F*(1,17) = 3.36, p = 0.08	22.91 ± 1.42 [22:55 ± 01:25]	23.7 ± 0.95 [23:42 ± 00:57]	*F*(1,17) = 0.92, p = 0.35
ST	23.66 ± 0.95 23:40 ± 00:57]	24.06 ± 0.91 00:04 ± 00:55]	t(35.94)= -1.31, p = 0.20	22.88 ± 0.69 22:53 ± 00:41]	23.94 ± 0.88 [23:56 ± 00:53]	*F*(1,17) = 5.87, p = 0.03	23.40 ± 1.19 [23:24 ± 01:54]	24.29 ± 0.69 [00:17 ± 00:41]	*F*(1,17) = 4.24, p = 0.06
WT	**30.97 ± 0.3** **06:58 ± 00:18]**	**32.46 ± 1.19** **08:28 ± 01:11]**	**t(20.31)= -5.32,** **p < 0.001**	30.87 ± 0.39 [06:52 ± 00:23]	31.00 ± 0.27 [07:00 ± 00:16]	*F*(1,17) = 0.68, p = 0.42	32.44 ± 0.89 [08:26 ± 00:53]	32.47 ± 1.31 [08:28 ± 01:19]	*F*(1,17) = 0.003, p = 0.96
RT	**31.11 ± 0.27** **[07:07 ± 00:16]**	**32.76 ± 1.23** **08:46 ± 01:14]**	**t(19.75)= -5.71,** **p < 0.001**	31.11 ± 0.23 [07:07 ± 00:14]	31.11 ± 0.29 [07:07 ± 00:17]	*F*(1,17) = 0, p = 0.99	32.67 ± 0.8 [08:40 ± 00:48]	32.79 ± 1.38 [08:47 ± 01:23]	*F*(1,17) = 0.33, p = 0.86
TIB	**7.86 ± 0.8** **[07:52 ± 00:48]**	**9.63 ± 1.18** **09:38 ± 01:11]**	**t(31.24)= -4.11,** **p < 0.001**	8.48 ± 0.77 [08:29 ± 00:46]	7.64 ± 0.7 [07:38 ± 00:42]	*F*(1,17) = 4.28, p = 0.054	9.91 ± 1.18 [09:55 ± 01:11]	9.53 ± 1.2 09:32 ± 01:12]	*F*(1,17) = 0.43, p = 0.52
SD	**7.31 ± 0.9** **[07:19 ± 00:54]**	**8.41 ± 1.12** **[08:25 ± 01:07]**	**t(34.34)= -3.35,** **p = 0.002**	**7.99 ± 0.58** **[07:59 ± 00:35]**	**7.06 ± 0.87** **[07:04 ± 00:52]**	***F*(1,17) = 4.8,** **p = 0.04**	9.04 ± 0.65 [09:02 ± 00:39]	8.18 ± 1.18 08:11 ± 01:11]	*F*(1,17) = 2.35, p = 0.14
NoA	**1.70 ± 0.82**	**1.62 ± 0.44**	**t(27.38)= 0.40,** **p = 0.69**	1.82 ± 0.57	1.66 ± 0.91	*F*(1,17) = 0.14, p = 0.72	1.8 ± 0.27	1.55 ± 0.47	*F*(1,17) = 1.19, p = 0.29
Time spent awake during the night	0.05 ± 0.05 [00:03 ± 00:03]	0.08 ± 0.08 [00:05 ± 0:05]	t(31.89)= -1.50, p = 0.14	**0.11 ± 0.05** **[00:07 ± 00:03]**	**0.03 ± 0.04** **[00:02 ± 00:02]**	***F*(1,17) = 10.27,** **p = 0.005**	**0.15 ± 0.06** **[00:09 ± 00:04]**	**0.06 ± 0.07** **[00:04 ± 00:04]**	***F*(1,17) = 5.95,** **p = 0.03**

Actigraphy Variables									
BT	23.15 ± 0.88 [23:09 ± 00:53]	23.49 ± 1.11 23:29 ± 01:07]	t(18) = -1.78, p = 0.09	22.56 ± 0.99 [22:34 ± 00:59]	23.37 ± 0.77 [23:22 ± 00:46]	*F*(1,17) = 3.51, p = 0.08	22.91 ± 1.42 22:55 ± 01:25]	23.7 ± 0.95 [23:42 ± 00:57]	*F*(1,17) = 1.94, p = 0.18
RT	**31.02 ± 0.33 [07:01 ± 00:20]**	**33.12 ± 1.18 [09:07 ± 01:11]**	**t(18) = -8.08, p < 0.001**	31.04 ± 0.46 [07:02 ± 00:28]	31.01 ± 0.29 [07:01 ± 00:17]	*F*(1,17) = 0.04, p = 0.85	32.83 ± 0.47 [08:50 ± 00:28]	33.28 ± 1.35 [09:17 ± 01:21]	*F*(1,17) = 0.40, p = 0.53
TIB	**7.86 ± 0.8 [07:52 ± 00:48]**	**9.63 ± 1.18 [09:38 ± 01:11]**	**t(18) = -6.69, p < 0.001**	**8.48 ± 0.77 [08:29 ± 00:46]**	**7.64 ± 0.7 [07:38 ± 00:42]**	***F*(1,17) = 4.98, p = 0.04**	9.91 ± 1.18 [09:55 ± 01:11]	9.53 ± 1.2 [09:32 ± 01:12]	*F*(1,17) = 0.38, p = 0.54
TST	6.95 ± 0.49 [06:57 ± 00:29]	8.43 ± 1.04 [08:26 ± 01:02]	t(18) = --5.96, p < 0.001	**7.31 ± 0.6 [07:19 ± 00:36]**	**6.82 ± 0.4 [06:49 ± 00:24]**	***F*(1,17) = 4.34, p = 0.05**	8.53 ± 0.68 [08:32 ± 00:41]	8.4 ± 1.17 [08:24 ± 01:10]	*F*(1,17) = 0.05, p = 0.83
SOL	0.18 ± 0.13 [00:11 ± 00:08]	0.15 ± 0.15 [00:09 ± 00:09]	t(18) = -1.28, p = 0.22	0.17 ± 0.08 [00:10 ± 00:05]	0.19 ± 0.14 00:11 ± 00:08]	*F*(1,17) = 0.11, p = 0.75	0.16 ± 0.13 [00:10 ± 00:08]	0.15 ± 0.16 [00:09 ± 00:10]	*F*(1,17) = 0.06, p = 0.81
WASO	0.78 ± 0.54 [00:47 ± 00:32]	0.96 ± 0.52 [00:58 ± 00:00:31]	t(18) = -1.24, p = 0.23	0.92 ± 0.46 [00:55 ± 00:28]	0.73 ± 0.57 [00:44 ± 00:34]	*F*(1,17) = 0.44, p = 0.52	1.15 ± 0.63 [01:09 ± 00:38]	0.89 ± 0.49 00:53 ± 00:29]	*F*(1,17) = 0.92, p = 0.35
Sleep Efficiency	0.87 ± 0.06	0.88 ± 0.05	t(18) = -0.64, p = 0.53	0.86 ± 0.05	0.88 ± 0.06	*F*(1,17) = 0.24, p = 0.63	0.87 ± 0.06	0.88 ± 0.05	*F*(1,17) = 0.46, p = 0.51

Note: SQ: sleep quality, Ref: waking feeling refreshed, SOL: sleep onset latency, BT: Bedtime, ST: Sleep time, WT: wake time, RT: rise time, TIB: time in bed, SD: sleep duration, NoA: number of awakenings, TST: total sleep time, WASO: wake after sleep onset; significant results are in **bold.**

6.5.2. Boarding students went to sleep later and spent a shorter period of time asleep

Study 1 and study 2 both showed that there were differences between day and boarding students' sleep timing, sleep duration, quality of sleep and daytime functioning. The current study used daily diaries to examine how day and boarding students' sleep differ.

Table 41 shows that boarding students went to sleep later (Figure 14A) spent a shorter period of time in bed (Figure 15A), slept for a shorter period of time (Figure 14B and Figure 15B) and spent less time awake during the night on weekdays (Figure 14C). Boarding students spent a shorter period of time awake during the night at the weekend.

There were no significant differences between adolescents' weekday and weekend device use (Table 42). Boarding students reported lower cognitive stimulation ratings from their mobile phones on weekdays and at the weekend than day students.

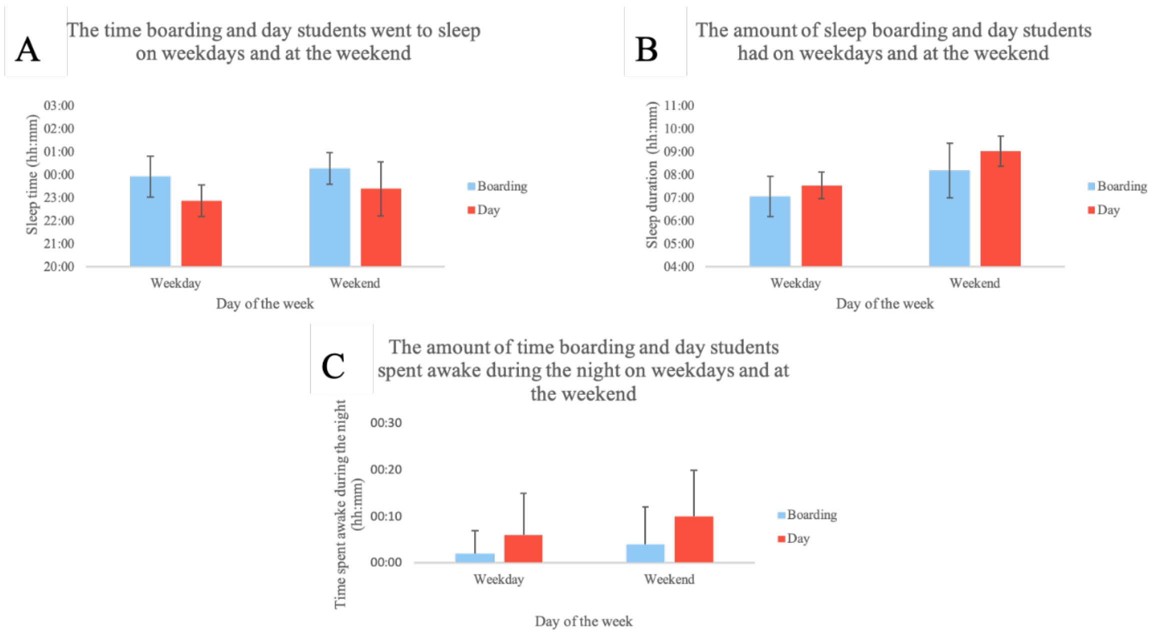

Figure 14 Mean weekday and weekend sleep time for boarding and day students; (b) Mean weekday and weekend sleep duration for day and boarding students; (C) Mean weekday and weekend time spent awake during the night for boarding and day students using daily diaries

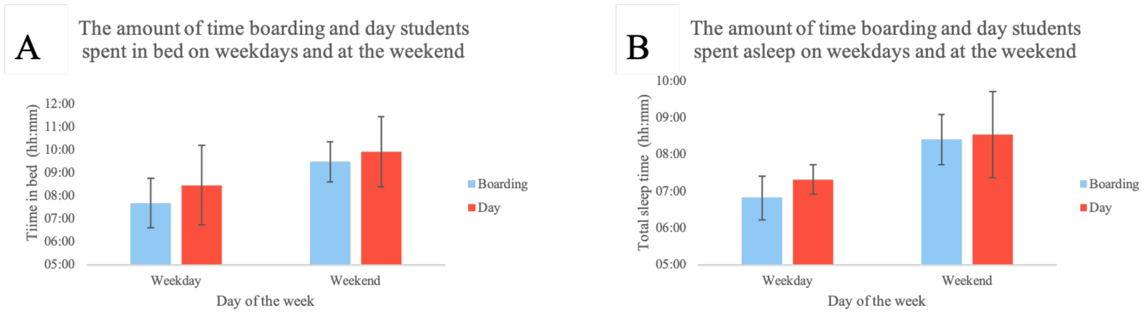

Figure 15: (A) Mean weekday and weekend time in bed for boarding and day students; (B) Mean weekday and weekend sleep duration for day and boarding students using actimetry. Error bars ± SD

Table 42 Means (M), standard deviation (SD), n, t-tests, ANOVAs for weekday and weekend and day student and boarding students' device use end time collected using daily diaries.

Tech variable	Weekday M ± SD [hh:mm] (n)	Weekend M ± SD [hh:mm] (n)	t-test	Day student weekday M ± SD [hh:mm] (n)	Boarding student weekday M ± SD [hh:mm] (n)	ANOVA	Day student weekend M ± SD [hh:mm] (n)	Boarding student weekend M ± SD [hh:mm] (n)	ANOVA
Daily Diary									
TV End	21.43 ± 1.43 [21:26 ± 01:26] (7)	21.76 ± 1.46 [21:46 ± 01:28] (12)	t(12.92) = -0.48, p = 0.64	21.35 ± 0.33 [21:21 ± 00:20] (3)	21.5 ± 2 [21:30 ± 02:00] (4)	*	21.44 ± 1.53 [21:26 ± 01:32] (4)	21.92 ± 1.5 [21:55 ± 01:30] (8)	*
MP End	22.79 ± 1.23 [22:47 ± 01:14] (19)	23.07 ± 1.47 [23:04 ± 01:28] (19)	t(34.94) = -0.62, p = 0.54	22.01 ± 1.43 [22:01 ± 01:26] (5)	23.07 ± 1.07 [23:04 ± 01:04] (14)	F(1,11) = 0.23, p = 0.74	22.73 ± 1.68 [22:44 ± 01:41] (5)	23.19 ± 1.44 [23:11 ± 01:26] (14)	F(1,11) = 0.14, p = 0.72
Tablet End	NA	23.75 ± 1.06 [23:45 ± 01:04] (2)	NA	NA	NA	-	23.00 ± NA [23:00] (1)	24.5 ± NA [00:30] (1)	-
E-reader End	21.89 ± 0.56 [21:53 ± 00:34] (2)	22.67 ± NA [22:40] (1)	NA	NA	21.89 ± 0.56 [21:53 ± 00:34] (2)	-	NA	22.67 ± NA [22:40] (1)	-
Comp End	21.9 ± 1.01 [21:54 ± 01:01] (17)	22.10 ± 1.26 [22:06 ± 01:16] (15)	t(26.83) = -0.48, p = 0.63	21.41 ± 1.23 [21:25 ± 01:14] (5)	22.11 ± 0.89 [22:07 ± 00:53] (12)	F(1,11) = 0.74, p = 0.41	22.41 ± 1.1 [22:25 ± 01:06] (4)	21.98 ± 1.35 [21:59 ± 01:21] (11)	F(1,11) = 0.74, p = 0.41
TV CA	3.67 ± 1.46 (7)	3.23 ± 1.8 (12)	t(13.98)= 0.58, p = 0.57	4.17 ± 1.36 (3)	3.29 ± 1.6 (4)	*	4.56 ± 1.85 (4)	2.56 ± 1.45 (8)	*
MP CA	2.72 ± 1.33 (19)	2.72 ± 1.51 (19)	t(35.45)= - 0.007, p = 0.99	**3.65 ± 1.55 (5)**	**2.38 ± 1.12 (14)**	**F(1,11) = 8.27, p = 0.02**	**3.95 ± 1.95 (5)**	**2.28 ± 1.09 (14)**	**F(1,11) = 4.95, p = 0.05**
Tablet CA	NA	3 ± 2.83 (2)	NA	NA	NA	-	5 ± NA (1)	1 ± NA (1)	-
E-reader CA	1.17 ± 0.24 (2)	1 ± NA (1)	NA	NA	1.17 ± 0.24 (2)	-	NA	1 ± NA (1)	-
Comp CA	2.43 ± 1.12 (17)	2.68 ± 1.45 (15)	t(26.23)= -0.55,	2.93 ± 1.31 (5)	2.22 ± 1.02 (12)	F(1,11) = 3.68,	3.29 ± 1.25 (4)	2.46 ± 1.51 (11)	F(1,11) = 1.54,

			p = 0.59			p = 0.08			p = 0.24
Objective									
Overall device use	4.26 ± 1.79 04:16 ± 01:47] (19)	4.6 ± 1.77 (18) [04:36 ± 01:46]	t(34.93) = -0.59, p = 0.56	3.71 ± 0.89 (5) [03:43 ± 00:53]	4.46 ± 2 (14) [04:28 ± 02:00]	F(1,11) = 0.43, p = 0.53	3.84 ± 1.44 (5) [03:50 ± 01:26]	4.9 ± 1.84 (14) [04:54 ± 01:50]	F(1,11) = 0.53, p = 0.48
Interactive activities	2.56 ± 1.45 [02:34 ± 01:27] (19)	2.93 ± 1.93 [02:56 ± 01:56] (18)	t(31.55) = -0.67, p = 0.51	2.69 ± 1.16 (5) [02:41 ± 01:10]	2.51 ± 1.58 (14) [02:31 ± 01:35]	F(1,11) = 0.28, p = 0.61	3.31 ± 2.5 (5) [03:19 ± 02:30]	2.79 ± 1.77 (13) [02:47 ± 01:46]	F(1,11) = 0.79, p = 0.39
Passive activities	1.03 ± 1.09 [01:02 ± 01:05] (19)	1.18 ± 1.52 [01:11 ± 01:31] (17)	t(28.76) = -0.35, p = 0.73	1.09 ± 1.07 (5) [01:05 ± 01:04]	1 ± 1.14 (14) [01:00 ± 01:08]	F(1,11) = 0.05, p = 0.83	1.29 ± 2.09 (5) [01:17 ± 02:05]	1.13 ± 1.33 (12) [01:08 ± 01:20]	F(1,11) = 0.25, p = 0.63

Note: TV = Television, MP = Mobile Phone, Comp = Computer**,** CA = Cognitive Arousal; * = TV end and TV cognitive arousal were not included in the multivariate ANOVA as there were so few responses from both boarding and day students. significant results are in **bold.**

6.5.3. Adolescents who used devices later and used more interactive content had later sleep timing

Mixed effects models were conducted to establish how adolescents' device use affected their sleep. The participant number was included in the model as a random effect. The amount of time adolescents spent on interactive activities, the amount of time adolescents spent on passive activities, the time adolescents used their mobile phone in evenings, how cognitively stimulated they felt after using their mobile phone and whether the mobile phone had a blue blocker screen enabled were included in the model as fixed effects.

