Sleep and mental wellbeing in young people: The role of electronic media use and school start times

by

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List of Abbreviations

ADHD	Attention Deficit Hyperactivity Disorder
CBT	Cognitive Behavioural Therapy
CBT-i	Cognitive Behavioural Therapy for Insomnia
CESD-10	Center for Epidemiological Depression Short Form
CG	Control Group
CG_{SSTc}	Comparison Group
CI	Confidence Interval
CM	Circadian misalignment
DLMO	Dim light melatonin onset
$DLMO_{off}$	Dim light melatonin offset
EEG	Electroencephalogram
ICC	Intracluster correlation coefficient
IG	Intervention Group
ITT	Intention to treat
LED	Lights emitted diodes
mEMA	Mobile Ecological Momentary Assessment
NA	Negative affect
NREM	non-Rapid Eye Movement
NSF	National Sleep Foundation
PA	Positive affect
PANAS	Positive and Negative Affect Scale

PPCT	Person-Place-Context-Time Model
PSQI	Pittsburgh Sleep Quality Inventory
RCT	Randomised Controlled Trial
REM	Rapid Eye Movement
SCN	Suprachiasmatic nucleus
SD	Standard deviation
SE	Standard error
SSTc	School start time change
SWA	Slow wave activity
SWS	Slow wave sleep
UK	United Kingdom
US/USA	United States of America
WHO	World Health Organization

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Declarations

This thesis is submitted to the University of Warwick in support of the application for the degree of Doctor of Philosophy. It has been composed by the author under the guidance of supervisors Professor Sakari Lemola and Professor Dieter Wolke, and has not been submitted in any previous application for any degree. Majority of the work presented (data collection, data analyses and write up) was carried out by the author, and others' contribution (in data collection) has been acknowledged. Parts of this dissertation have been published as peer-reviewed research articles:

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Summary

Research on the sleep of young people (12-24 years) has examined determinants and consequences of poor sleep. Poor mental health and wellbeing is one consequence that has received sustained empirical focus. In recent years, the rapid uptake of electronic and social media use has been regarded as an important risk factor for poor sleep. Avenues for improving sleep have focused on targeting these behaviours, but also addressing systemic factors such as school start times. This dissertation explores the relationships between these variables, and focusses on understanding how sleep problems within this population can be improved.

Chapter 1 introduces the topic and provides an overview of the literature.

Chapter 2 discusses the theoretical underpinnings, by reviewing Bronfenbrenner's bioecological theory of human development and the two-process model of sleep. Developmental changes occurring in sleep during adolescence are explored, and how electronic media use and school start times impact sleep during this time are discussed.

Chapter 3 presents the research questions.

Chapter 4 examines a 25-minute school-based intervention aimed at improving sleep of adolescents by addressing sleep hygiene behaviours of bedtime electronic media use. Though bedtime electronic media use decreased for those in the Intervention Group, it did not reflect in changes in sleep or wellbeing.

Chapter 5 explores the temporal links between bedtime social media use, sleep and affective wellbeing in young adults, by using an experience sampling methodology. Bedtime media use did not predict sleep the same night or affective wellbeing the following day for healthy participants.

Chapter 6 evaluates the impact of a policy-level decision of delaying school start times for all public schools in the Swiss city of Basel, on the sleep duration and mental wellbeing of adolescents. The 20-minute delay did not lead to long-term improvements in sleep or wellbeing.

Chapter 7 presents the overall findings, implications and avenues for future research, as well as a critical evaluation of the studies.

Chapter 1
Introduction

1.1 Prologue

Adolescence is a period of human life that is marked with significant physical, cognitive and social development. Of much interest, both within and outside the scientific community, are the observable changes that occur in the sleeping behaviours of this group – as children transition through adolescence into young adulthood, a consensus is that it becomes increasingly difficult for many to wake up early in the morning, which is paralleled with them preferring to and being able to stay awake for longer periods at night. A direct effect of these changes is thought to result in shorter and poorer sleep, especially within the context of early school start times; spill-over effects are discussed within the context of mental health and wellbeing, and the overall day-to-day functioning of this population. Over the last decade, another factor has become part of the sleep and mental wellbeing narrative amongst young people, that being the dependence on and almost around-the-clock use of electronic and social media, with an overwhelming part of the narrative discussing the ill-effects of this excessive use on the sleep and wellbeing of its users.