One of the main aims of this study was to investigate *how* device use affected sleep. Gradisar et al (2013) argued that the interactivity of the device determined the impact on sleep, however a device is not in itself interactive or passive. For example, an individual can engage with social media (interactive) and they can also stream TV programmes on a smartphone (passive). It is likely that it is when activities that demand more interaction affect sleep rather than the device itself being interactive or passive.

The current study collected information on the applications participants used and these were sorted into general categories e.g., social media, communication, video games etc. A table of all applications used by participants can be seen in the appendices. These categories were then split into two categories, interactive and passive activities. Table 43 shows the categorisation of applications.

Table 43 Categorisation of applications used by participants

Interactive activities	Passive Activities
Social media	Video streaming services
Communication	Music streaming services
Video games	News
Email	Photos
Information search	Sports
Search engines	Health and fitness
Professional	Tracker
Study participation	Storage
Studying for school	Reading
Online shopping	Utilities
Document writing	Mobile banking

6.5.3.1. Adolescents who used devices later in the evening went to bed later, went to sleep later, woke up later and rose out of bed later

Mixed effects models were used to account for random variation between participants. This is described in greater detail in the "Statistical analysis" section in "Data management". The mixed effects model used the participant's number as a random effect and the amount of time adolescents spent on interactive activities, the amount of time adolescents spent on passive activities, the time adolescents used their mobile phone in an evening, how cognitively stimulated they felt after using their mobile phone, and whether a blue blocker screen was enabled on their mobile phone as fixed effects.

6.5.3.1.1. Bedtime

A generalised mixed-effects model was conducted to examine how device use affected daily diary measured bedtime. A random-intercepts only model and a mixed effects model were conducted. The mixed effects model (AIC = 46.84, LogLik = -15.42) predicted more variance than the random intercept only model (AIC = 57.13, LogLik = -25.57, Likelihood Ratio = 20.29, p = 0.001). Adolescents who used their mobile phone later in the evening went to bed later (beta = 0.44, CI = 0.19 – 0.68) t(13) = 3.21, p = 0.007). The amount of time an adolescent spent on interactive activities (Beta = 0.22, CI = -0.02 – 0.46) t(13) = 1.63, p = 0.13), how cognitively aroused they felt after using their mobile phone (Beta = 0.11, CI = - 0.15 – 0.36) t(13) = 0.75, p = 0.47), the amount of time an adolescent spent on passive activities (beta = -0.17, CI = -0.42 – 0.08) t(13) = -1.20, p = 0.25) and whether their mobile phone had a blue blocker screen enabled (beta = 0.22, CI = -0.54 – 0.97) t(13) = 0.52, p = 0.61 did not predict the time they went to bed.

As daily diary reported bedtimes may be less accurate than objectively measured bedtimes, a generalised linear mixed effects model was conducted to understand the impact of interactive activities, passive activities, mobile phone end time, mobile phone arousal, mobile phone blue blocker screen and participant on bedtime measured using actigraphy. A generalised mixed-effects model was conducted to examine how device use affected objectively measured bedtime. A random-intercepts only model and a mixed effects model were conducted. The mixed effects model (AIC = 46.66, LogLik = -15.33) predicted more variance than the random intercept only model (AIC = 55.67, LogLik = -24.83, Likelihood Ratio = 19.00, p = 0.002). Adolescents who used their mobile phone later in the evening went to bed later (beta = 0.42, CI = 0.19 – 0.68) t(13) = 3.09, p = 0.009). The amount of time an adolescent spent on interactive activities (Beta = 0.2, CI = -0.04 - 0.44) t(13) = 1.49, p = 0.16), the amount of time an adolescent spent on passive activities (Beta = -0.18, CI = -0.43

- 0.07) t(13) = -1.29, p = 0.22), how cognitively aroused they felt after using their mobile phone (Beta = 0.09, CI = -0.16 - 0.34) t(13) = 0.64, p = 0.53 and whether their mobile phone had a blue blocker screen enabled (beta = 0.19, CI = -0.56 – 0.94) t(13) = 0.45, p = 0.66) did not predict the time they went to bed.

6.5.3.1.2. Sleep time

A generalised mixed-effects model was conducted to examine how device use affected daily diary measured sleep time. A random-intercepts only model and a mixed effects model were conducted. The mixed effects model (AIC = 50.63, Log lik = -17.32) predicted more variance than the random intercept only model (AIC = 54.45, Log lik = -24.23, Likelihood Ratio = 13.82, p = 0.02). Adolescents who used their mobile phone later in the evening went to sleep later (Beta = 0.39, CI = 0.12 – 0.66) t(13) = 2.57, p = 0.02). The amount of time an adolescent spent on interactive activities (Beta = 0.08, CI = -0.18 – 0.35) t(13) = 0.55, p = 0.59); the amount of time an adolescent spent on passive activities (Beta = -0.13, CI = -0.41 – 0.14) t(13) = -0.87, p = 0.40); how cognitively aroused they felt after using their mobile phone (Beta = 0.08, CI = -0.20 - 0.36) t(13) = 0.49, p = 0.63) and whether their mobile phone had a blue blocker screen enabled (Beta = 0.63, CI = -0.21– 1.46) t(13) = 1.35, p = 0.2) did not predict the time they went to sleep.

6.5.3.1.3. Wake time

A generalised mixed-effects model was conducted to examine how device use affected daily diary measured wake time. A random-intercepts only model and a mixed effects model were conducted. The mixed effects model (AIC = 22.74, LogLik = -3.37) predicted more variance than the random intercept only model (AIC = 29.25, LogLik = -11.62, Likelihood Ratio = 16.50, p = 0.006). Adolescents who used their mobile phone later in the evening (beta = 0.17, CI = 0.04 – 0.30) t(13) = 2.4, p = 0.02) woke up later the following morning. The amount of time an adolescent spent on interactive activities (beta = 0.13, CI = 0.005 – 0.26) t(13) = 1.86, p = 0.09), the amount of time an adolescent spent on passive activities (beta = -0.03, CI = -0.16 – 0.10) t(13) = -0.38, p = 0.71), how cognitively aroused they felt after using their mobile phone (beta = 0.007, CI = -0.13 – 0.14) t(13) = 0.09, p = 0.93) and whether a blue blocker screen was enabled on their mobile phone (beta = 0.35, CI = -0.05 – 0.75) t(13) = 1.55, p = 0.15) did not predict the time they woke up at on the following morning.

6.5.3.1.4. Rise time

A generalised mixed-effects model was conducted to examine how device use affected objectively measured rise time. A random-intercepts only model and a mixed effects model were conducted. The mixed effects model (AIC = 24.97, LogLik = - 4.49) predicted more variance than the random intercept only model (AIC = 28.39, LogLik = -11.19, Likelihood Ratio = 13.42, p = 0.02). Adolescents who used their mobile phone later in the evening rose out of bed later (beta = 0.17, CI = 0.04 – 0.31) t(13) = 2.28, p = 0.04). The amount of time an adolescent spent on interactive activities (beta = 0.10, CI = -0.04 – 0.23) t(13) = 1.31, p = 0.21, how cognitively stimulated they felt after using their mobile phone (Beta = 0.05, CI = -0.10 – 0.19) t(13) = 0.58, p = 0.57, the amount of time an adolescent spent on passive activities (beta = 0.0002, CI = -0.14 – 0.14) t(13) = 0.003, p = 0.99 and whether a blue blocker screen was enabled on their mobile phone (beta = 0.12, CI = -0.3 – 0.55) t(13) = 0.52, p = 0.61 did not predict the time that adolescents rose out of bed the following morning.

6.5.3.2. Adolescents who used more interactive content or felt more cognitively aroused rose out of bed later and had a poorer quality of sleep

6.5.3.2.1. Rise time

A number of studies have shown that activities which demand greater interaction from the user resulted in adverse sleep outcomes (Gradisar et al, 2013; Jones et al, 2018). A generalised mixed-effects model was conducted to examine how device use affected daily diary measured rise time. A random-intercepts only model and a mixed effects model were conducted. The mixed effects model (AIC = 22.81, LogLik = - 3.4) predicted more variance than the random intercept only model (AIC = 29.35, LogLik = -11.67, Likelihood Ratio = 16.54, p = 0.006). Adolescents who spent a longer period of time using interactive activities (beta = 0.16, CI = 0.04 – 0.29) t(13) = 2.31, p = 0.04) rose out of bed at a later time the following morning. The time they used their mobile phone in an evening (beta = 0.15, CI = 0.02 – 0.28) t(13) = 2.08, p = 0.06), the amount of time an adolescent spent on passive activities (beta = 0.02, CI = -0.11 – 0.16) t(13) = 0.33, p = 0.75), how cognitively aroused they felt after using their mobile phone (beta = - 0.02, CI = -0.15 – 0.12) t(13) = -0.2, p = 0.84), and whether a blue blocker screen was enabled on their mobile phone (beta = -0.35, CI = -0.05 – 0.75) t(13) = 1.55, p = 0.14 did not predict the time that adolescents rose out of bed the following morning.

6.5.3.2.2. Sleep quality

Studies have shown that greater device use resulted in a poorer quality of sleep (Woods and Scott, 2016; Brown et al, 2002). An ordinal mixed-effects model was conducted to examine how device use affected sleep quality. A random-intercepts only model and a mixed effects model were conducted. The mixed effects model (AIC = 135.12, Log Lik = -45.56) predicted more variance than the random intercept only model (AIC = 139.29, LogLik = -52.65, Likelihood Ratio = 14.17, $p = 0.01$). Adolescents who reported feeling more cognitively aroused from their mobile phone had a poorer quality of sleep (Beta = 1.58, CI = 0.09 – 3.07; z value = 2.08, $p = 0.04$). The amount of time an adolescent spent on interactive activities (Beta = 0.59, CI = -0.33 – 1.5; z value = 1.26, $p = 0.21$), the amount of time an adolescent spent on passive activities (Beta = -0.47, CI = -1.47 – 0.53; z value = -0.93, $p = 0.35$), the time they used their mobile phone in an evening (Beta = -0.21, CI = -1.02 – 0.6; z value = -0.51, $p = 0.61$) and whether they had a blue blocker screen enabled on their mobile phone (Beta = -0.28, CI = -3.06 – 2.49; z value = -0.2, $p = 0.84$) did not significantly predict their quality of sleep.

6.5.4. Adolescents who had a poorer quality of sleep had worse mood

It is important to understand how sleep affects state mood (positive and negative mood) as this may contribute to a reduction in the prevalence of poor mental health. This is the final aim of this doctoral thesis.

As can be seen in Table 44, there were no significant differences between weekday and weekend positive or negative mood. There were also no differences between day and boarding students positive and negative mood on weekdays or weekends.

Table 44 Mean (M), standard deviation (SD), t-tests and ANOVAs for weekday vs weekend and day (n = 5) and boarding (n = 14) students' positive and negative affect (overall n = 19).

	Weekday M ± SD	Weekend M ± SD	t-test	Day student weekday M ± SD	Boarding student weekday M ± SD	ANOVA	Day student weekend M ± SD	Boarding student weekend M ± SD	ANOVA
Positive affect	13.1 ± 3	13.45 ± 3.23	$t(35.79) = -0.34$, $p = 0.73$	12.5 ± 1.31	13.32 ± 3.42	$F(1,17) = 0.26$, $p = 0.62$	13.5 ± 2.53	13.43 ± 3.53	$F(1,17) = 0.002$, $p = 0.97$
Negative affect	7.27 ± 2.54	7.36 ± 2.81	$t(35.66) = -0.10$, $p = 0.92$	5.85 ± 0.47	7.78 ± 2.8	$F(1,17) = 2.27$, $p = 0.15$	6.3 ± 0.57	7.73 ± 3.2	$F(1,17) = 0.96$, $p = 0.34$

6.5.4.1. Poorer quality of sleep was related to poorer mood

Mixed effects models have been conducted to understand the impact of sleep[168] on positive and negative mood. The quality of sleep, the time adolescents went to bed, the time adolescents went to sleep, the time adolescents rose out of bed at, the amount of time it took them to fall asleep, the amount of time they spent awake after they had fallen asleep and how efficient their sleep was were included as fixed effects. The time adolescents went to bed and rose out of bed were chosen rather than the amount of time they spent in bed or asleep or as device use predicted later bed and rise times. Total sleep time, time in bed and waking feeling refreshed were not included to avoid issues with multicollinearity. The correlations between the sleep variables can be seen in the appendices. The participant's number was included as a random effect.

6.5.4.1.1. Negative affect

Several studies have shown that participants who were sleep restricted had a worse mood the following morning (Dinges et al, 1997; Baum et al, 2014). An ordinal mixed-effects model was conducted to examine how poor, short and ill-timed sleep impacted negative affect. A random-intercepts only model and an ordinal mixed effects model were conducted. The mixed effects model (AIC = 144.07, LogLik = - 47.03) predicted more variance than the random intercept only model (AIC = 145.11, LogLik = -54.56, Likelihood Ratio = 15.04, p = 0.035). Adolescents who had a poorer quality of sleep felt worse (beta = 2.56, CI = 0.05 – 4.62, z value = 2.44, p = 0.01). The time an adolescent went to bed (beta = 0.84, CI = -1.10 – 2.77, z value = 0.85, p = 0.40), the time an adolescent went to sleep (beta = -0.05, CI = -1.38 – 1.29, z value = -0.07, p = 0.94), how long it took an adolescent to fall asleep (beta = -3.47, CI = -14.98 – 8.03, z value = -0.59, p = 0.55), the time an adolescent rose out of bed (beta = 0.12, CI = -2.75 – 2.99, z value = 0.08, p = 0.93), the amount of wake after sleep onset (beta = - 0.05, CI = -3.80 – 3.71, z value = -0.03, p = 0.98) and how efficient their sleep period was (beta = -8.62, CI = -59.31 – 42.07, z value = -0.33, p = 0.74) did not predict how negative the adolescent felt.

6.5.4.1.2. Positive affect

Several studies have shown that participants who were sleep restricted had a less positive mood (Franzen et al, 2008; Lo et al, 2016, 2017). An ordinal mixed-effects model was conducted to examine how poor sleep impacted positive affect. A random-intercepts only

[168] Sleep was measured using daily diaries and actigraphy

model and an ordinal mixed effects model were conducted. The mixed effects model (AIC = 159.88, LogLik = -52.9) predicted less variance than the random intercept only model (AIC = 149.88, LogLik = -55.94, Likelihood Ratio = 6.08, $p = 0.64$).

There was no impact of sleep on adolescents' positive mood.

6.6. Discussion

6.6.1. The purpose of the study

This study had two main aims; to examine how device use affects sleep when objective methods are used and to examine how poor sleep affected mood. The study also aimed to examine the differences between day and boarding students' sleep.

6.6.2. The current study's results

The current study found that adolescents did not get adequate sleep on weekdays or at the weekend. The National Sleep Foundation and the American Academy of Sleep Medicine recommend that adolescents aged 14 – 17-year-olds should get 8 – 10 hours sleep per night (Hirshkowitz et al, 2015; Paruthi et al, 2016). They were at least an hour short of the recommended 8 hours of sleep per night on weekdays. They compensated for not getting enough sleep during the week by delaying the time they woke up at on the weekend and thus delayed the time they woke up at the weekend even though they still fell short of getting the recommended sleep duration.

The current study also found that boarding students went to sleep later, spent a shorter time in bed and spent a shorter time asleep, spent less time awake during the night and were less cognitively stimulated than day students. A possible explanation for this finding is that boarding students sleep in dormitories with their peers and so it will be harder for them to fall asleep whilst their friends are talking, and the room lights are still on. Thus, each boarding students' sleep is restricted by the student who wants to go to sleep the latest. This is not the case for day students. This finding partially supports the first hypothesis of this study. The findings from study 2 showed that boarding students woke up later than day students, this was not the case in the current study. The school which took part in the current study had a very strict sleep/wake timetable for their boarding students and so whilst they did not need to commute to school, they still had to wake up early in the morning. It is possible that boarding students may have felt less cognitively stimulated from their devices because they were in a more stimulating environment than day students and so there are other activities that also demand their attention. Day students are not around their peers at home and so they may be susceptible to more cognitive stimulation from their devices. It is easier to ignore a notification from a mobile phone or device than it is to ignore a friend who is speaking directly to you in your dormitory.