1.2 Defining adolescence and young adulthood

Adolescence, the developmental stage between childhood and adulthood, is typically defined as the period spanning the second decade of human life, *i.e.* between 10 to 19 years of age (WHO, 2001). This definition has often been disputed in the academic, public and health policy literature, in part due to the difficulty in clearly outlining the boundaries of when childhood ends on the one hand, and importantly, when adulthood begins on the other (Ledford, 2018; Sawyer et al., 2018). It has been proposed that even though the lower boundary of 10 years is perhaps suitable, given its coincidence with the onset of puberty and therefore a marked departure from childhood, the upper boundary should be shifted to 24 years to better align with current understandings of developmental growth and societal transition (Sawyer & Patton, 2018). The term 'young adults' or ‘emerging adults’ is also used to identify the transition from adolescence to adulthood, defining this period as being between 18 and 24 years of age (Arnett, 2000). Due to the lack of universal agreement regarding the specific age group for persons to be considered adolescents, individuals aged between 10 and 24 years old are often called ‘young people’, or ‘adolescents and young adults’ (Patton et al., 2016; Sawyer et al., 2012; WHO, 2001). Data from studies based on adolescent samples are divided into the following three groups: young adolescents for persons aged 10 – 14 years, older adolescents for persons aged 15 – 19 years old, and young adults for persons aged 20 – 24 years old (Patton et al., 2016). In this thesis, the term ‘adolescents and young adults’ or ‘young persons’ will be used to refer to the 10 – 24 -year age group, with studies in Chapters 4 and 6 focusing on younger and older adolescents (12 – 19 years), and the study in Chapter 5 focusing on older adolescents and young adults (18 – 23 years).

In contrast to the ongoing definition debate, what remains undisputed amongst researchers and policymakers alike, is that adolescence is a period that sees profound development in all aspects and spheres of a human being’s life. It marks the transition of an individual from a non-reproductive to a fertile, reproductive human being, and includes physical, physiological, cognitive, behavioural and societal changes; it is how young people navigate and negotiate with these changes that are crucial in determining a healthy transition to adulthood (Waylen & Wolke, 2004). Of importance to this thesis are the changes that occur in the sleep and thereby the mental wellbeing of young people, which is discussed henceforth.

1.3 Sleep and mental health during adolescence and young adulthood

1.3.1 Duration and quality of sleep and its implications for wellbeing

Sleep can be defined as a state of unconsciousness or immobility with reduced responsiveness to external stimuli or surroundings (Siegel, 2005). Sleep has also been described as being an altered state of mind and consciousness, since, although an individual has decreased awareness of their surroundings for instance, or do not remember that they have just fallen asleep, the brain can still engage in mentation such as dreaming (Revonsuo et al., 2009). Our understanding about the importance of sleep stems not only from studies examining how sleep contributes to different functions such as memory consolidation (Diekelmann & Born, 2010) or maintenance of our immune system (K. Ackermann et al., 2012), but also from studies that investigate the impact of sleep deficit/restriction/extension/deprivation on our ability to function. For example, it has been demonstrated that chronic sleep restriction of between 4 to 6 hours of sleep per night for adults aged between 21 and 38 years, results in severe impairment of cognitive functioning, made worse by the fact that persons experiencing these deficits remained unaware of it (Van Dongen et al., 2003). Similarly for adolescents, findings suggest that a two-week period of restricting sleep to 6.5 hours per night, increases negative mood and tiredness, as well as an inability to regulate negative mood (Baum et al., 2014). Both lines of research provide concrete evidence regarding the negative effects of sustained insufficient sleep on our ability to function optimally – however, what sets them apart because of their samples, is the boundary which is used to define sleep restriction (*i.e.*, 4-6 hours for adults versus 6.5 hours for adolescents). This distinction highlights a key assumption in our approach to understanding sleep, namely that the amount of sleep required for human beings to efficiently and optimally function depends (and a result differs based) on their biological age or developmental phase. As such, sleep need is thought to be highest for new-borns, decreasing steadily with age, and stabilising around adulthood (Wolke, 1994). These sleep need suggestions imply two things. First, that sleep changes or evolves as a function of human maturation. Second, that by using sleep as a marker for developmental changes, the bulk of changes that occur in the first twenty years of life can be viewed as being significantly different from those that follow later in life (*e.g.*, developmental changes versus degenerative changes).