One of the most interesting findings from the current study was that adolescents who used their mobile phone later in the evening went to sleep later. This finding shows that using devices before going to sleep delays the onset of sleep. Furthermore, adolescents who used their mobile phone later in the evening woke up and rose[169] out of bed later the following morning. These findings show that adolescents tried to compensate for their delayed sleep onset by delaying the time they woke up and got out of bed at the following morning. Adolescents are able to delay the time that they wake up and get out of bed at on weekend mornings, however the school schedule restricts the time that they can wake up and get out of bed at on weekday mornings. Thus, adolescents who use a mobile phone late in the evening did not spend as long asleep on weekdays as their device use delayed the time that they fell asleep and they needed to wake up the following morning in time for school. This finding supports the second hypothesis.

The study has also found that adolescents who were more cognitively aroused from their mobile phone, used their mobile phones later in the evening and for a longer period of time had a poorer quality of sleep and had poorly timed sleep. Adolescents who were more cognitively stimulated from their mobile phone had a poorer quality of sleep. This finding may suggest that the content that the adolescents were engaging with on their mobile phones was more interactive and adolescents felt more cognitively stimulated, which was then related to a poorer quality of sleep. The study also found that adolescents who had a poorer quality of sleep had worse mood. These findings are particularly interesting as they depict an interesting relationship between devices which are linked to higher cognitive arousal, poorer sleep quality and poorer mood. These findings support the third and fourth hypothesis.

In a similar way, adolescents who used more interactive applications in the evening rose[170] out of bed at a later time. There was no relationship between the time adolescents spent on passive applications and sleep outcomes. This suggests that adolescents who used passive applications were not more cognitively aroused as a result. These findings show that applications that demand more interaction from the adolescent may also delay the time that

[169] Measured using actigraphy
[170] Measured using daily diaries

they fall asleep and so they also delay the time they get out of bed at the following morning to compensate for going to sleep later. This finding supports the third hypothesis.

6.6.3. How do the results fit with previous research?

There are very few studies which have examined the differences between day and boarding students' sleep. Boarding schools tend to enforce strict sleep/wake routines and so the findings are less relevant to the wider adolescent population who attend day schools. The findings from the current study showed that boarding students went to sleep later on weekdays, spent a shorter period of time in bed on weekdays, spent a shorter time asleep on weekdays and they spent a shorter time awake during the night on weekdays and at the weekend. These findings somewhat support Owens et al (2010), who reported that boarding students went to bed later. However, their findings also showed that there were no differences between the amount of sleep day and boarding students got on weekdays. This is not supported by the current study's findings. The boarding school which was used in the current study had a strict sleep/wake timetable during the school week for their boarding students. They had to get up, get dressed, have had their temperature checked (Covid precaution) by 07:00 and have had their breakfast by 07:10. If the timetable had been less strict, then the day and boarding students may have slept for a similar period of time. Boarding students went to sleep later than day students on weekdays and this is probably because they cannot go to sleep until everyone in the dormitory is ready to go to sleep. The strict morning routine that is imposed on the boarding students further restricts the time that they had to sleep, thus boarding students had been getting approximately 7 hours sleep on weekdays. The National Sleep Foundation and American Academy of Sleep Medicine recommends between 8 – 10 hours sleep per night (Hirshkowitz et al, 2015; Paruthi et al, 2016). Thus, by the weekend boarding students will have lost at least 5 hours of sleep and this sleep is then not repaid at the weekend as the school also enforces a strict timetable on the weekend.

The current study's findings do not support the findings from study 2, which found that day students woke up earlier, had a shorter time in bed and spent a shorter time asleep than boarding students. Study 2 used three schools which had very different timetables for their boarding students. One was very strict and the other two were fairly relaxed. Thus, it is likely that the current study's findings do not support the findings from study 2 because of the differences between the boarding students' timetables. The two studies had very different sample sizes and ratios of day: boarding students, which may have influenced the findings too.

One of the most important findings from this study was that adolescents who used their mobile phone later in the evening went to bed later, went to sleep later, woke up later and rose out of bed at a later time the following morning. These findings support Bartel et al (2016) results which showed that adolescents who used their mobile phone or the internet later in the evening went to bed later on weekdays. The findings from the current study showed that adolescents who used their mobile phone later in the evening went to bed later, regardless of the day of the week. The current study's findings extend Bartel and colleagues' work and they show that device use affects weekday and weekend sleep in a similar way, the only difference being that adolescents are able to delay the time that they wake up and get out of bed at on weekends and so they are still able to get enough sleep at the weekend. They are unable to do this on weekdays as the school schedule restricts the time they can wake up and get out of bed at.

The findings from the current study also support Gamble et al (2014), who found that adolescents who used a mobile phone "every/almost every night" when they should have been asleep fell asleep and woke up later on weekdays and at the weekend. The current study used objective methods to measure sleep and device use and so they provide convincing evidence that adolescents who use devices later in the evening go to bed later, fall asleep later, wake up later and rise out of bed later. The current study's findings and Gamble and colleagues' findings both show that adolescents will try to compensate for falling asleep later by delaying the time they wake up at the following morning. Bartel and colleagues' findings show that adolescents are unable to compensate for delaying the time they fall asleep by waking up later on weekday mornings and so they do not get enough sleep on weekdays. Adolescents will acquire sleep debt which then needs repaying at the weekend and so adolescents will further delay the time they wake up at on weekend mornings to repay their sleep debt.

The current study also showed that adolescents who spent a longer period of time on interactive applications got out of bed at a later time the following morning. Passive applications did not affect sleep. This finding support Jones et al (2018) who found that participants felt more alert before going to bed when they had completed paper-based puzzles rather than when they had been reading print-based materials. Both the current study's finding and Jones and colleague's finding suggest that activities which demand more interaction are associated with adolescents feeling more alert and wanting to continue using their mobile phone. This finding also supports Gradisar and colleagues' findings. Weaver et al, (2010) showed that participants who played an interactive computer game took longer to fall asleep, were less sleepy and more alert in comparison to participants who watched a DVD. Gradisar et al (2013) then reported that individuals who used interactive[171] devices found it harder to fall asleep, found it harder to maintain sleep and woke feeling less refreshed. Gradisar and colleagues concluded that interactive devices affected sleep. The current study's finding shows that it is the degree of interactivity that the application demands from the participant, which is important. The interactive computer video game was related to longer onset latency, lower sleepiness, and greater cognitive alertness. This may be due to the activity being engaging. The DVD condition did not require participant engagement and so did not affect sleep. Devices are not inherently interactive or passive. New advancements in technology now mean that the interactivity depends on the application an individual is engaging with. Computers and smartphones can be used to interact with their friends on social media (interactive), but they can also be used to stream television programmes (passive).

The current study's findings also showed that adolescents who were more cognitively aroused from their mobile phone had a poorer quality of sleep. This finding supports Brown et al (2002) who found that adolescents who were more cognitively aroused when they were going to bed had a poorer quality of sleep. The current study also showed that adolescents who had a poorer quality of sleep had worse mood. This finding supports Shen et al (2018), who found that poorer sleep quality was associated with a more negative mood. Taken together, these findings show that adolescents who go to bed whilst they are in a state of high arousal have a poorer quality of sleep, which may continue into the following day.

Previous research showed that participants who were either sleep deprived or sleep restricted were in a less positive mood and/ or were in a more negative mood the following morning (Franzen et al, 2008; Lo et al, 2016; Dinges et al, 1997; Baum et al, 2014). The findings from the current study do not support these findings. This may be due to the current study recruiting a small sample and thus may have lacked the power to detect differences.

6.6.4. Evaluation of the study

The current study is one of the first studies to investigate the impact of electronic device use using the inbuilt applications "Screen Time" (Apple) and "Digital Balance" (Android). Previous research which has aimed to understand how device use affects sleep have used self-report measures to examine how the timing, duration of use and interactivity of the

[171] Interactive devices were mobile phones, computers and video gaming console

device affect sleep. It has been previously noted that these measures of electronic device use are inaccurate and unreliable (Kaye et al, 2020). The measure of device use used in the current study is more accurate than other studies which have relied on subjective self-report methods.

The current study used both daily diaries and actigraphy to measure sleep patterns. Previous research has shown that a combination of methods is best to account for any under or overestimation of sleep patterns (Kushida et al, 2001). Most of the participants who began the study complied with the study's protocol and only removed their actigraph when they were about to bathe or swim. This shows that using a combination of methods to measure sleep is preferrable to using either daily diaries or actigraphy.

The current study is also one of the first studies to examine the differences in day and boarding students[172] sleep/wake patterns. It is often necessary to recruit participants from several schools to achieve a sample that has enough power. However, this also increases the number of confounding variables[173] that may affect the findings. The current study has used a single school which has reduced the number of confounding variables that may have influenced the findings.

6.6.4.1. Limitations

The current study has a few weaknesses. Firstly, the current study was conducted during a global pandemic (Covid-19) and so whilst the students were all attending school whilst data was being collected, their school life was not normal in that there was less physical socialisation which may have meant that students spent more time socialising with their friends online to compensate.

Secondly, it was anticipated that the study would recruit a larger sample of adolescents. The government were faced with mounting pressure in November – December 2020 to close all schools. As schools had already been closed for 7 months[174] it was decided that the study should be conducted, albeit with a smaller sample than was anticipated. If the study had been able to run under normal circumstances[175], then a larger sample of participants would have been obtained as there would have been a longer time frame to collect the data. The school

[172] The day and boarding students were all recruited from one school.
[173] Examples of confounding variables are geographical location of the school, socioeconomic status (low, middle and high), size of the school (i.e., staff: student ratio) and type of school (independent, private, comprehensive).
[174] Schools in England were shut between March- September 2020 due to Covid-19.
[175] The term "normal circumstances" refers to the time when all social distancing rules are relaxed, and life becomes "normal".

which was used in the current study also suffered an outbreak of Covid-19 which meant that some participants had to fly home before the study began and some students had to leave during the study to ensure they could get home before Christmas 2020, which reduced the sample size even further.

Following on from this, the analyses which have been conducted on the sample probably lack sufficient power. Future research should look to perform a similar study and recruit a larger sample of adolescents to ensure the analyses have sufficient power to detect any effects.

Reminders were sent to participants at 17:00, 19:00 and at 21:00. Reminders were sent to prompt students who had not finished answering the daily diary as they had little time to complete the daily diary in the morning. The evening reminders may have influenced the results as participants may have felt more tired or sleepy after a full day of school. This type of protocol is typical of studies of this nature. Stone et al (2021) sent reminders to adolescents to improve compliance to their sleep diary between 6am and midnight.

6.6.5. Future research

Firstly, as the current study was conducted during a global pandemic it is important to establish whether the current study's findings are relevant to adolescents under normal circumstances. The findings that have been reported in the current study support a number of studies that were conducted pre-pandemic and so it is likely that the findings will still be applicable to adolescents in normal circumstances.

This study has shown that using screenshots of inbuilt device use applications such as "Screen Time" (Apple) and "Digital Balance", is a more accurate and more reliable than using self-report measures (Kaye et al, 2020). It is also an efficient and effective measure to use when examining the impact of device use. Other examples of device use applications include "Screen On/Off Logger Lite" and "Know Addiction" (Lin et al, 2015). It is highly likely that this software will trickle into other devices such as laptops and tablets which means that research will then be able to examine the impact of other devices on adolescents' sleep using these screen time applications. Previous work has shown that participants may not send their screen time usage screenshots on to the researcher (Bartel et al, 2019). However, that has not been the case in the current study. The current study has shown that this is a cost-effective, easy, and accurate measure to use even in a sample of adolescents who may be less compliant than other groups of the population. Thus, future research should make use of these methods as they are pre-installed on newer smartphone models.

6.7. <u>Conclusion</u>

The current study has found that boarding students went to sleep later, spent a shorter time in bed and slept for a shorter period of time on weekdays than day students. Importantly the current study has shown that adolescents who were more cognitively stimulated from their devices, used their devices later in the evening and who used their devices for a longer period of time had a poorer quality of sleep, went to bed later, went to sleep later, woke up later and got out of bed later. Interestingly, the findings have shown that adolescents who had a poorer quality of sleep had worse mood. These findings are important as they show that devices both directly displaced sleep as they delayed the time adolescents fell asleep at and that interactive content was related to adolescents having a poorer quality of sleep and rising out of bed at a later time. That is not to say that the blue light which is emitted from devices does not have an impact on sleep. It was not possible to properly measure this pathway in the current study due to the restrictions enforced due to the global pandemic.

This study has shown that future research should not view a device as being interactive or passive. Instead, it should examine the amount of interaction that an activity requires from the individual. Finally, inbuilt applications such as "Screen Time" and "Digital "Balance" are effective, efficient and cost-effective measures of device use and could revolutionise how researchers measure device use.

7. Chapter 7: General discussion

7.1. Objectives of the studies

This thesis aimed to understand the relationship between adolescents' device use, sleep, and mood. The studies: examined whether electronic device use was related to poorer sleep quality, ill-timed sleep, and shorter sleep duration (study 1); established how device use is related to sleep (study 2); and (3) examined how evening device use is related to that evening's sleep and following day mood (study 3). Weekday and weekend sleep were measured in each of the studies as schedules on weekdays are often very different to weekend schedules. The studies in this thesis have all tested Cain and Gradisar's (2010) theory that electronic devices affect sleep in three ways:

1. Blue light suppresses melatonin secretion.
2. Content viewed on devices makes pre-sleep relaxation harder to achieve.
3. The time spent on devices could be spent asleep.

Study 1 examined the differences in weekday and weekend sleep timing, duration and quality and the factors which affect weekday and weekend sleep. Device usage was identified as an aspect which affected sleep quality and waking feeling refreshed. Study 2 established how device use affected sleep. Adolescents who put their device down later went to bed later on weekdays and at the weekend, spent a shorter period of time in bed and slept for a shorter period of time on weekdays.

The studies in this thesis also examined the relationship between sleep and mood. Anxiety and depression were incorporated into the models in study 1 and study 2. Study 3 aimed to understand the impact of objective measures of sleep and electronic device use on state mood (positive and negative affect).

This thesis has addressed some of the limitations of the existing adolescents' sleep and electronic device use literature. Firstly, whilst several researchers have noted the quantitative difference between weekday and weekend sleep this study has examined whether weekday and weekend sleep are explained in the same way.

Secondly, much of the literature which has investigated whether electronic device use predicts weekday and weekend sleep have omitted other health risk factors which also contribute to poor sleep quality, ill-timed sleep and short sleep duration. The health risk factors used in study 1 and study 2 were determined using the Royal College of Paediatric and Child Health report (2017).

Thirdly, study 3 asked participants to send daily screenshots of their smartphone usage during the previous day. Previous studies have used self-report measures to examine adolescent's electronic device use. This method has been heavily criticised for being inaccurate and unreliable (Kaye et al, 2020). This study has successfully demonstrated that using daily screenshots of smartphone usage is an efficient, reliable, accurate and easy method to use when investigating adolescents' electronic device use. This is an important finding as the updates to the device operating system which make this possible are now trickling into other devices such as tablets, laptops and computers meaning this method can be used to investigate a wider variety of devices.

7.2. What has the thesis found and how do they relate to the literature?

This section will summarise the findings from the thesis and discuss how these findings relate to previous literature. The main findings from this thesis are that adolescents sleep and wake up later, have a better quality of sleep and sleep longer at the weekend than on weekdays. The thesis has also found that later device use, engaging with more interactive technological activities and more cognitively stimulating device use results in later bedtimes, later sleep times, later wake times, later rise times and poorer sleep quality. Finally, the thesis has found that adolescents who use their mobile phones later in the evening and those who are more cognitively aroused from their mobile phone have worse mood.

7.2.1. What are the differences between weekday and weekend sleep?

The first aim of this thesis was to understand whether weekday and weekend sleep were different to one another. It was expected that weekday and weekend sleep would differ in the timing and duration as many studies have previously shown this (Wolfson & Carskadon, 1998; Carskadon et al, 1990; Wolfson et al, 2007; Owens et al, 2010; Boergers et al, 2014). Carskadon et al (1990) were amongst the first to observe a difference between weekday and weekend sleep in adolescents. Their findings showed that adolescents had later bedtimes, later wake times, longer times in bed and longer sleep durations on weekends than on weekdays. The findings from this thesis support these findings. Study 1 showed that adolescents had a better sleep quality, woke feeling more refreshed, had a shorter sleep onset latency, went to bed later, woke up later, spent a longer time in bed and spent a longer time asleep on weekends than on weekdays. The results from study 2 replicated these findings. Analysis of the self-reported and actigraphy derived sleep variables from study 3 showed that adolescents woke up later, rose out of bed later, spent a longer time in bed and spent a longer time asleep on weekends than on weekdays. The table of means and standard deviations showed that adolescents also went to bed later, fell asleep later, had a shorter sleep onset latency, had a better sleep quality, and woke feeling more refreshed on weekends than on weekdays. However, these findings were not significant. This is due to study 3 recruiting a small sample. Despite only some of the weekday vs weekend comparisons in study 3 being significant, each study in this thesis has shown that adolescents go to bed later, fall asleep later, wake later, rise out of bed later, have a shorter sleep onset latency, spend a longer time in bed, spend a longer time asleep, have a better sleep quality and woke feeling more refreshed at the weekend than on weekdays. The school schedule restricts weekday sleep by forcing adolescents to wake up and rise out of bed early in the morning (when their circadian system is still promoting sleep). As a result, adolescents do not get adequate sleep and so they acquire sleep debt, which must be repaid at the next available opportunity which is often the weekend. The findings from this thesis support previous literature which shows that adolescents delay their sleep schedules, spend a longer time asleep and have a better quality of sleep on weekend nights than on weeknights (Wolfson & Carskadon, 1998; Carskadon et al, 1990; Wolfson et al, 2007; Owens et al, 2010; Boergers et al, 2014).