The National Sleep Foundation (NSF), recommends that 6 to 13 year old children and adolescents require 9 – 11 hours of sleep per night, 14 to 17 year old adolescents require 8 – 10 hours of sleep per night, and 18 to 24 year old adolescents and young adults require 7 – 9 hours of sleep per night (Hirshkowitz et al., 2015); these have been echoed by other organisations (Paruthi et al., 2016). However, the validity of these recommendations, which are based primarily on cross-sectional studies and studies utilising sleep restriction and/or extension designs, have been questioned in light of trends that highlight that sleep duration recommendations have generally decreased over the years (Matricciani et al., 2012, 2013). However, recent attempts at estimating sleep need using dose-response methods have been made, and preliminary results seem to be aligned with existing recommendations (*e.g.*,, for 15-17 year olds, an optimal duration of 9.35 hours has been suggested by Short et al. 2018). The current utility of NSF guidelines is that they provide a universal, consistent and comparable standard against which to examine and understand the sleep behaviours of and its impact on young persons. Based on these guidelines, evidence suggests that adolescents worldwide are not sleeping enough. In a meta-analysis of over 40 studies and surveys from different countries, Gradisar et al. (2011) reported that a majority of adolescents were sleeping 8 hours or less per school night, with variation across countries, for example, an average of around 7 hours for Chinese adolescents (Chung & Cheung, 2008) versus 8 hours for German adolescents (Loessl et al., 2008). It was also reported that the amount of sleep that adolescents were getting reduced with increasing age, a finding corroborated by further research (Gradisar et al., 2011). For instance, a sleep habits poll conducted by the NSF (2014) found that the amount that American adolescents were sleeping dramatically decreased as they progressed from early to late adolescence, with parents reporting that 8% of 6-11 year olds were sleeping 7 hours or less on school nights, whereas more than half (or 56%) of 15-17 year olds were sleeping 7 hours or less on the same nights. Given that sleep need is suggested to remain stable across adolescence (Crowley et al., 2018; Tarokh et al., 2016), these findings of insufficient sleep experienced by young persons become concerning when taken together with knowledge of the effects that sleep deprivation can have on adolescents' abilities to optimally function (*e.g.*, Baum et al., 2014). A large number of young adults are also not sleeping enough, obtaining an average of less than 7 hours, especially on weeknights (Hershner & Chervin, 2014; Lund et al., 2010). Chronic sleep deprivation in young adults has been associated with increased risk of experiencing severe sleep debt and worsening health outcomes (Klerman & Dijk, 2005; Steptoe et al., 2006).

Significant problems with sleep quality amongst adolescents (Dewald et al., 2010; Gradisar et al., 2011) and young adults (Lund et al., 2010) are also prevalent. Consensus over defining sleep quality is mixed, and as such, a universal definition of sleep quality does not exist. In the simplest manner, sleep quality can be defined as an indicator of how good or bad one's sleep is or how rested one feels after waking up – this definition implies that sleep quality is often a subjective assessment, and one that is most widely employed in adolescent studies due to ease of use and access (Ji & Liu, 2016). A common method of measuring sleep quality in research is by asking participants to indicate on Likert scales how satisfied they are with their sleep, for example, via the Pittsburgh Sleep Quality Inventory (Buysse et al., 1989). Objective assessments of sleep quality are also utilised in research, for example, how many times an individual wakes up through the night, not counting the final morning awakening (Short et al., 2012). The NSF recommends parameters for assessing sleep quality using objective sleep measures, drawn from a review of over 270 primarily cross-sectional, experimental and cohort studies (Ohayon et al., 2017). For instance, a sleep latency (defined as time taken to fall asleep) of 15 minutes or lesser, or one or fewer awakenings (defined as the number of times a person wakes up for a period longer than 5 minutes) are considered indicators of good sleep quality for young persons; in contrast, a sleep latency of more than 45 minutes or three/four or more awakenings are indicators of poor sleep quality. There is evidence to argue that subjective and objective sleep indicators capture different aspects of sleep (Krystal & Edinger, 2008; Tremaine et al., 2010), implying differential associations with varying outcome measures. As a result, it is recommended to use a combination of both types of assessment in order draw comprehensive conclusions of the links between sleep quality and a broad range of outcomes (Dewald et al., 2010). Within the sleep literature, varied types of sleep quality assessments and indicators are included under the umbrella term of sleep disturbances or sleep problems.

Both insufficient sleep, as well as poor sleep quality have been linked to a range of negative consequences such as obesity (Miller et al., 2018; Nielsen et al., 2011; Sluggett et al., 2019; Wu et al., 2017), and a higher risk of engaging in risky or impulsive behaviours. (McKnight-Eily et al., 2011; Rossa et al., 2014). Specifically for young persons, a commonly reported negative consequence of poor sleep is daytime sleepiness or tiredness, which can be defined as an inability to stay awake or alert during the day, and generally feeling sleepy and/or tired (Thorarinsdottir et al., 2019). Carskadon et al. (1980), using a controlled experiment, found that mid and late pubertal adolescents were likely to fall asleep quicker during the day in comparison to pre and early pubescent children; this was assumed to be a measure of daytime sleepiness and one of the first few studies to report this link. Since then, evidence has confirmed that the incidence of daytime sleepiness is unusually high among adolescents and young adults alike (Hershner & Chervin, 2014; Y. Liu et al., 2019; Millman, 2005; Moore & Meltzer, 2008; Murugesan et al., 2018; Perkinson-Gloor et al., 2013; Short, Gradisar, Lack, & Wright, 2013; Short & Chee, 2019), providing strong support for the assumption that this population is not sleeping enough. In turn, daytime sleepiness has been linked to increased aggression, suicidal ideation, decreased productivity, poor executive functioning and increased consumption of alcoholic beverages, amongst other outcomes (Anderson et al., 2009; X. Liu et al., 2019; Y. Liu et al., 2019).

Another frequently reported link is between sleep and academic performance, and in particular, that poor sleep (short duration and poor sleep quality) is associated with poor academic performance. Using survey data to obtain subjective measures of sleep behaviours, such as sleep duration, and using school registries to obtain an objective measurement of grade point average scores of over 7000 adolescents aged 16-19 years, it was found that poor sleep, and shorter sleep duration in particular, was linked to a higher risk for poor school performance (Hysing et al., 2016). In a meta-analysis examining around 17 studies, that were primarily cross-sectional, with cumulative sample sizes of between 13,600 and 19,500 adolescents (mean age between 8 and 17 years), findings highlighted that longer sleep, better sleep quality and lower sleepiness were associated with better performance, with sleepiness showing the strongest relation, followed by sleep quality and sleep duration (Dewald et al., 2010). For young adults, too, an inverse relationship between sleep and academic performance has been suggested (Eliasson et al., 2010; Gomes et al., 2011), with longer sleep, better sleep quality, and importantly, sleeping well consistently being associated with better grades (Okano et al., 2019). The link between sleep and academic performance can be understood by our knowledge regarding the negative impact that sleep deprivation has on a range of neurobehavioral and cognitive processes such as learning-memory processes. Evidence from a wide range of studies, including cross-sectional surveys, case studies, and experimental designs where sleep duration has been restricted or extended, point in the direction of sleep deprivation having a detrimental effect on adolescents' ability to learn, for instance, via a decrease in their attentive behaviours, and poor performance on verbal creativity and abstract thinking tasks (Beebe, 2011; Beebe et al., 2017; Curcio et al., 2006; Short & Chee, 2019). Similar effects have been found in young adults; for instance a deterioration of neurobehavioral functions, such as increasing attentional lapses, as sleep duration decreases or is restricted (Zitting et al., 2018).

Though the links between sleep and daytime sleepiness or academic performance have received significant attention from various stakeholders, the area that has received sustained focus over decades from researchers, policymakers, parents, and teachers alike, is the impact that sleep has on the mental health and wellbeing of young people.

1.3.2 Mental health and sleep

The World Health Organization (WHO; 2004) defines mental health as a state of wellbeing, wherein an individual can recognize their own abilities, can cope with regular stresses of life, can be productive and contribute positively to society. Poor mental health or mental health problems can then be understood as a health condition that impairs an individual's ability to function optimally, primarily through significant changes in a person's emotions, thinking or behaviour (American Psychiatric Association, 2018). Current estimates suggest that approximately 1 in 10 people struggle with a mental health problem, and that mental health disorders cause 1 in 5 years lived in disability (S. L. James et al., 2018; Ritchie & Roser, 2018). In other words, the global burden of disease for mental health disorders is substantial.