7.2.2. What are the factors that impact sleep?

7.2.2.1. Weekday and weekend sleep are explained differently

The findings in this thesis have shown that weekday and weekend sleep are explained differently as well. Weekday sleep is explained by anxiousness and higher arousal, whereas weekend sleep is, on the whole, explained by socialisation activities. Study 1 showed that adolescents who were more anxious had a poorer quality of sleep on weekdays and woke feeling less refreshed on weekday mornings. Study 2 showed that adolescents who were more physiologically aroused and were more anxious had a poorer quality of sleep on weekdays and woke feeling less refreshed on weekday mornings. The adolescents may have felt more anxious on weekdays because they knew they were going to school the following day. Levita et al (2020) reported that 90% of adolescents were either borderline anxious or anxious in April 2020. Recent qualitative evidence has shown that school life is causing adolescents a great deal of anxiety, especially at the moment, through worrying about their own and their parent’s health, needing to catch up on lost learning and getting good grades (Children’s commissioner, 2020; NSPCC, 2020). Even prior to the pandemic, adolescents were put under a huge amount of academic pressure from their school, parents, and society (Crenna-Jennings, 2021). The findings from study 1 and study 2 support this evidence that adolescents feel anxious about attending school and is one of the predictors of adolescents’ weekday sleep.

The findings from study 1 showed that adolescents who frequently checked their phone during the night had a poorer quality of sleep at the weekend. Study 2 showed that adolescents who consumed more substances and used their mobile phone later in the evening went to bed later at the weekend. Study 2 also found that adolescents who used more substances had a poorer quality of sleep and woke feeling less refreshed at the weekend. The adolescents may have been using the substances whilst they were socialising with their friends. Recent statistics show that 67% of adolescents who had drank alcohol in the previous week, had drank on a Saturday and 38% had drank alcohol on a Friday (NHS England, 2019b). The findings from study 2 support these statistics. They suggest that adolescents were consuming substances at the weekend whilst they were socialising with their friends as most parties that involve alcohol occur at the weekend.

The findings from study 1 and study 2 show that weekday sleep is predicted by anxiousness and a state of high arousal, whereas weekend sleep is predicted by social activities such as substance consumption and using mobile phones later in the evening. Weekdays and weekend days have very different schedules. Adolescents are often able to do what they want to when they want to at the weekend, whereas the school schedule restricts their activities on weekdays. It is likely that the school schedule is one of the reasons why weekday and weekend sleep are explained differently.

7.2.2.2. Device use was related to greater cognitive arousal which was related to poorer sleep quality

The findings in this thesis have shown that electronic device use is associated with the quality of sleep. Study 1 found that adolescents who frequently checked their phone during the night (FOPC) had poorer weekday sleep quality, poorer weekend sleep quality and woke feeling less refreshed on weekdays. Adolescents who checked their phones frequently during the night, who had fewer technological friendships and were more anxious had poorer weekday sleep quality. Additionally, adolescents who frequently checked their phone during the night had poorer weekend sleep quality. These findings' complement Woods and Scott's work. Woods and Scott (2016) found that adolescents who used more night-time social media and were more anxious had poorer sleep quality. Study 1 may show that adolescents who have fewer online friendships regularly checked their phone during the night as they were anxious to keep up to date with the conversation so that they could join in the following day at school. Woods and Scott's work suggests that adolescents were also anxious to stay in touch with their friends in the evening. The higher state of arousal or anxiousness may have been related to adolescents to having a poorer quality of sleep.

The findings from study 2 showed that adolescents who were more physiologically aroused and had irregular sleep/ wake patterns had poorer weekday sleep quality. These findings tie in with the line of thought that a state of higher arousal led to poorer sleep quality and directly support a number of studies which have investigated the relationship between sleep hygiene and sleep quality. LeBouregois et al (2005) showed that sleep hygiene predicted a substantial proportion of the variance observed in sleep quality. Similarly, Galland et al (2017) showed that adolescents who were more physiologically aroused and had irregular sleep/wake patterns had poorer sleep quality. These pieces of research suggest that adolescents who consume stimulating substances, engage in stimulating behaviours before going to bed and do not have a regular sleep/wake pattern have a poorer quality of sleep.

The findings from study 3 further support this theory that a state of higher arousal reduces the quality of sleep. In study 3, adolescents who were more cognitively aroused from their mobile phone had poorer sleep quality. Ivarsson et al (2013) showed that adolescents who played violent video games were more alert at bedtimes, had poorer sleep quality and were more anxious than those playing non-violent video games. Similarly, Weaver et al (2010) showed that adolescents who played a violent video game were more alert (as measured using alpha power) than adolescents who watched a non-violent DVD. The findings from study 3 have shown that activities that induce a state of high cognitive arousal have an adverse impact on sleep quality. Together these findings show that adolescents become more alert when they are exposed to exciting or emotion provoking content, which results in poorer sleep quality.

Not only does the content that is viewed on devices increase arousal and anxiousness, but this thesis has also shown that more interactive activities and devices which are used later negatively impact sleep. The following section of this discussion will discuss how the activity an individual engages with or when an individual uses a device impacts their sleep.

7.2.2.3. Using devices later and more interactively was related to disrupted sleep timing

The findings from this thesis have shown that electronic device use is associated with poor sleep timing. Study 1 showed that older adolescents went to bed later on weekdays and at the weekend. It was unclear from these findings whether age was related to bedtime due to older adolescents' having more freedom to self-select their bedtimes or whether this was due to older adolescents' having more opportunity to use their devices later in the evening, thus displacing their sleep. These two explanations were both put forward by Carskadon et al (1990). Carskadon and colleagues observed older adolescents were less reliant on their parents telling them to go to bed. Older adolescents' homeostatic sleep pressure also accumulated at a slower rate and so they fell asleep 2 hours after dim light melatonin secretion onset (DLMO), whereas younger adolescents fell asleep 1 hour after DLMO. Thus, the older adolescents had much more opportunity for device use just before sleep than younger adolescents (Crowley et al, 2018). An aim of study 2 was to investigate why older adolescents went to bed later in study 1. The findings from study 2 showed that adolescents who put their mobile phones and computers down later went to bed later on weekdays. This finding is consistent with recent statistics that showed that older adolescents are more likely to own devices and take them to bed with them than younger adolescents. 83% of 12 -15-year-olds own a smartphone and 71% of those who own a smartphone are allowed to take it to bed with them, in comparison to 35% of 8 – 11-year-olds owning a smartphone and 40% of those owning a smartphone are allowed to take it to bed with them. Moreover, older adolescents may be more inclined or tempted to use their smartphones later in the evening as a larger proportion have social media profiles (69% of 12 – 15-year-olds have a social media profile in comparison to 18% of 8 – 11-year-olds) (Ofcom, 2018). These findings support Crowley and colleagues' argument that the slower accumulation of homeostatic sleep pressure allows older adolescents greater opportunity to use their devices later in the evening which further delayed the time they fell asleep. The findings from study 3 further support this argument. The results showed that adolescents that put their mobile phones down later also fell asleep later. These adolescents had greater exposure to light and content on their smartphone and as a result they fell asleep later. Evening light exposure results in a circadian phase delay and slower homeostatic sleep pressure accumulation, which leads to adolescents feeling more alert before sleep (Crowley et al, 2018). The findings from this thesis show that older adolescents spend more time on their devices as they accumulate homeostatic sleep pressure at a slower rate. This results in them feeling less sleepy and so they fall asleep later.

Technology usage also predicted wake time. Whilst there were no significant models of wake time in study 1, study 2 showed that boarding students who used their computer later in the evening and were more depressed had later weekday wake times. Day students who were more cognitively or emotionally aroused and used their mobile phone later in the evening woke up later on the weekend. These two findings support previous research which showed that adolescents who used their devices later in the evening went to bed later and woke up later the following morning. Van den Bulck (2004) showed that children who had spent more time watching television and playing computer games went to bed later and woke up later the following morning. The findings from study 3 showed that adolescents who used their mobile phone later in the evening woke up later the following morning. Moreover, adolescents who used their mobile phone later in the evening and used more interactive activities rose out of bed at a later time the following morning. These findings show that using a device later in the evening lead adolescents to delay the time they woke up at the following morning so that they could compensate for falling asleep later the previous evening. These findings support Gamble et al (2014) research which showed that adolescents who used mobile phones “every/ almost every night” had longer wake lag than adolescents who did not use these devices. Wake lag is the difference in weekday and weekend wake times. Thus, Gamble and colleagues’ findings suggest that adolescents delayed the time they woke up at on the weekend to maximise on the time they spent asleep and repay back any sleep debt they had acquired during the week.

Additionally, the degree of interaction of the technological activity also seems to affect sleep. Study 3 showed that adolescents who engaged with more interactive activities rose out of bed later. Unlike Gradisar and colleagues (Weaver et al, 2010; Gradisar et al, 2013) this thesis argues that a device itself is not interactive or passive. It is the activity that an individual engages with which is interactive or passive. Gradisar and colleagues argued that devices such as mobile phones and computers are more interactive than e-readers and MP3 players. However, as technology advances, devices become more capable of performing more than what they were originally intended for. For example, a smartphone is capable of making phone calls, sending text messages, surfing social media, but it is also capable of streaming television programmes. Likewise, televisions are capable of streaming programmes, but they are also capable of surfing the internet, making video calls and playing video games. There is no such thing as a passive or interactive device anymore. It is important to examine how the interactivity of different activities that individuals engage with on their devices affect sleep. This will show whether it is the fact that individuals are using devices or whether it is the activity that an individual engages with which affects their sleep. Study 3 showed that adolescents who used more interactive activities rose out of bed later. The current literature has only investigated how certain activities such as surfing the internet and watching television impact sleep duration and so the findings from study 3 do not directly support any of the previous findings (Arora et al, 2014; Twenge et al, 2017). However, it must be noted that previous research has shown that interactive activities (e.g., social media and video games) were strongly associated with shorter sleep duration. Study 3 did not find any association between interactive activities and shorter sleep duration, but this may have been due to the study having a small sample size and thus may have lacked the power to detect an effect.

Activities that require more interaction negatively affect sleep. This is an important finding and one that extends beyond electronic device use. Jones et al (2018) showed that participants who completed paper puzzles were less sleepy than those who read print materials. This finding may explain why study 3 showed adolescents who used interactive activities rose out of bed later the following morning. The interactive activities may have made the adolescents less sleepy and so, just like when adolescents use their devices later in the evening, they may have fallen asleep later and so they tried to compensate for this by rising later the following morning. The findings did not show that adolescents who used interactive activities fell asleep later, however as previously noted the sample used in this study was particularly small and so a more representative study should be conducted to examine this line of enquiry. It is important to understand how interactive activities affect adolescents' sleep as laboratory research studies which aim to understand how light emitting devices (e.g., e-readers and tablets) do not monitor the content of what participants are viewing, reading, or interacting with (e.g., Chang et al, 2013; Chinoy et al, 2018).

This thesis has shown that adolescents who use more interactive technological activities rise out of bed later the following morning and this is probably due to interactive activities reducing sleepiness, which may make adolescents fall asleep later and then to compensate for this they get out of bed later the following morning.

7.2.3. What is the relationship between electronic device use, sleep and mood?

Study 3 showed that adolescents who were more cognitively stimulated by their mobile phone had poorer sleep quality; adolescents with poorer sleep quality had worse mood. The previous research which has investigated how sleep restriction impacts negative affect is inconsistent. The findings from study 3 do not support Lo et al (2016; 2017) findings. Adolescents who were sleep restricted[176] for a week showed lower positive affect. There was no change in negative affect. Even when the sleep restricted adolescents were given daytime naps (1 hour in the afternoon[177]) there was no difference in negative affect between adolescents who napped and those who did not nap.

[176] Participants who were sleep restricted were allowed to sleep for 5 hours per night.
[177] The daytime nap was timed between 14:00 – 15:00.

The findings from study 3 do, however, support the findings from Dinges et al (1997) and Baum et al (2014). All of these studies found that adolescents who were sleep restricted had worse mood and showed more negative behaviours. It is likely that study 3 supports Dinges and colleagues and Baum and colleagues' work as none of these studies strictly controlled adolescents' sleep/wake patterns in the weeks before the study began. This means that their participants began the study with sleep debt that they had accumulated over the previous weeks. Study 3 was conducted over a two-week period at the end of the Autumn term and so the participants may have been tired and would probably have had some sleep debt that they had carried over from previous weekends. Adolescents in Lo et al (2016; 2017) were asked to obtain 9 hours sleep per night in the week prior to beginning the study. This was done to reduce the sleep debt the adolescents already had and so the adolescents all began the study well rested. This does not replicate everyday life and so the generalisability of these findings is limited.

7.3. <u>Evaluation of the Studies</u>

A strength of this thesis is that it has examined how electronic device usage affects sleep whilst accounting for a range of other factors which may also contribute to poor sleep. The other factors which were included in the models were determined using Royal College of Paediatric and Child Health report (2017), Bartel et al (2015), Crowley et al (2018) systematic review. To the researcher's knowledge, there has been no other study which has examined whether device usage predicts adolescents' sleep whilst accounting for other factors which are known to be related to weekday and weekend sleep (e.g., age, mental health, school start time etc.). Simultaneously including various other factors shows the true predictiveness of electronic device usage, the school day, mood and BMI on sleep.

Inbuilt applications were used to measure adolescents' screen time usage (Screen Time [Apple] and Digital Balance [Android]. Despite other studies having used similar applications (Bartel et al, 2019; Christensen et al 2016), this is the first study which has successfully used the applications to understand how device use affects adolescents' sleep. This is a significant strength of the thesis as it was recently reported that self-report measures of electronic device use are inaccurate and unreliable measures (Kaye et al, 2020). Moreover, all participants in study 3 consented to sending screenshots of the breakdown of their screen time by application. This allowed the categorisation of all applications used based on their interactivity of the application, which provided a further measure of how cognitively arousing the devices were. Study 3 has shown that using inbuilt applications to measure device usage is an efficient method for remote data collection even in adolescents where recruitment and compliance may be lower than in other populations such as adults.

7.3.1. Limitations

As with any research there are limitations to this thesis's studies. All of the studies used adolescents' self-reported sleep and electronic device usage to assess the impact of device use on sleep. Whilst study 1 and 2 were completely reliant on these self-reports, study 3 improved upon this by using daily diaries and actigraphy to measure electronic device use, mood, and sleep. The studies would have been improved by using the gold standard measure of sleep, PSG, and obtaining information about the blue light (spectral composition, intensity of light and distance from the eye) emitted from the devices individuals were using. It was not possible to run a study using these alternatives as the final two studies were conducted during the Covid-19 pandemic and so there needed to be minimal researcher-participant contact.

A further limitation was that the survey used in study 1 and study 2 and used to screen participants in study 3 did not include ethnicity or socio-economic status measures. Recent work has shown that there are differences in adolescents' sleep and these differences may be related to the adolescents'' ethnicity. Galland et al (2020) showed that Asian teenagers reported later bedtimes and sleeping for a shorter period of time than New Zealand European adolescents. Similarly, the literature has shown that socio-economic status moderates the relationship between shorter and less efficient sleep and lower cognitive performance (El-Sheikh et al, 2020). The studies in this thesis should have examined how ethnicity and socio-economic status were related to device use and weekday and weekend sleep.

Maintaining a healthy weight was highlighted as being a health risk factor from the Royal College of Child and Paediatric Health (2017) report which was used to determine the factors which would be examined within study 1 and study 2. BMI was used to measure how well an adolescent was able to maintain a healthy weight. As adolescents are still underdeveloped their BMI should be corrected for their age otherwise the value is inaccurate. This was not done in the studies within this thesis and so the models which have used BMI as a variable should be interpreted with caution.

All of the studies used a vast and diverse selection of sleep variables from asking participants to report the time they went to bed to asking them to rate how refreshed they felt upon waking the following morning. Study 1 and study 2 had no measure of wake after sleep onset. Wake after sleep onset is frequently measured and may have indicated whether electronic devices were increasing adolescents' physiological or cognitive arousal. This was rectified for study 3 and a subjective and objective measure of wake after sleep onset was included. Self-reported measures of sleep onset latency and wake after sleep onset should always be interpreted with caution as they typically differ from objectively measurements (Lauderdale et al, 2008).

Examining the influence of adolescents' electronic device use over longer durations would have improved the reliability and accuracy of the findings. Both study 1 and 2 were cross-sectional and so the findings are restricted in their ability to determine a temporal relationship between electronic device usage and sleep. Study 3 was longitudinal and conducted for 14 days which is a typical duration for a similar complexity of study. A balance between extending the study's duration and ensuring participant compliance must be achieved in any study and so whilst it would have been interesting to observe the impact of electronic device use over a longer duration, it is likely that the study would have had a higher attrition rate, especially during the Covid-19 pandemic. Study 3 was able to show how device use timing, cognitive arousal and blue light emissions impacted sleep duration, quality and timing and how these then impacted next day mood fluctuations.

Finally, the recruitment of adolescents for all of these studies was difficult and lengthy. It was hoped that a larger sample, equal proportions of males: females and day: boarding students would be recruited for each of the studies. This did not happen and recruitment for Study 3 was lower than anticipated. Study 2 and study 3 were conducted during the Covid-19 pandemic and so the schools which agreed to participate in the studies pre-determined which year groups and populations of the school would be accessible. Due to the uncertainty of the pandemic, participants were recruited, and data collection began promptly to avoid finishing the study early due to an outbreak of Covid-19 at the schools.