Adolescents and young adults are a particularly vulnerable population. According to the WHO (2020), 10-20% of adolescents around the world experience mental health problems, with lack of diagnosis and/or treatment being a significant concern. Data from the United States (US) indicates that young adults, aged between 18 and 25 years, have a prevalence rate of 25.8% for any mental illness (National Institute of Mental Health, 2019); in the United Kingdom (UK), at least 1 in 5 young people aged between 16 and 24 years reportedly experienced symptoms of mental health disorders (Office of National Statistics, 2014); and a study in Norway found that between 20% – 32% of young men and women in their early twenties experience a mental disorder (Gustavson et al., 2018). This evidence implies that young adults are perhaps the most affected by mental health problems amongst the adult population. Similar to trends within the whole population, depression and anxiety are identified as the most commonly occurring mental health problems affecting the adolescent and young adult populations, with suicide being a major contributor to mortality among older adolescents (WHO, 2020).

Poor sleep has been identified as a significant risk factor for poor mental health and wellbeing amongst young people. For instance, findings from a meta-analytic review of cross-sectional, longitudinal and experimental studies on over 360,000 adolescents, implicate shorter sleep duration with a 55% increased risk of experiencing mood deficits, particularly with positive mood, anger, depression, negative affect and anxiety (Short et al., 2020). Similarly, shorter sleep and later weeknight bedtimes have been linked with an increased risk of suicidal ideation as well as behavioural and substance use disorders in adolescent populations (Owens, 2014; Zhang et al., 2017); these patterns have been demonstrated for young adults too (Glozier et al., 2010). Similar trends of poor mental health have also been linked with poor sleep quality indicators (Short et al., 2019). Intervention studies aimed at improving sleep have equally contributed to evidence supporting its link with mental health (Blake et al., 2016; Friedrich & Schlarb, 2018). For instance, in a large-scale randomized control trial involving 26 UK-based universities, Freeman et al. (2017) allocated over 3700 participants experiencing insomnia to one of two groups, a treatment as usual and a cognitive behavioural training for insomnia (CBT-i) group. It was reported that compared to the control group, participants in the CBT-i group experienced decreased levels of insomnia as well as fewer psychotic symptoms of hallucinations and paranoia. Results were suggested to be evidence for insomnia being a causal factor in psychotic experiences, and in general that poor sleep plays a causal role in the development of mental health problems. However, a bidirectional relationship between sleep and mental health problems such as depression (Fang et al., 2019), anxiety (Leahy & Gradisar, 2012) and attention deficit and hyperactivity disorders (ADHD; Mulraney et al., 2016) has also been demonstrated. Here, poor sleep has been identified as a risk factor for developing mental health problems, but also experiencing mental health problems are found to be risk factors for poor sleep. Poor sleep is in fact an important diagnostic criteria for several mental health problems experienced by children, adolescents and young adults (Gregory & Sadeh, 2016; Ramtekkar & Ivanenko, 2015), with subjective assessments of poor sleep being a more reliable and consistent markers than objective assessments in for example ADHD, autism spectrum disorders, and anxiety and depressive disorders (Baddam et al., 2018). These competing arguments regarding the directionality of the links between sleep and mental health highlight how complex it is to disentangle the relationships between these variables. Indeed, the most likely answer to this conundrum is that both arguments are valid, and that while mental health influences sleep, so also does sleep influence mental health.

Given the importance of sleep is for one's mental health, and considering evidence that young people are not sleeping enough begs the question: what is causing this loss of sleep? Likely there are several contributing factors, such as sleep-related developmental changes occurring during adolescence or having to attend schools that have early start times. However, one factor that stands out for being unique of modern times is the introduction and rise of the smartphone, which has paralleled a significant increase in electronic media consumption among young people.

1.4 Factors impacting sleep during adolescence: Electronic media use and early school start times

1.4.1 Electronic media use

Since its introduction in the late 2000's, the smartphone has found its way into the lives of more than 3 billion people worldwide (Statista, 2020). Its success can be attributed to its utility – a usually small, pocket-sized device that, in current times, can be used to perform a myriad of daily tasks, and importantly, affording its users complete privacy when performing these tasks. The smartphone can be tailored to meet the unique needs of individual people, and has evolved to meet our evolving digital needs making it an important element of the 21st century world. For adolescents too, smartphones have become a way of life, with reports estimating that more than 90% of this population, globally, owns or has access to a smartphone (Childwise, 2020; Pew Research Center, 2019). For young people, the appeal of the smartphone lies perhaps largely on its ability to access the 'online' world, majority of which constitutes being connected with their peers, via communication applications such as WhatsApp or WeChat, but also via social media applications such as Instagram, TikTok or YouTube. Given how easily smartphones lend themselves to be used, it does not come as a surprise that electronic media use among young people has matched the rise of the smartphone itself, with some reports suggesting that young people are using their devices constantly throughout the day, and evening (Hysing et al., 2015).

Screen time, which can be loosely defined as the amount of time spent using a smartphone, tablet, laptop or television, has been associated with negative outcomes in young people. Increased screen time has been associated with poorer sleep outcomes, such as shorter sleep duration, delayed sleep and poorer sleep quality (Cain & Gradisar, 2010; Hale & Guan, 2015; Twenge et al., 2017), and conversely restricting mobile use before bedtime has been linked to better sleep outcomes (Bartel et al., 2019). These effects are found to be more intense when young people engage in media use in the evening time, and particularly before going to bed. The mechanisms underlying these effects have been summarized as being mainly three-fold – first, that engaging in electronic media use before sleep simply replaces the time that young people could use for sleep; second, by consuming electronic media or engaging in social media use before sleep prevents the mind from 'shutting off', and this cognitive arousal interferes with the body's ability to fall asleep; and third, that the blue light emitted from these devices have physiological effects on young people's circadian rhythms and sleeping patterns (discussed in detail in Chapter 2; Cain & Gradisar, 2010; Hale et al., 2018; LeBourgeois et al., 2017). However, evidence on the impact of screen time on other outcomes has been mixed; for instance, even though there is strong evidence for the links between screen time and health outcomes such as obesity and depressive symptoms, the evidence for the effects of screen time on behavioural outcomes such as self-esteem, and general wellbeing is weak (Orben & Przybylski, 2019; Stiglic & Viner, 2019). These effects are thought to be mediated by other factors, and not screen time per se; for instance, the association between screen time and obesity has been attributed to the sedentary behaviours that screen time encourages, or that engaging in electronic media use replaces the time spent on exercising (Ashton & Beattie, 2019; Samantha Marsh et al., 2013). There is also evidence to suggest that the effects of screen time on mental health and wellbeing outcomes are only present when mediated by poor sleep (Lemola et al., 2015). In contrast, engaging in digital interactions with peers and friends has been found to have positive effects on young people's relationships and self-esteem, as well as their mental health (Odgers, 2018). Increasingly, however, studies suggest that the negative effects of screen time are disproportionately experienced by vulnerable populations, such as young people belonging to lower socio-economic backgrounds, suggesting that individuals negative offline experiences imitate their online ones (Odgers, 2018).

Attempts to establish guidelines for young people's engagement in screen time have been made, with for instance, the Canadian 24-hour movement guidelines outlining that a cap of two hours of daily screen time should be exercised for individuals aged 5-17 years (Tremblay et al., 2016). However, recognising that the existing evidence in this topic is mixed, governments have updated their recommendations regarding screen time use among young people. In the UK, the Royal College of Paediatrics and Child Health (2019) suggests that screen time should be tailored to the needs of each individual, but with a focus of restricting media use for at least an hour before bed; the American Academy of Pediatrics (2016) have established similar guidelines. These guidelines imply that while a universal cut-off of screen time exposure for young people cannot be recommended, the ill-effects of evening or bedtime electronic media use should be recognised, particularly on the sleep of this population.