7.4. Future Research

Understanding how greater cognitive arousal from devices affects sleep has almost entirely been investigated using video gaming consoles and televisions. This thesis has shown that interactive activities and content which increases cognitive stimulation leads to a poorer quality of sleep and later rise times. A larger sample size was anticipated, however as the study was conducted during the Covid-19 pandemic this was not possible. Further investigations should examine whether activities which require a great deal of interaction from the user (e.g., social media) affect sleep more so than activities which do not require the same level of interaction (e.g., streaming television programmes) in a larger sample. This research would provide more reliable results as to how the degree of interaction a technological activity requires affects adolescents' sleep.

All of the studies in this thesis have shown that poorer sleep leads to poorer mood. In particular, study 3 showed that poorer sleep quality was related to greater negative affect. Previous research on the relationship between sleep and mood have shown conflicting findings. Lo et al (2016; 2017) showed no difference in sleep restricted and well slept individual's negative affect. However, Baum et al (2014) and Dinges et al (1997) both found that sleep restricted participants had worse mood than their well-rested counterparts. It is likely that the difference in findings is due to Lo and colleagues enforcing a strict sleep schedule prior to beginning the study (~ 9 hours per night), whereas Dinges, Baum and colleagues did not. These findings suggest that individuals who are sleep restricted for several nights have worse mood than individuals who are sleep restricted for one or two nights. Future research should examine the impact of device use on sleep at the beginning of the autumn term (just after the long summer holiday) and then measure the impact of device use on sleep again just before the end of the autumn term (Christmas break). Assessing sleep at the start of the term would show how one or two nights of sleep restriction influences mood fluctuations and assessing sleep at the end of the term would then show how sustained sleep restriction, influences mood fluctuations.

The studies in this thesis have examined how adolescents' device use affects their sleep and mood, however another important area of research is how their device use affects their sleep and cognitive performance. It was intended that study 3 would examine how adolescents' device use affected their sleep and their cognitive performance however, due to human error in the cognitive battery, this was not possible. It is important to examine how adolescents' device use affects their sleep and their cognitive performance to understand how device use may be affecting adolescents' academic performance. Whilst some studies have investigated how poor sleep affects their grades, they can be unreliable markers of performance. Self-reported grades may be over or underestimated and teacher assigned grades may differ between schools. The teacher assigned grade only relates to that specific subject and several teachers may estimate the grade differently. Some teachers may estimate the grade the student would achieve if they sat their GCSE or A-level at that moment, some may estimate what grade they will achieve at the end of the year if they continue on the same trajectory. The only reliable academic grade measure is a national examination grade. Schools are reluctant to allowing the students in these year groups take part in research studies and so this is often not a viable option. Thus, future research should examine how electronic device use and poor sleep impact cognitive battery performance. Asking participants to regularly complete a cognitive battery can provide data on their ability to sustain their attention, use their working memory and use other cognitive domains. All of these cognitive abilities are used across subjects and so they are not only relevant to a small number of subjects.

7.5. Impact of the research

The findings from this thesis have several implications for research. This thesis's findings have shown that greater consideration and investigation needs to be given to the idea that electronic devices affect sleep through increasing cognitive arousal. Study 3 showed that participants who were more cognitively aroused from their mobile phone had poorer sleep quality and participants who spent a longer time on interactive technological activities rose out of bed later the following morning. Gradisar and colleagues (Weaver et al, 2010; Gradisar et al, 2013) suggested that interactive devices caused poorer sleep. However, this assumes that devices are either interactive or passive and this oversimplifies the relationship between electronic devices and sleep. Study 3 examined how interactive and passive activities, which were completed on a smartphone, impacted sleep. If it were the device which caused poorer sleep then there should have been no difference between interactive and passive activities. Moreover, Jones et al (2018) showed that individuals who completed paper-based puzzles were less sleepy than those who read paper-based materials. Activities which require active engagement from the individual influence sleep and daytime functioning. The findings from this thesis show that the activity an individual engages with is an important factor to consider when conducting research into how device use impacts sleep.

Following on from this, recent research found that pre sleep cognitive arousal mediated the relationship between adult TikTok use and following day fatigue (Wang and Scherr, 2021). The relationship between electronic device use and sleep may vary as a function of how interactive and relevant the activity is to the individual. TikTok uses algorithms to predict the content that individuals want to see based on their previous interaction with the application. Snapchat, Instagram and other social media platforms allow individuals the opportunity to communicate with their friends and so the content seen on these applications is directly relevant to the individual. Future research should investigate whether there is a difference between social media applications (which are more relevant to individuals) in comparison to video game applications (which are more likely to be less relevant to individuals) despite both being interactive.

The majority of research which has previously examined the relationship between adolescents' electronic device usage and sleep has used self-report measures (Lemola et al, 2014; Bartel et al, 2016; Woods and Scott, 2016; Hysing et al, 2015; Gamble et al 2014; Gradisar et al, 2014). Kaye et al (2020) described how these measures of device use are highly unreliable and inaccurate. Study 3 has shown that inbuilt applications such as "Screen Time" [Apple] and "Digital Balance" [Android] can be used. These applications are inbuilt on newer smartphones models, but other applications can be download via the relevant application stores for older models. Whilst these inbuilt applications are predominately available on smartphones, the technology is filtering down into other devices such as laptops and tablets. This thesis has shown that asking participants to send daily screenshots of their device use is an efficient and cost-effective method to quickly collect accurate information on their device usage. It is recommended that future studies which investigate device use, in any population, use these applications.

All of the studies in this thesis have shown that greater electronic device usage is associated with adverse sleep outcomes. Study 1 showed that participants who frequently checked their phone during the night had poorer weekday and weekend sleep quality and woke feeling less refreshed on weekdays. Study 2 showed that participants who used their mobile phone and/ or computer later in the evening went to bed later and woke up later on weekdays and at the weekend and spent a shorter time in bed and a shorter time asleep on weekdays. Study 3 showed that adolescents who were more cognitively stimulated by their mobile phones had poorer sleep quality. Additionally, adolescents who used their mobile phones later in the evening and used more interactive activities went to bed later, went to sleep later, woke later and rose later. Parents and guardians should be encouraged to enforce curfews on device use, especially on interactive technological activities (e.g., Instagram and Tiktok) to ensure optimal sleep and daytime functioning. By encouraging curfews on devices, adolescents would have a greater opportunity to sleep during the week and thus adolescents would not need to extend the amount of time they sleep for at the weekend by delaying the time they wake up at. Technological curfews could be studied in boarding schools which would provide an opportunity to understand how feasible a technological curfew is with few extraneous variables influencing the results. Some boarding schools have already begun restricting device use in the evenings by switching the internet router off.

7.6. Clinical implications

The three studies within this thesis have all indicated that adolescents who use electronic devices in the evening before going to sleep have poorer sleep quality and ill-timed sleep. Adolescents are able to repay the sleep debt that they have acquired during the week by waking up later at the weekend. All of the studies showed that adolescents slept for a longer period of time at the weekend than they did during the week. It is important to recognise that, on average, adolescents still fell short of their recommended sleep duration. In study 1 adolescents slept for an average of 9.34 hours at the weekend. In study 2, adolescents slept for an average of 9.13 hours and in study 3 adolescents slept for an average of 8.41 hours. The studies did not consider the age of the participant when sleep duration was being analysed and so it is difficult to understand whether adolescents were completely repaying the sleep debt, that they had acquired during the week, at the weekend. It is possible that adolescents are still not spending enough time asleep at the weekend despite having the opportunity to do so.

Secondly, whilst this thesis has identified that technological curfews could be implemented in boarding schools, it also recognises that this type of intervention would not be feasible with the wider public. A technological curfew would only be viable if all adolescents at an institution were subject to this intervention. If they were not then adolescents' sleep may then become disrupted by increased cognitive arousal and thus disturb sleep quality and sleep timing.

7.7. Original contribution to knowledge

This thesis has made a number of contributions to knowledge. Firstly, study 1 and 2 examined the impact of device use on adolescents' weekday and weekend sleep whilst accounting for several other health risk factors relevant to adolescents. Study 1 and 2 accounted for a multitude of variables including sex, age, school start and end time, anxiety, depression, sleep hygiene and BMI. Even after including other adolescent health risk factors electronic device usage remained a consistent predictor of adverse sleep outcomes.

A further contribution to knowledge is that the final study in this thesis has shown that inbuilt applications such as "Screen Time" and "Digital Balance" can be used to obtain objective data on adolescents' electronic device use. All future studies which investigate the impact of electronic device use on sleep should consider using these applications, which monitor screen time usage in the background. Study 3 has shown how these applications can be used remotely with adolescents, which is a population that is hard to recruit and less compliant than other groups. The applications have been very effective and efficient in this study and should be considered for future research as they are accessible and cost-effective measures.

7.8. Conclusion

This thesis has shown that adolescents' weekday and weekend sleep are different to one another. As was expected adolescents obtained a better sleep quality, woke feeling more refreshed, later bedtimes, later wake times, longer time in bed and longer sleep durations at the weekend than on weekdays. The thesis has also shown that the variables which explain weekday and weekend sleep are different to one another. Weekday sleep was explained by adolescents being more anxious and more physiologically aroused, whereas weekend sleep was explained by adolescents wanting to socialise with their friends.

One of the most important findings from this thesis is that the studies have shown that device use affects sleep even when accounting for other variables that are relevant to adolescents. The studies in this thesis have shown that the content which adolescents view on their devices reduces their quality of sleep. The studies have also shown that devices which are used later or more interactively affect the quality of sleep, how refreshed the individual feels upon waking, the time they go to bed, the time they go to sleep, the time they wake up at and the time they get out of bed. These findings show that greater attention should be given to the timing of device use and interactivity of the activities that individuals engage with on their devices, rather than concentrating solely on the impact of blue light emitted from devices.

Finally, the final study showed that adolescents who felt more cognitively aroused from devices had a poorer quality of sleep. Adolescents who had a poorer quality of sleep had a more negative mood. The findings from this study shows that the degree of interactivity that activities demand from that user affects sleep and that poor sleep quality is associated with poorer mood.

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9. Appendices

Appendix 1: Self-report sleep questions used in study 1, study 2 and the screening survey in study 3

Q3.1

How would you rate your sleep quality...

	Very Good			Satisfactory			Very Poor
	1	2	3	4	5	6	7
on Weekdays							
on Weekends							

Q3.2

How refreshed do you feel when you wake ...

	Very Refreshed			Satisfactory			Very Unrefreshed
	1	2	3	4	5	6	7
on Weekdays							
on Weekends							

Q3.3

How long does it take you to fall asleep on **weekdays** after you start trying?

0
Hours

0
Minutes

Q3.4

How long does it take you to fall asleep on **weekends** after you start trying?

0
Hours

0
Minutes

Q3.5

What time do you go to bed at on **weekdays**?

Please give your answer in 24:00 clock.

Q3.6

What time do you go to bed at on **weekends**?

Please give your answer in 24:00 clock.

Q3.7

What time do you wake up at on **weekdays**?

Please give your answer in 24:00 clock.

Q3.8

What time do you wake up at on **weekends**?

Please give your answer in 24:00 clock.

Appendix 2: Cleveland Adolescent Sleepiness Questionnaire- Modified

We would like to know about when you might feel sleepy during a usual week.

For each statement, choose the response that best fits with how often it applies to you.

It's important to answer them yourself- don't have people help you.

There are no right or wrong answers.

	Never	Rarely	Sometimes	Often	Almost every day
I fall asleep during my morning classes	○	○	○	○	○
I go through the whole school day without feeling tired	○	○	○	○	○
I fall asleep during the last class of the day	○	○	○	○	○
I feel wide awake the whole day	○	○	○	○	○
I fall asleep at school in my afternoon classes.	○	○	○	○	○
I feel alert during my classes	○	○	○	○	○
I feel sleepy in the evening after school	○	○	○	○	○
In the morning when I am in school, I fall asleep	○	○	○	○	○
When I am in class, I feel wide-awake	○	○	○	○	○
I feel sleepy when I do my homework in the evening after school	○	○	○	○	○
I feel wide-awake the last class of the day	○	○	○	○	○
During the school day there are times when I realise that I have just fallen asleep	○	○	○	○	○
I fall asleep when I do school work at home in the evening	○	○	○	○	○

These questions are about how sleepy you might feel at the **weekend**.

For each statement, choose the response that best fits with how often it applies to you.

	Never	Rarely	Sometimes	Often	Almost every day
I fall asleep during my morning activities at the weekend.	○	○	○	○	○
I go through a whole day at the weekend without feeling tired.	○	○	○	○	○
I fall asleep in the late afternoon at the weekends.	○	○	○	○	○
I feel wide awake for the whole day during the weekend.	○	○	○	○	○
I fall asleep just after lunch at the weekends.	○	○	○	○	○
I feel alert during my weekend activities.	○	○	○	○	○
In the morning, at weekends when I am at home, I fall asleep.	○	○	○	○	○
When I am at home during the weekend, I feel wide awake.	○	○	○	○	○
I feel wide awake in the late afternoon at the weekend.	○	○	○	○	○
During the weekend, there are times when I realise that I have just fallen asleep.	○	○	○	○	○

Appendix 3: Descriptive results for study 1

Appendix 3.1 Means, SD and n for Munich Chronotype Questionnaire

Variable	n	Mean ± SD (hh:mm)
School Day Bedtime	86	22.29 ± 0.96 (22:17 ± 00:58)
Weekend Bedtime	86	23.32 ± 1.25 (23:19 ± 01:15)
School Day Prep for Sleep	86	22.52 ± 1.13 (22:31 ± 01:08)
Weekend Prep for Sleep	86	23.38 ± 1.4 (23:23 ± 01:24)
School Day Sleep Latency	86	0.66 ± 0.62 (00:40 ± 00:37)
Weekend Sleep Latency	86	0.52 ± 0.44 (00:31 ± 00:26)
School Day Sleep Onset	86	23.18 ± 1.41 (23:11 ± 01:25)
Weekend Sleep Onset	86	24.05 ± 1.88 (00:03 ± 01:53)
School Day Sleep End	86	30.99 ± 0.64 (06:59 ± 00:38
Weekend Sleep End	86	33.17 ± 1.42 (09:10 ± 01:25)
School Day Sleep Inertia	86	0.29 ± 0.35 (00:17 ± 00:21)
Weekend Sleep Interia	86	0.48 ± 0.44 (00:29 ± 00:26)
School Day Get Out of Bed	86	7.28 ± 0.6 (07:17 ± 00:36)
Weekend Get Out of Bed	86	9.68 ± 1.56 (09:41 ± 01:34)
School Day Sleep Duration	86	8.14 ± 1.54 (08:08 ± 01:32)
Weekend Sleep Duration	86	9.30 ± 1.45 (09:18 ± 01:27)
School Day Time in Bed	86	8.99 ± 1.08 (08:59 ± 01:05)
Weekend Time in Bed	86	10.36 ± 1.45 (10:22 ± 01:27)
School Day Mid Sleep	86	2.91 ± 0.82 (02:55 ± 00:49)
Weekend Mid Sleep	86	4.55 ± 0.28 (04:33 ± 00:17)
School Day Light Exposure	77	2.19 ± 0.18 (02:11 ± 0:11)
Weekend Light Exposure	77	5.78 ± 13.46 (05:47 ± 13:28)
Average Weekly Sleep Duration	77	8.48 ± 1.35 (08:29 ± 01:21)
Chronotype	77	5.47 ± 6.67 (05:28 ± 06:40)
Weekly Sleep Loss	77	2.15 ± 1.76 (02:09 ± 01:46)
Social Jetlag	77	3.48 ± 6.04 (03:29 ± 06:02)
Average Weekly Light Exposure	77	2.30 ± 1.8 (02:18 ± 01:48)
School Start Time	77	8.73 ± 0.61 (08:44 ± 00:37)
School End Time	77	15.44 ± 0.78 (15:26 ± 00:47)
Commute to School	77	0.39 ± 0.3 (00:23 ± 00:18)
Commute from School	77	0.46 ± 0.32 (00:28 ± 00:19)
School Day Time Outdoors	77	1.53 ± 1.4 (00:32 ± 01:24)
Weekend Time Outdoors	77	1.22 ± 2.05 (00:13 ± 02:03)
Cigarettes per day	77	0.12 ± 0.76
Cigarettes per week	77	0.25 ± 1.76
Cigarettes per month	77	0.78 ± 6.84
Beers per day	77	0.00 ± 0.00

Beers per week	77	0.09 ± 0.43
Beers per month	77	0.31 ± 0.89
Wine per day	77	0.03 ± 0.16
Wine per week	77	0.52 ± 0.58
Wine per month	77	0.52 ± 2.5
Spirits per day	77	0.00 ± 0.00
Spirits per week	77	0.01 ± 0.11
Spirits per month	77	0.21 ± 0.75
Coffee per day	77	0.17 ± 0.57
Coffee per week	77	0.84 ± 1.9
Coffee per month	77	2.26 ± 7.37
Black Tea per day	77	0.19 ± 0.83
Black Tea per week	77	0.61 ± 3.62
Black Tea per month	77	1.70 ± 11.85
Caffeinated Drinks per day	77	0.08 ± 0.39
Caffeinated Drinks per week	77	0.57 ± 1.24
Caffeinated Drinks per month	77	1.13 ± 3.33
Sleep Medication per day	77	0.00 ± 0.00
Sleep Medication per week	77	0.00 ± 0.00
Sleep Medication per month	77	0.00 ± 0.00

Appendix 3.2 Mean ± SD, Std. Mean ± Std. SD for Adolescent Sleep Hygiene Scale (n = 125)

Variable	Mean ± SD	Std. Mean ± Std. SD
Physiological arousal	22.78 ± 3.74	4.56 ± 0.75
Behavioural arousal	11.46 ± 3.47	3.82 ± 1.16
Cognitive/ emotional arousal	26.25 ± 5.73	4.37 ± 0.95
Sleep environment	26.71 ± 3.47	5.34 ± 0.69
Sleep stability	11.16 ± 3.69	3.72 ± 1.23
Daytime sleepiness	10.89 ± 1.94	5.44 ± 0.97
Substance use	11.81 ± 0.81	5.9 ± 0.41
Bedtime routine	5.09 ± 1.82	5.09 ± 1.82
Total ASHS score	15.77 ± 1.75	

Appendix 3.3 Mean ± SD, Std. Mean ± Std. SD and n for BIS/BAS

Variable	n	Mean	Std. Mean ± Std. SD
BIS	105	20.04 ± 3.84	2.86 ± 0.55
BAS drive	108	9.38 ± 2.77	2.34 ± 0.69
BAS fun seeking	107	12.11 ± 2.48	3.03 ± 0.62
BAS reward responsiveness	106	16.73 ± 2.33	3.35 ± 0.47

Appendix 4 – Other regression models from study 1

Appendix 4.1 Hierarchical linear regression for weekend waking feeling refreshed (n = 146)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	2.05	1.06		0.06
	Sex	0.25	0.25	0.08	0.32
	Age	0.04	0.07	0.05	0.55
2	(Constant)	-0.81	5.01		0.87
	Sex	0.11	0.30	0.04	0.72
	Age	0.01	0.09	0.01	0.93
	Social media usage	-0.12	0.13	-0.08	0.37
	Smartphone / internet usage	-0.02	0.14	-0.01	0.87
	Email usage	0.27	0.16	0.17	0.10
	Media sharing usage	-0.04	0.13	-0.03	0.75
	Anxiety and dependence on electronic device	-0.17	0.14	-0.11	0.22
	TV/ phone calling /texting	-0.10	0.14	-0.07	0.47
	Technological friendships	0.01	0.14	0.01	0.95
	Video gaming	-0.01	0.16	-0.01	0.96
	Log frequency of phone checking	0.23	0.77	0.03	0.77
	HADS- anxiety	0.01	0.04	0.04	0.76
	HADS- depression	0.04	0.04	0.16	0.27
	BMI	0.04	0.04	0.12	0.20
	School start time	0.42	0.51	0.11	0.41
	School end time	-0.09	0.25	-0.04	0.71

Appendix 4.2 Hierarchical linear regression for weekday Sleep Onset Latency (n = 146)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	1.00	0.37		0.01
	Sex	0.04	0.09	0.04	0.67
	Age	-0.03	0.02	-0.10	0.24
2	(Constant)	-0.33	1.73		0.85
	Sex	-0.01	0.10	-0.01	0.95
	Age	-0.05	0.03	-0.17	0.15
	Social media usage	-0.07	0.05	-0.14	0.11
	Smartphone / internet usage	0.02	0.05	0.03	0.72
	Email usage	-0.04	0.06	-0.08	0.46
	Media sharing usage	0.00	0.05	0.00	0.97
	Anxiety and dependence on electronic device	-0.01	0.05	-0.02	0.81
	TV/ phone calling /text usage	-0.02	0.05	-0.04	0.70
	Technological friendships	0.01	0.05	0.02	0.84
	Video gaming	0.00	0.06	0.00	0.97
	HADS- anxiety	0.02	0.01	0.17	0.24
	HADS- depression	0.02	0.01	0.21	0.17
	BMI	-0.01	0.01	-0.04	0.67

	School start time	0.22	0.18	0.16	0.22
	School end time	-0.03	0.09	-0.04	0.73

Appendix 4.3 Hierarchical linear regression for Weekend Sleep Onset Latency (n= 146)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	0.85	0.40		0.04
	Sex	0.11	0.09	0.10	0.26
	Age	-0.03	0.03	-0.09	0.29
2	(Constant)	1.95	1.82		0.29
	Sex	0.01	0.11	0.01	0.97
	Age	-0.02	0.03	-0.07	0.53
	Social media usage	-0.11	0.05	-0.21	0.02
	Smartphone / internet usage	0.01	0.05	0.02	0.82
	Email usage	-0.04	0.06	-0.07	0.51
	Media sharing usage	0.03	0.05	0.05	0.54
	Anxiety and dependence on electronic device	-0.08	0.05	-0.15	0.11
	TV/ phone calling /text usage	0.01	0.05	0.02	0.81
	Technological friendships	0.01	0.05	0.02	0.86
	Video gaming	0.00	0.06	-0.01	0.95
	HADS- anxiety	0.02	0.01	0.19	0.17
	HADS- depression	0.01	0.02	0.05	0.75
	BMI	-0.01	0.01	-0.05	0.57
	School start time	0.12	0.19	0.09	0.52
	School end time	-0.14	0.09	-0.19	0.12

Appendix 4.4 Hierarchical linear regression for weekday wake time (n = 146)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	29.98	0.45		< 0.001
	Sex	-0.05	0.11	-0.04	0.66
	Age	0.06	0.03	0.18	0.03
	(Constant)	26.84	2.10		< 0.001
2	Sex	0.03	0.13	0.02	0.82
	Age	0.04	0.04	0.10	0.36
	Social media usage	-0.04	0.06	-0.06	0.45
	Smartphone / internet usage	-0.03	0.06	-0.04	0.67
	Email usage	0.05	0.07	0.07	0.51
	Media sharing usage	0.03	0.05	0.05	0.56
	Anxiety and dependence on electronic device	0.01	0.06	0.02	0.82
	TV/ phone calling /texting	0.05	0.06	0.07	0.43
	Technological friendships	-0.09	0.06	-0.13	0.13
	Video gaming	0.03	0.07	0.05	0.65
	Log frequency of phone checking	0.58	0.32	0.16	0.08
	HADS- anxiety	-0.02	0.02	-0.16	0.22
	HADS- depression	0.02	0.02	0.14	0.33

	BMI	-0.01	0.02	-0.08	0.36
	School start time	0.39	0.21	0.23	0.07
	School end time	0.02	0.11	0.02	0.84

Appendix 4.5 Hierarchical linear regression for weekend Wake Time (n = 146)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	34.69	1.23		< 0.001
	Sex	-0.42	0.29	-0.12	0.15
	Age	-0.06	0.08	-0.06	0.46
2	(Constant)	19.48	5.77		< 0.001
	Sex	-0.18	0.34	-0.05	0.60
	Age	-0.15	0.10	-0.16	0.15
	Social media usage	-0.07	0.15	-0.04	0.66
	Smartphone / internet usage	-0.05	0.16	-0.03	0.76
	Email usage	0.20	0.19	0.11	0.28
	Media sharing usage	-0.02	0.15	-0.01	0.91
	Anxiety and dependence on electronic device	-0.05	0.16	-0.03	0.75
	TV/ phone calling /texting	-0.05	0.16	-0.03	0.76
	Technological friendships	0.06	0.16	0.03	0.71
	Video gaming	-0.14	0.19	-0.08	0.44
	Log frequency of phone checking	1.43	0.88	0.14	0.11
	HADS- anxiety	-0.04	0.04	-0.12	0.37
	HADS- depression	0.10	0.05	0.32	0.03
	BMI	-0.03	0.04	-0.07	0.45
	School start time	1.39	0.58	0.30	0.02
	School end time	0.27	0.29	0.11	0.35

Appendix 4.6 Hierarchical linear regression for weekday time in bed (n = 146)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	11.76	0.77		< 0.001
	Sex	-0.09	0.18	-0.04	0.62
2	Age	-0.20	0.05	-0.33	0.00
	(Constant)	12.37	3.79		< 0.001
	Sex	-0.02	0.23	-0.01	0.93
	Age	-0.20	0.07	-0.33	0.00
	Social media usage	-0.09	0.10	-0.08	0.35
	Smartphone / internet usage	-0.02	0.11	-0.02	0.82
	Email usage	0.05	0.12	0.04	0.67
	Media sharing usage	0.04	0.10	0.04	0.67
	Anxiety and dependence on electronic device	0.16	0.10	0.14	0.14
	TV/ phone calling /texting	-0.03	0.10	-0.03	0.77
	Technological friendships	0.03	0.10	0.03	0.77
	Video gaming	0.02	0.12	0.02	0.86
	Log frequency of phone checking	0.04	0.58	0.01	0.95

	HADS- anxiety	0.00	0.03	-0.01	0.95
	HADS- depression	-0.01	0.03	-0.07	0.63
	BMI	-0.01	0.03	-0.02	0.84
	School start time	-0.07	0.38	-0.02	0.85
	School end time	0.01	0.19	0.01	0.96

Appendix 4.7 Hierarchical linear regression for weekend time in bed (n = 146)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	14.63	1.05		< 0.001
	Sex	-0.21	0.25	-0.07	0.41
	Age	-0.29	0.07	-0.35	0.00
2	(Constant)	5.28	5.00		0.29
	Sex	0.12	0.30	0.04	0.68
	Age	-0.34	0.09	-0.40	0.00
	Social media usage	-0.05	0.13	-0.03	0.72
	Smartphone / internet usage	-0.08	0.14	-0.05	0.55
	Email usage	-0.02	0.16	-0.01	0.92
	Media sharing usage	0.13	0.13	0.08	0.32
	Anxiety and dependence on electronic device	0.10	0.14	0.06	0.49
	TV/ phone calling /texting	-0.01	0.14	0.00	0.96
	Technological friendships	0.09	0.14	0.06	0.49
	Video gaming	-0.21	0.16	-0.13	0.20
	Log frequency of phone checking	0.14	0.77	0.02	0.85
	HADS- anxiety	-0.01	0.04	-0.05	0.68
	HADS- depression	0.06	0.04	0.19	0.16
	BMI	-0.05	0.04	-0.12	0.16
	School start time	0.93	0.51	0.22	0.07
	School end time	0.13	0.25	0.06	0.61

Appendix 4.8 Hierarchical linear regression for weekday sleep duration (n = 145)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	10.66	0.92		< 0.001
	Sex	-0.24	0.22	-0.09	0.27
	Age	-0.17	0.06	-0.23	0.01
2	(Constant)	14.89	4.35		< 0.001
	Sex	-0.15	0.26	-0.06	0.57
	Age	-0.14	0.08	-0.19	0.09
	Social media usage	0.03	0.11	0.02	0.82
	Smartphone / internet usage	-0.11	0.12	-0.08	0.35
	Email usage	0.11	0.14	0.08	0.45
	Media sharing usage	0.08	0.11	0.06	0.45
	Anxiety and dependence on electronic device	0.20	0.12	0.15	0.09
	TV/ phone calling /texting	0.00	0.12	0.00	0.99
	Technological friendships	-0.02	0.12	-0.01	0.90

	Video gaming	0.02	0.14	0.02	0.88
	Log frequency of phone checking	-0.71	0.67	-0.09	0.29
	HADS- anxiety	0.01	0.03	0.02	0.88
	HADS- depression	-0.06	0.03	-0.24	0.10
	BMI	0.00	0.03	0.01	0.91
	School start time	-0.63	0.44	-0.18	0.16
	School end time	0.07	0.22	0.04	0.74

Appendix 4.9 Hierarchical linear regression for weekend sleep duration (n = 145)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	13.25	1.22		< 0.001
	Sex	-0.31	0.29	-0.09	0.28
	Age	-0.24	0.08	-0.26	< 0.001
2	(Constant)	9.07	5.90		0.13
	Sex	0.00	0.35	0.00	0.99
	Age	-0.22	0.11	-0.23	0.04
	Social media usage	-0.02	0.15	-0.01	0.91
	Smartphone / internet usage	-0.11	0.16	-0.06	0.52
	Email usage	0.05	0.19	0.03	0.78
	Media sharing usage	0.13	0.15	0.07	0.40
	Anxiety and dependence on electronic device	0.15	0.16	0.08	0.36
	TV/ phone calling /texting	0.05	0.16	0.03	0.77
	Technological friendships	0.04	0.16	0.02	0.83
	Video gaming	-0.26	0.19	-0.14	0.18
	Log frequency of phone checking	-0.41	0.90	-0.04	0.65
	HADS- anxiety	-0.02	0.04	-0.05	0.70
	HADS- depression	0.01	0.05	0.04	0.81
	BMI	-0.05	0.04	-0.10	0.26
	School start time	0.23	0.60	0.05	0.70
	School end time	0.15	0.29	0.06	0.60

Appendix 4.10 Hierarchical linear regression for sleepiness at school (n = 146)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	0.38	2.37		0.87
	Sex	0.97	0.56	0.14	0.09
	Age	0.33	0.15	0.18	0.03
2	(Constant)	-14.89	10.36		0.15
	Sex	0.44	0.62	0.07	0.47
	Age	0.25	0.19	0.14	0.18
	Social media usage	0.04	0.27	0.01	0.88
	Smartphone / internet usage	0.02	0.29	0.01	0.93
	Email usage	0.45	0.34	0.12	0.19
	Media sharing usage	-0.09	0.26	-0.03	0.72
	Anxiety and dependence on electronic device	-0.46	0.28	-0.14	0.11

	TV/ phone calling /texting	-0.12	0.29	-0.04	0.67
	Technological friendships	-0.61	0.28	-0.17	0.03
	Video gaming	-0.05	0.33	-0.02	0.88
	Log frequency of phone checking	3.99	1.59	0.20	0.01
	HADS- anxiety	-0.04	0.07	-0.07	0.56
	HADS- depression	0.13	0.08	0.22	0.10
	BMI	0.24	0.07	0.28	0.00
	School start time	-0.42	1.05	-0.05	0.69
	School end time	0.98	0.52	0.20	0.06

Appendix 4.11 Hierarchical linear regression for alertness at school (n = 146)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	4.23	3.21		0.19
	Sex	1.83	0.76	0.20	0.02
	Age	0.52	0.20	0.21	0.01
2	(Constant)	-39.43	13.77		0.01
	Sex	1.54	0.82	0.16	0.06
	Age	0.11	0.25	0.05	0.65
	Social media usage	0.12	0.36	0.03	0.74
	Smartphone / internet usage	-0.30	0.38	-0.06	0.43
	Email usage	0.77	0.45	0.15	0.09
	Media sharing usage	0.04	0.35	0.01	0.91
	Anxiety and dependence on electronic device	-1.01	0.38	-0.22	0.01
	TV/ phone calling /texting	-0.16	0.38	-0.03	0.67
	Technological friendships	-0.51	0.38	-0.10	0.18
	Video gaming	0.03	0.44	0.01	0.94
	Log frequency of phone checking	0.17	0.10	0.20	0.09
	HADS- anxiety	0.22	0.11	0.26	0.04
	HADS- depression	0.05	0.10	0.04	0.61
	BMI	3.93	1.39	0.31	0.01
	School start time	0.70	0.69	0.10	0.31

Appendix 4.12 Hierarchical linear regression for sleepiness on weekday evenings (n = 146)

Model	Predictor	Unstandardised B	Std. Error	β	p-value
1	(Constant)	2.44	1.80		0.18
	Sex	0.65	0.43	0.12	0.13
	Age	0.31	0.12	0.22	0.01
2	(Constant)	-25.57	7.74		< 0.001
	Sex	0.38	0.46	0.07	0.42
	Age	-0.04	0.14	-0.03	0.79
	Social media usage	-0.10	0.20	-0.04	0.62
	Smartphone / internet usage	-0.08	0.22	-0.03	0.71
	Email usage	0.52	0.25	0.19	0.04
	Media sharing usage	-0.24	0.20	-0.09	0.22

	Anxiety and dependence on electronic device	-0.44	0.21	-0.17	0.04
	TV/ phone calling /texting	0.08	0.21	0.03	0.69
	Technological friendships	0.13	0.21	0.05	0.53
	Video gaming	0.24	0.25	0.09	0.33
	Log frequency of phone checking	0.11	0.05	0.24	0.04
	HADS- anxiety	0.08	0.06	0.17	0.18
	HADS- depression	0.09	0.05	0.13	0.11
	BMI	1.96	0.78	0.28	0.01
	School start time	0.83	0.39	0.22	0.04
	School end time	0.76	0.38	0.20	0.05

Appendix 4.13 Hierarchical linear regression for sleepiness at the weekend (n = 146)

Model	Predictor	B	Std. Error	Beta	Sig.
1	(Constant)	4.37	2.38		0.07
	Sex	0.50	0.56	0.08	0.37
	Age	0.18	0.15	0.10	0.25
2	(Constant)	-7.94	10.69		0.46
	Sex	-0.10	0.64	-0.02	0.88
	Age	-0.08	0.19	-0.04	0.69
	Social media usage	-0.06	0.28	-0.02	0.82
	Smartphone / internet usage	-0.23	0.30	-0.07	0.44
	Email usage	0.12	0.35	0.03	0.73
	Media sharing usage	0.08	0.27	0.02	0.77
	Anxiety and dependence on electronic device	-0.23	0.29	-0.07	0.43
	TV/ phone calling /texting	-0.23	0.29	-0.07	0.45
	Technological friendships	-0.56	0.29	-0.16	0.06
	Video gaming	0.71	0.34	0.21	0.04
	Log frequency of phone checking	5.33	1.64	0.28	0.00
	HADS- anxiety	0.02	0.08	0.04	0.78
	HADS- depression	0.10	0.08	0.17	0.23
	BMI	0.10	0.07	0.12	0.18
	School start time	0.48	1.08	0.05	0.66
	School end time	0.60	0.53	0.12	0.26

Appendix 4.14 Hierarchical linear regression for alertness at the weekend

Model	Predictor	B	Std. Error	Beta	Sig.
1	(Constant)	5.97	2.88		0.04
	Sex	1.79	0.68	0.22	0.01
	Age	0.24	0.18	0.11	0.19
2	(Constant)	-2.61	12.71		0.84
	Sex	1.04	0.76	0.13	0.17
	Age	-0.14	0.23	-0.06	0.55
	Social media usage	-0.48	0.33	-0.11	0.15
	Smartphone / internet usage	-0.06	0.35	-0.01	0.86
	Email usage	0.12	0.42	0.03	0.77

Media sharing usage	0.20	0.32	0.05	0.54
Anxiety and dependence on electronic device	-0.68	0.35	-0.16	0.06
TV/ phone calling /texting	-0.45	0.35	-0.11	0.20
Technological friendships	-0.66	0.35	-0.15	0.06
Video gaming	1.14	0.41	0.27	0.01
Log frequency of phone checking	5.45	1.96	0.23	0.01
HADS- anxiety	0.09	0.09	0.12	0.31
HADS- depression	0.00	0.10	0.00	0.99
BMI	0.05	0.09	0.05	0.55
School start time	1.96	1.28	0.18	0.13
School end time	-0.30	0.64	-0.05	0.64

Appendix 5 Descriptive results for study 2

Appendix 5.1 Mean, SD, n and paired sample t-tests for weekday and weekend days and by day or boarding student for Adolescent Sleep Hygiene Scale bed and wake time

Variable	Weekday M ± SD [hh:mm] (n)	Weekend M ± SD [hh:mm] (n)	Paired sample t-test	Day student weekday M ± SD [hh:mm] (n)	Boarding student weekday M ± SD [hh:mm] (n)	Paired sample t-test	Day student weekend M ± SD [hh:mm] (n)	Boarding student weekend M ± SD [hh:mm] (n)	Multivariate ANOVA
ASHS Bedtime	22.34 ± 1.49 [22:20 ± 01:29] (281)	23.14 ± 2.75 [23:08 ± 02:45] (279)	t(278)= -4.51, p < 0.001	22.34 ± 1.64 [22:20 ± 01:38] (218)	22.35 ± 0.8 [22:21 ± 00:48] (63)	F(1,270) = 0, p = 0.99	23.14 ± 3.04 [23:08 ± 03:02] (218)	23.14 ± 1.26 [23:08 ± 01:16] (61)	F(1,270)= 0, p = 0.98
ASHS Wake Time	30.9 ± 1.13 [06:54 ± 01:08] (278)	33.22 ± 1.7 [09:13 ± 01:42] (273)	t(271) = -20.55, p < 0.001	30.91 ± 1.24 [06:55 ± 01:14] (216)	30.88 ± 0.6 [06:46 ± 00:36] (62)	F(1,270) = 0.05, p = 0.83	33.36 ± 1.76 [09:22 ± 01:46] (214)	32.71 ± 1.32 (59) [08:43± 01:19]	F(1,270) = 6.96,p = 0.009

Appendix 5.2 Mean, SD, n, standardised mean and standardised standard deviation for the media, technology and attitudes scales

Subscale	M ± SD (n)	Std. M ± Std. SD
Text-messaging usage	20.91 ± 5.28 (433)	6.97 ± 1.76
Television viewing	8.9 ± 4.47 (433)	4.45 ± 2.24
Video gaming usage	11.08 ± 6.90 (433)	3.69 ± 2.3
Online friendships	9.07 ± 4.04 (379)	4.54 ± 2.02
Facebook friendships	4.15 ± 2.87 (379)	2.08 ± 1.43
Multi-tasking preference	9.93 ± 2.99 (415)	2.48 ± 0.75

Appendix 5.3 Mean, SD, n and paired sample t-test for weekday and weekend days and by day or boarding students for BIS/BAS

Variable	Mean ± SD	Std Mean ± Std SD
BAS Drive	10.28 ± 2.56	2.57 ± 0.64
BAS Fun Seeking	11.37 ± 2.29	2.84 ± 0.57
BAS Reward Responsiveness	15.91 ± 2.34	3.18 ± 0.47
BIS	21.64 ± 4.28	3.09 ± 0.61

Appendix 6 – Other regression models from study 2

Appendix 6.1 Hierarchical linear regression for weekday time in bed

		Unstandardised B	Std. Error	β	t-value	p-value
Model1	Intercept	11.04	1.04		10.63	< 0.001
	Sex (1 = Male; 2 = female)	-0.34	0.26	-0.11	-1.28	0.20
	Age	-0.16	0.06	-0.21	-2.57	0.01
Model 2	(Intercept)	15.69	4.63	< 0.001	3.39	0.001
	Sex (1 = male; 2 = female)	-0.39	0.23	-0.14	-1.72	0.09
	Age	-0.03	0.09	-0.05	-0.36	0.72
	Type of student (1 = day school; 2 = boarding)	0.52	0.22	0.21	2.40	0.02
	School start time	0.33	0.37	0.08	0.89	0.38
	School end time	-0.04	0.11	-0.05	-0.39	0.70
	Anxiety	0.02	0.03	0.07	0.71	0.48
	Depression	0.001	0.03	0.004	0.02	0.98
	Physiological arousal	-0.02	0.03	-0.09	-0.89	0.38
	Behavioural arousal	-0.03	0.03	-0.11	-1.10	0.27
	Cognitive emotional arousal	-0.001	0.02	-0.01	-0.07	0.94
	Sleep environment	0.08	0.03	0.25	2.76	0.01
	Sleep stability	-0.01	0.03	-0.05	-0.56	0.58
	Daytime sleep	0.05	0.04	0.09	1.05	0.30
	Substance use	-0.09	0.08	-0.09	-1.09	0.28
	Bedtime routine	0.02	0.05	0.03	0.33	0.74
	Weekend mobile phone end	-0.27	0.06	-0.42	-4.25	< 0.001
	Weekend computer end	-0.21	0.06	-0.34	-3.85	< 0.001
	Weekend mobile phone buzz	-0.03	0.06	-0.04	-0.44	0.66
	Weekend computer buzz	0.09	0.06	0.14	1.48	0.14

Appendix 6.2 Hierarchical linear regression for weekday sleep duration

		Unstandardised B	Std. Error	β	t-value	p-value
Model1	Intercept	10.34	1.03		10.03	< 0.001
	Sex (1 = Male; 2 = female)	-0.20	0.26	-0.06	-0.77	0.44
	Age	-0.16	0.06	-0.22	-2.62	0.01
Model 2	(Intercept)	10.98	4.68	< 0.001	2.35	0.02
	Sex (1 = male; 2 = female)	-0.08	0.23	-0.03	-0.33	0.74
	Age	-0.05	0.09	-0.07	-0.54	0.59
	Type of student (1 = day school; 2 = boarding)	0.53	0.22	0.22	2.46	0.02
	School start time	0.48	0.37	0.12	1.29	0.20
	School end time	-0.01	0.11	-0.01	-0.12	0.90
	Anxiety	0.02	0.03	0.08	0.77	0.45
	Depression	-0.004	0.03	-0.0	-0.14	0.89
	Physiological arousal	-0.04	0.03	-0.16	-1.60	0.11
	Behavioural arousal	-0.03	0.03	-0.1	-0.99	0.32

	Cognitive emotional arousal	0.04	0.02	0.18	1.84	0.07
	Sleep environment	0.09	0.03	0.26	2.86	0.01
	Sleep stability	-0.01	0.03	-0.03	-0.30	0.77
	Daytime sleep	0.04	0.04	0.08	0.90	0.37
	Substance use	-0.12	0.08	-0.13	-1.49	0.14
	Bedtime routine	0.06	0.06	0.08	1.05	0.30
	Weekend mobile phone end	-0.24	0.06	-0.38	-3.77	< 0.001
	Weekend computer end	-0.16	0.06	-0.26	-2.92	0.004
	Weekend mobile phone buzz	-0.05	0.06	-0.08	-0.82	0.41
	Weekend computer buzz	0.12	0.06	0.18	1.93	0.06

Appendix 6.3 Hierarchical linear regression for sleepiness at school

		Unstandardised B	Std. Error	β	t-value	p-value
Model1	Intercept	2.28	0.28		8.15	< 0.001
	Sex (1 = Male; 2 = female)	-0.09	0.07	-0.11	-1.27	0.21
	Age	-0.01	0.02	-0.04	-0.42	0.67
Model 2	(Intercept)	2.62	1.35	< 0.001	1.94	0.06
	Sex (1 = male; 2 = female)	-0.17	0.07	-0.22	-2.62	0.01
	Age	-0.01	0.03	-0.04	-0.30	0.77
	Type of student (1 = day school; 2 = boarding)	0.04	0.06	0.06	0.62	0.53
	School start time	-0.06	0.11	-0.05	-0.57	0.57
	School end time	0.03	0.03	0.10	0.82	0.41
	Anxiety	0.01	0.01	0.06	0.56	0.58
	Depression	0.01	0.01	0.15	0.84	0.41
	Physiological arousal	-0.004	0.01	-0.06	-0.59	0.56
	Behavioural arousal	0.01	0.01	0.13	1.27	0.21
	Cognitive emotional arousal	-0.001	0.01	-0.03	-0.24	0.81
	Sleep environment	-0.03	0.01	-0.26	-2.77	0.01
	Sleep stability	-0.02	0.01	-0.29	-3.27	0.001
	Daytime sleep	-0.04	0.01	-0.27	-3.12	0.002
	Substance use	0.07	0.02	0.27	3.02	0.003
	Bedtime routine	-0.01	0.02	-0.06	-0.71	0.48
	Weekend mobile phone end	0.01	0.02	0.03	0.27	0.78
	Weekend computer end	0.01	0.02	0.05	0.51	0.61
	Weekend mobile phone buzz	0.01	0.02	0.07	0.70	0.49
	Weekend computer buzz	< 0.001	0.02	0.002	0.02	0.99

Appendix 6.4 Hierarchical linear regression for alertness at school

		Unstandardised B	Std Error	Standardised Beta	t value	p-value
Model1	Intercept	7.74	4.1321		1.8730	0.0632
	Sex (1 = Male; 2 = female)	1.37	1.0499	0.11	1.3010	0.1954
	Age	0.47	0.2448	0.16	1.9380	0.0547
Model 2	(Intercept)	-39.10	23.13	< 0.001	-1.69	0.09
	Sex (1 = male; 2 = female)	0.06	1.13	0.01	0.05	0.96

	Age	-0.77	0.43	-0.26	-1.78	0.08
	Type of student (1 = day school; 2 = boarding)	0.92	1.07	0.08	0.86	0.40
	School start time	3.68	1.84	0.20	2.00	0.048
	School end time	1.07	0.56	0.25	1.89	0.06
	Anxiety	0.26	0.14	0.21	1.84	0.07
	Depression	0.34	0.14	0.47	2.50	0.01
	Physiological arousal	0.05	0.13	0.05	0.41	0.68
	Behavioural arousal	0.07	0.15	0.05	0.46	0.65
	Cognitive emotional arousal	-0.04	0.10	-0.04	-0.39	0.70
	Sleep environment	-0.04	0.15	-0.03	-0.27	0.79
	Sleep stability	-0.17	0.12	-0.13	-1.39	0.17
	Daytime sleep	-0.12	0.22	-0.05	-0.56	0.57
	Substance use	0.24	0.40	0.06	0.60	0.55
	Bedtime routine	-0.37	0.27	-0.12	-1.38	0.17
	Weekend mobile phone end	0.70	0.32	0.25	2.21	0.03
	Weekend computer end	-0.12	0.28	-0.04	-0.44	0.66
	Weekend mobile phone buzz	-0.24	0.31	-0.09	-0.80	0.43
	Weekend computer buzz	0.38	0.30	0.13	1.23	0.22

Appendix 6.5 Hierarchical linear regression for sleepiness on weekday evenings

		Unstandardised B	Std. Error	β	t-value	p-value
Model1	Intercept	2.94	2.12		1.39	0.17
	Sex (1 = Male; 2 = female)	-0.35	0.54	-0.05	-0.64	0.52
	Age	0.41	0.13	0.27	3.28	0.001
Model 2	(Intercept)	-3.13	10.59	< 0.001	-0.30	0.77
	Sex (1 = male; 2 = female)	-0.002	0.52	-0.0003	-0.004	1.00
	Age	-0.03	0.20	-0.02	-0.16	0.87
	Type of student (1 = day school; 2 = boarding)	-0.18	0.49	-0.03	-0.37	0.71
	School start time	1.98	0.84	0.21	2.36	0.02
	School end time	0.02	0.26	0.01	0.09	0.93
	Anxiety	0.11	0.06	0.17	1.64	0.11
	Depression	0.02	0.06	0.04	0.25	0.80
	Physiological arousal	0.04	0.06	0.08	0.75	0.45
	Behavioural arousal	-0.06	0.07	-0.08	-0.83	0.41
	Cognitive emotional arousal	-0.08	0.05	-0.17	-1.76	0.08
	Sleep environment	-0.14	0.07	-0.18	-1.97	0.05
	Sleep stability	-0.05	0.06	-0.08	-0.91	0.37
	Daytime sleep	-0.26	0.10	-0.22	-2.61	0.01
	Substance use	-0.16	0.18	-0.08	-0.89	0.38
	Bedtime routine	-0.06	0.12	-0.04	-0.45	0.66
	Weekend mobile phone end	-0.24	0.15	-0.16	-1.62	0.11
	Weekend computer end	0.44	0.13	0.32	3.49	0.001
	Weekend mobile phone buzz	0.01	0.14	0.01	0.08	0.94
	Weekend computer buzz	-0.15	0.14	-0.10	-1.09	0.28

Appendix 6.6 Hierarchical linear regression for weekend time in bed

		Unstandardised B	Std. Error	β	t-value	p-value
Model1	Intercept	12.41	1.28		9.67	< 0.001
	Sex (1 = Male; 2 = female)	-0.14	0.33	-0.04	-0.43	0.67
	Age	-0.18	0.08	-0.20	-2.38	0.02
Model 2	(Intercept)	11.50	7.10	< 0.001	1.62	0.11
	Sex (1 = male; 2 = female)	-0.26	0.36	-0.07	-0.71	0.48
	Age	-0.05	0.13	-0.05	-0.35	0.73
	Type of student (1 = day school; 2 = boarding)	-0.57	0.33	-0.17	-1.74	0.09
	School start time	0.26	0.58	0.05	0.44	0.66
	School end time	-0.004	0.16	-0.004	-0.03	0.98
	Anxiety	-0.03	0.04	-0.08	-0.69	0.49
	Depression	-0.01	0.04	-0.06	-0.32	0.75
	Physiological arousal	0.03	0.04	0.10	0.889	0.38
	Behavioural arousal	0.01	0.05	0.03	0.24	0.81
	Cognitive emotional arousal	-0.08	0.03	-0.30	-2.80	0.01
	Sleep environment	0.04	0.05	0.08	0.78	0.44
	Sleep stability	-0.01	0.04	-0.02	-0.26	0.780
	Daytime sleep	-0.08	0.07	-0.11	-1.17	0.24
	Substance use	0.34	0.13	0.26	2.68	0.01
	Bedtime routine	0.03	0.08	0.03	0.36	0.72
	Weekend mobile phone end	-0.14	0.09	-0.20	-1.65	0.10
	Weekend computer end	-0.10	0.07	-0.15	-1.46	0.15
	Weekend mobile phone buzz	0.03	0.09	0.04	0.31	0.76
	Weekend computer buzz	0.05	0.09	0.06	0.54	0.59

Appendix 6.7 Hierarchical linear regression for weekend sleepiness

		Unstandardised B	Std. Error	β	t-value	p-value
Model1	Intercept	1.62	0.28		5.74	< 0.001
	Sex (1 = Male; 2 = female)	-0.05	0.07	-0.06	-0.69	0.49
	Age	0.04	0.02	0.20	2.44	0.02
Model 2	(Intercept)	5.34	1.47	0.000	3.64	< 0.001
	Sex (1 = male; 2 = female)	-0.09	0.08	-0.11	-1.23	0.22
	Age	-0.002	0.03	-0.01	-0.09	0.93
	Type of student (1 = day school; 2 = boarding)	0.01	0.07	0.01	0.08	0.94
	School start time	-0.18	0.12	-0.15	-1.52	0.13
	School end time	0.001	0.03	0.01	0.04	0.97
	Anxiety	0.01	0.01	0.14	1.30	0.17
	Depression	0.01	0.01	0.20	1.14	0.6
	Physiological arousal	0.01	0.01	0.12	1.20	0.23
	Behavioural arousal	-0.01	0.01	-0.09	-0.86	0.39
	Cognitive emotional arousal	-0.001	0.01	-0.01	-0.12	0.91

	Sleep environment	-0.03	0.01	-0.24	-2.64	0.01
	Sleep stability	-0.01	0.01	-0.15	-1.74	0.09
	Daytime sleep	-0.06	0.01	-0.36	-4.08	< 0.001
	Substance use	-0.002	0.03	-0.01	-0.09	0.93
	Bedtime routine	0.02	0.02	0.09	1.109	0.27
	Weekend mobile phone end	-0.01	0.02	-0.07	-0.63	0.53
	Weekend computer end	-0.003	0.01	-0.02	-0.22	0.82
	Weekend mobile phone buzz	0.01	0.02	0.05	0.48	0.63
	Weekend computer buzz	-0.03	0.02	-0.14	-1.38	0.17

Appendix 6.8 Hierarchical linear regression for weekend alertness

		Unstandardised B	Std. Error	β	t-value	p-value
Model1	Intercept	1.63	0.29		5.54	< 0.001
	Sex (1 = Male; 2 = female)	0.06	0.07	0.06	0.79	0.43
	Age	0.06	0.02	0.28	3.45	< 0.001
Model 2	(Intercept)	-4.32	23.03	0	-0.19	0.85
	Sex (1 = male; 2 = female)	0.51	1.17	0.04	0.43	0.67
	Age	-0.12	0.43	-0.04	-0.27	0.79
	Type of student (1 = day school; 2 = boarding)	0.67	1.07	0.06	0.62	0.54
	School start time	0.78	1.89	0.04	0.41	0.68
	School end time	0.56	0.53	0.14	1.04	0.30
	Anxiety	0	0.14	0	0	1.00
	Depression	0.31	0.14	0.42	2.25	0.03
	Physiological arousal	0.06	0.12	0.05	0.48	0.63
	Behavioural arousal	0.05	0.15	0.03	0.31	0.76
	Cognitive emotional arousal	-0.06	0.09	-0.07	-0.67	0.50
	Sleep environment	-0.09	0.15	-0.06	-0.64	0.53
	Sleep stability	0.08	0.12	0.06	0.69	0.50
	Daytime sleep	-0.32	0.22	-0.14	-1.46	0.15
	Substance use	0.24	0.41	0.06	0.57	0.57
	Bedtime routine	-0.64	0.27	-0.21	-2.37	0.02
	Weekend mobile phone end	0.21	0.28	0.09	0.75	0.46
	Weekend computer end	0.075	0.220	0.035	0.343	0.73
	Weekend mobile phone buzz	-0.158	0.296	-0.061	-0.534	0.60
	Weekend computer buzz	-0.201	0.306	-0.073	-0.657	0.51

<u>**Appendix 7: Daily diary self-reported sleep questions from study 3**</u>

Q2.1

These questions are about your sleep last night.

How would you rate your sleep quality...

	Very Good			Satisfactory			Very Poor
	1	2	3	4	5	6	7
Sleep Quality							

Q2.2

How refreshed did you feel upon waking this morning?

	Very Refreshed			Satisfactory			Very Unrefreshed
	1	2	3	4	5	6	7
Refreshed							

Q2.3

These questions are still about your sleep last night.

What time did you **go to bed** at last night?

Please answer in 24:00 clock.

Q2.4

What time did you **start trying to get to sleep**?

Please answer in 24:00 clock.

Q2.5

How long did it take you to **fall asleep once you had started trying**?

Please provide your answer in hours and minutes e.g. 30 minutes would be 00:30.

Q2.6

How many times did you wake during the night, not counting your final awakening?

- Not at all
- Once
- Twice
- Three times
- Four times
- Five or more times

In total, how long did these wakings last?

Please provide your answer in hours and minutes e.g. 30 minutes would be 00:30.

Page Break

Q2.8

When you woke this morning...

What time did you **wake up** at before you got up for the day?

Please provide your answer in 24:00 clock.

Q2.9

What time did you **get out of bed** at?

Please provide your answer in 24:00 clock.

Appendix 8: Screening data results from study 3

Appendix 8.1: Demographic and sleep hygiene descriptive statistics from the screening survey

Variable	M ± SD	Std. M ± SD	Day student M ± SD	Boarding student M ± SD	Paired t-tests
Age	16.75 ± 0.37	-	16.78 ± 0.34	16.73 ± 0.39	t(8.01) = 0.27, p = 0.8
School start time	8.89 ± 0.28 [08:53 ± 00:17]	-	-	-	
School end time	16.09 ± 0.64 [16:05 ± 00:38]	-	-	-	
Time spent at school before classes	0.82 ± 0.53 [00:49 ± 00:32]	-	0.72 ± 0.38 [00:43 ± 00:23]	0.85 ± 0.58 [00:51 ± 00:35]	t(11.03) = -0.58, p = 0.58
Time spent at school after classes	2.20 ± 2.03 [02:12 ± 02:02]	-	1.33 ± 0.69 [01:20 ± 00:41]	2.51 ± 2.27 [02:31 ± 02:16]	t(16.92) = -1.73, p = 0.1
BMI	20.95 ± 2.49	-	21.52 ± 2.56	20.75 ± 2.52	t(6.99) = 0.58, p = 0.58
HADS- Anxiety	7.74 ± 4.04	-	6.00 ± 3.74	3.00 ± 2.55	t(7.71) = -1.18, p = 0.27
HADS -Depression	3.11 ± 2.05	-	8.36 ± 4.09	3.14 ± 1.96	t(5.78) = -0.11, p = 0.91
ASHS- Physiological arousal	24.79 ± 3.46	4.96 ± 0.69	23 ± 4.12	25.43 ± 3.11	t(5.71) = -1.20, p = 0.28
ASHS- Behavioural arousal	9.74 ± 3.03	3.25 ± 1.01	8.6 ± 2.97	10.14 ± 3.06	t(7.29) = -0.99, p = 0.35
ASHS- Cognitive emotional arousal	22.79 ± 5.4	3.8 ± 0.9	23 ± 4.24	22.71 ± 5.9	t(9.97) = 0.12, p = 0.91
ASHS- Daytime sleepiness	11.47 ± 1.02	5.74 ± 0.51	27 ± 3.08	27.57 ± 2.1	t(13) = 2.35, p = 0.04
ASHS- Sleep environment	27.42 ± 2.32	5.48 ± 0.46	10.6 ± 3.97	11.21 ± 2.15	t(5.39) = -0.38, p = 0.72
ASHS- Sleep stability	11.05 ± 2.63	3.68 ± 0.88	12 ± 0	11.29 ± 1.14	t(4.87) = -0.33, p = 0.76
ASHS- Substances	11.53 ± 1.17	5.76 ± 0.59	11.2 ± 1.79	11.64 ± 0.93	t(4.79) = -0.53, p = 0.62

ASHS- Bedtime routine	3.74 ± 1.19	-	3.6 ± 0.89	3.79 ± 1.31	t(10.58) = -0.35, p = 0.73
Total ASHS score	122.53 ± 12.78	-	119 ± 6.43	123.79 ± 11.68	t(5.52) = -0.60, p = 0.57

Appendix 8.2 Self-reported sleep descriptive statistics from the screening survey

Variable	Weekday M ± SD [hh:mm]	Weekend M ± SD [hh:mm]	Paired t-test	Day student weekday M ± SD [hh:mm]	Boarding student weekday M ± SD [hh:mm]	Multivariate ANOVA	Day student weekend M ± SD [hh:mm]	Boarding student weekend M ± SD [hh:mm]	Multivariate ANOVA
SQ	3.16 ± 1.38	2.32 ± 0.82	t(18) = 2.92,	3.2 ± 1.3	3.14 ± 1.46	*F*(1,17) = 0.006,	2 ± 0	2.43 ± 0.94	*F*(1,17) = 1.001,
			p = 0.009			p = 0.94			p = 0.33
Ref	3.42 ± 1.5	2.47 ± 1.17	t(18) = 2.81,	3.00 ± 1.23	3.57 ± 1.60	*F*(1,17) = 0.52,	2.00 ± 1.23	2.64 ± 1.15	*F*(1,17) = 1.12,
			p = 0.012			p = 0.48			p = 0.31
SOL	0.5 ± 0.44	0.5 ± 0.55	t(18) = -0.006,	0.63 ± 0.62	0.45 ± 0.38	*F*(1,17) = 0.62,	0.62 ± 0.32	0.46 ± 0.62	*F*(1,17) = 0.3,
	[00:30 ± 00:26]	[00:30 ± 00:33]	p = 0.99	[00:38 ± 00:37]	[00:27 ± 00:23]	p = 0.44	[00:37 ± 00:19]	[00:28 ± 00:37]	p = 0.59
BT	23.1 ± 0.75	23.71 ± 1.04	t(18) = -3.59,	22.48 ± 0.77	23.32 ± 0.64	*F*(1,17) = 5.74,	23.05 ± 1.28	23.95 ± 0.87	*F*(1,17) = 3.08,
	[23:06 ± 00:45]	[23:43 ± 01:02]	p = 0.002	[22:29 ± 00:46]	23:19 ± 00:38]	p = 0.03	[23:03 ± 01:17]	[23:57 ± 00:52]	p = 0.1
WT	30.8 ± 0.39	32.68 ± 0.99	t(18) = -7.37,	30.7 ± 0.64	30.83 ± 0.28	*F*(1,17) = 0.42,	32.45 ± 1.35	32.76 ± 0.87	*F*(1,17) = 0.36,
	[06:48 ± 00:23]	[08:41 ± 00:59]	p < 0.001	[06:42 ± 00:38]	[06:50 ± 00:17]	p = 0.53	[08:27 ± 01:21]	[08:46 ± 00:52]	p = 0.56
TIB	7.7 ± 0.71	8.97 ± 0.84	t(18) = -598,	8.22 ± 0.80	7.51 ± 0.61	*F*(1,17) = 4.23,	9.4 ± 0.65	8.82 ± 0.86	*F*(1,17) = 1.88,
	[07:42 ± 00:43]	[08:58 ± 00:50]	p < 0.001	[08:13 ± 00:48]	[07:31 ± 00:37]	p = 0.06	[09:24 ± 00:39]	[08:49 ± 00:52]	p = 0.19
SD	7.2 ± 0.78	8.47 ± 0.96	t(18) = -5.51,	7.58 ± 1.13	7.06 ± 0.61	*F*(1,17) = 1.75,	8.78 ± 0.63	8.36 ± 1.05	*F*(1,17) = 0.71,
	[07:12 ± 00:47]	[08:28 ± 00:58]	p < 0.001	[07:35 ± 01:08]	[07:04 ± 00:37]	p = 0.20	[08:47 ± 00:38]	[08:22 ± 01:03]	p = 0.41

Note: SQ: sleep quality, Ref: waking feeling refreshed, SOL: sleep onset latency, BT: Bedtime, WT: wake time, TIB: time in bed, SD: sleep duration; significant results are in **bold**

Appendix 8.3: Number of participants who had night screen enabled on weekdays and at the weekend

	Number of participants who had night screen enabled on weekdays	Number of participants who did not have night screen enabled on weekdays	Number of missing responses	Number of participants who had night screen enabled at the weekend	Number of participants who did not have night enabled at the weekend	Number of missing responses
TV	0	6	1	0	5	7
MP	13	6	-	12	6	1
Tablet	-	-	-	-	-	2
E-reader	2	-	-	1	-	-
Computer	4	12	1	3	9	3

Appendix 8.4: Weekday and weekend device end time and cognitive arousal from the screening survey

Tech variable	Weekday M ± SD [hh:mm] (n)	Weekend M ± SD [hh:mm] (n)	t-test
Daily Diary			
TV End	20.25 ± 2.47 (2)	22.8 ± 1.52 (5)	-
MP End	22.32 ± 1.49 (19)	23.18 ± 1.69 (19)	t(18) = -2.15, p = 0.05
Tablet End	21.25 ± 3.18 (2)	21.5 ± 5.66 (2)	t(1) = -0.14, p = 0.91
E-reader End	22.75 ± 0.35 (2)	23 ± 0 (2)	-
Comp End	21.19 ± 1.32 (18)	21 ± 1.63 (16)	t(15) = 0.65, p = 0.53
TV CA	3.5 ± 2.12 (2)	4.6 ± 1.14 (5)	t-
MP CA	3.84 ±1.68 (19)	3.84 ± 1.57 (19)	t(18) = 0, p = 1.0
Tablet CA	3.5 ± 2.12 (2)	3 ± 2.83 (2)	t(1) = 1, p = 0.5
E-reader CA	1 ± 0 (2)	1 ± 0 (2)	-
Comp CA	2.59 ± 1.5 (17)	2.56 ± 1.46 (16)	t(14) = 0, p = 1.0

Appendix 9 - Categorisation of applications for study 3

Social Media	Video Streaming Services	Music Streaming Services	Communication	Studying for school	Video Games	Online Shopping	Email	News	Document Writing	Information Search	Photos	Mobile Banking	Sports	Health and Fitness	Search Engines	Utilities	Food delivery	Sat nav	Storage	Tracker	Professional	Reading	Study Participation
Instagram	Youtube	Spotify	Whatsapp	Quizlet	Among us	Motel Rocks	Outlook	Sky News	Watt Pad	Bible	VSCO	HSBC	Premier League	Nike Training	Ecosia	Calculator	Uber Eats	Google Maps	One drive	P.D. (Period tracking)	LinkedIn	Fanfiction.net	Qualtrics
Snapchat	Netflix	Apple Music	Viber	Spanish Dictionary	8 Ball Pool	ASOS	Gmail	BBC News	Excel	Wikipedia	Camera	Barclays	NFL	Tabata	Google	Settings	Dominos		Google Drive	D of E (Duke of Edinburgh tracking app)		TheFreeOnlineNovel.com	Labvanced
Facebook	Apple TV	Music	Messages	My Study Life	Subway Surf	Etsy	School Email	Guardian- Live World News	Powerpoint	Reddit	Photos	Paypal		Strava		Reminders						Chitanka.info (Bulgarian book site)	
Twitter	BBC I player	Boomplay	Facebook Messenger	Classroom	Bubble Sort	Amazon		News	Word	Quora		Lloyds bank		Interval Timer		X-VPN							
Tiktok	ITV Hub	Audio Mack (Amazon	Zoom	Timetable	Clash of Clans	Zara			Documents	Word Reference				thriveglobal.com (wellbeing		Clock							

	music)							website)	
Prime Video	Podcasts?	Skype	Homework pal	Clash Royale	Urban Outfitters	Notes	Spanish Dictionary?		App Store
SkyGo		Phone	Google Translate	Water Sort Puzzle	Depop	Files	Pintrest		Halo Verify 9Covid-19 test results)
Cricket Australia Live		Telegram	Translate	Woody	Currys	Office	Panmacmillan.com (publisher site)		Calendar
Friendly Streaming brower		Signal	Classroom	2048	My Protein	Simple Mind	English Heritage		Weather
Turkish123.com (Turkish streaming service)			Microsoft Teams	Candy Crush	Next.co.uk	One Note	Latin Dictionary		Stocks
La123movies.com (Movie streaming site)			Reverso Context (Translator)	Xbox	Uk.tommy.com	Office Lens (makes documents more readable)	Worldometers.info		Voice Memos
			Idle Human (Anatomy)	SSG3	Uk.gymshark.com	Forms.office.com	Goodhousekeeping.com		Contacts

iStudent (security and school information)	Grand Mountain Adventure	Jaeger.co.uk		sway.office.com (create presentations, newsletters etc.)	everydaypower.com		Scanner Pro
wf2.bromsgrove-school.co.uk (school intranet)	1010!	Mango.co.uk			1jour1actu.com (French information site)		Xmas Clock
Bookshelf.oxfordsecondary.co.uk- online textbook viewer	ChainCube	Poster store.co.uk			idealhome.co.uk		
Kahoot.it	NSS	Nastygal.co.uk			rrauk.com (romanian dog adoption service)		
Menti.com	Ea.com	Ussupply.com (plumbing equipment)			john whitaker.com (horse riding equipment)		
Kerboodle.com					Victoria secret.com		
ib.bioninja.com.au (biology website)					Bbc.co.uk		
socscms.com (calendar management system for schools)							

Appendix 10 – Correlations matrix between daily diary sleep variables and actigraphy derived sleep variables.

	Ref	BT DD	ST DD	SOL DD	WT DD	RT DD	Wake Night	TIB DD	SD DD	BT SW	SOL SW	RT SW	WASO SW	TIB SW	TST SW	%SE
SQ	0.88	0.54	0.35	0.1	0.32	0.33	0.24	-0.43	-0.21	0.54	-0.08	0.49	-0.16	-0.35	-0.06	0.35
Ref		0.35	0.13	0.19	0.35	0.37	0.2	-0.2	0.05	0.34	-0.11	0.56	0.02	-0.08	0.22	0.22
BT DD			0.77	-0.33	0.49	0.47	-0.24	-0.88	-0.59	1	-0.56	0.55	-0.61	-0.86	-0.5	0.79
ST DD				-0.21	0.48	0.42	-0.18	-0.64	-0.86	0.77	-0.44	0.45	-0.43	-0.65	-0.42	0.54
SOL DD					-0.51	-0.54	0.23	0.08	-0.06	-0.31	0.62	-0.41	0.23	0.13	0.1	-0.26
WT DD						0.97	0.04	-0.03	0.04	0.47	-0.7	0.9	-0.41	-0.04	0.27	0.52
RT DD							0	0.01	0.09	0.44	-0.7	0.9	-0.37	-0.01	0.22	0.45
Wake Night								0.28	0.23	-0.25	0.07	-0.05	-0.16	0.27	0.32	0.09
TIB DD									0.72	-0.89	0.25	-0.13	0.49	0.97	0.69	-0.65
SD DD										-0.6	0.1	0.01	0.25	0.72	0.64	-0.31
BT SW											-0.54	0.53	-0.6	-0.87	-0.5	0.79
SOL SW												-0.61	0.43	0.28	-0.02	-0.64
RT SW													-0.18	-0.05	0.34	0.43
WASO SW														0.61	0.41	-0.86
TIB SW															0.79	-0.68
TST SW																-0.22