To tackle excessive screen time engagement, a number of sleep interventions focussed on improving sleep hygiene behaviours have been trialled on young people. Sleep hygiene habits relate to behaviours engaged in prior to sleep, that can influence sleep outcomes, such as sleep quality, sleep onset and sleep duration. Apart from evening time and general daytime electronic media use, other habits addressed in interventions may also include for example, consumption of caffeinated products in the evening or engagement in vigorous physical activity in the evening. In general, studies have reported poor sleep hygiene habits among young people (Brick et al., 2010; F. C. Brown et al., 2002; LeBourgeois et al., 2017; Murugesan et al., 2018; Tandon et al., 2020). A vast number of sleep-hygiene based interventions in varying lengths (from a few hours to four-week long protocols) have been psychoeducative in nature, and conducted primarily at school or university settings (F. C. Brown et al., 2006; Cain et al., 2011; Dewald-Kaufmann et al., 2014; Kira et al., 2014; Kloss et al., 2016; Moseley & Gradisar, 2009; Rigney et al., 2015; Tan et al., 2012; Weiss et al., 2006; Wolfson et al., 2015). A review synthesising results from such interventions concluded that most interventions, while being successful in improving sleep-related knowledge, were not effective in improving sleep hygiene, sleep behaviours such as sleep duration or sleep quality, or were partially effective in improving some indicators but not all (Blunden et al., 2012). Interventions that found positive outcomes in the form of improved bedtimes or even associated mental wellbeing benefits such as reduction in internalised behaviours, reported that when participants were followed-up after the study, these improvements were not sustained (Wolfson et al., 2015). Given that a majority of the interventions focussed on addressing multiple aspects of sleep behaviours, future psychoeducative interventions might benefit from addressing solely sleep hygiene behaviours, individually or in combination, and in particular, the effects of electronic media use in the evening of night-time on subsequent sleep. The consistent finding of improved sleep knowledge implies that young people, adolescents and young adults, may lack the knowledge that poor sleep hygiene and subsequent poor sleep can detrimentally impact their daily functioning and wellbeing; educating young people on these topics might therefore be an important starting point to address sleep problems experienced this population.

1.4.2 School start times

Our understanding of the effects of school start times on the sleep and wellbeing of young people comes primarily from research in the US. One of the first studies on this topic outlined changes in adolescents' sleep patterns, involving progressively later sleep and wake up times compared to pre-pubescent children (Carskadon et al., 1993); early school start times were proposed to be a hindrance to adolescent sleep, and as a result, two schools in the US delayed start times by over an hour, finding that the students attending these schools benefitted from sleeping an extra hour every day (Wahlstrom, 1999). Since then, the US has experienced a significant policy attention leading to a delay in start times, given the beneficial impact it has on young people, and in light of evidence that highlights the chronic sleep deprivation experienced by young people (Gradisar et al., 2011). Similar debates have kick-started in other parts of the world, with school start times being discussed as a major factor in contributing to adolescent sleep problems (Illingworth et al., 2018; Winnebeck et al., 2020), and importantly one that can be modified.

Delaying school start times have been associated with positive outcomes. Delays of over one hour have been associated with better academic performance, attendance and graduation rates, and improved attention and cognitive performance (Edwards, 2012; Kelley et al., 2017; Lufi et al., 2011; McKeever & Clark, 2017). These studies have employed varying study designs, from utilising longitudinal administrative data and large sample sizes but a lack of a control or comparison group (Edwards, 2012), to using an experimental approach and comparing effects of start times for an experimental versus control group, but with extremely small samples (Lufi et al., 2011), or using an observational approach and a before-after-before design (Kelley et al., 2017). A few studies where delays of 25 – 30 minutes have been experimentally implemented for one semester, have also yielded promising results. Boergers et al. (2014) found that students attending a boarding school where school start times were delayed by 25 minutes from 08:00 to 08:25 during the winter term, were able to sleep on average 29 minutes longer, and the number of students who were able to sleep the recommended 8 hours per night doubled. Students also reported better mental wellbeing. These findings supported a previous study conducted by Owens et al. (2010), which found that a 30 minute delay in school start times during the winter term was associated with an average of 45 minutes of additional sleep on weekdays, and a reduction in daytime sleepiness and an improvement of mood outcomes. The number of participants in this study who were able to sleep longer than 8 hours also doubled, whereas the number of students sleeping lesser than 7 hours decreased by nearly 80%. The main mechanism promoting improvements in wellbeing indicators has been attributed to longer sleep achieved as a result of later wake up times (Bowers & Moyer, 2017). Evidence supports the link between longer sleep durations as a result of later school start times and fewer incidences of mental health problems as well as substance use (Wahlstrom et al., 2017). Such findings have led some to declare early school start times as a systemic and social injustice problem, because it helps maintain and perpetuate poor health among the young, especially in light of evidence that it provides a further layer of disadvantage to already vulnerable groups of young people (Edwards, 2012; Hale & Troxel, 2018). To this end, the American Academy of Sleep published a statement in support of delaying school start times across American schools, urging policymakers and local councils to consider shifting start times to not before 08:30 a.m. (N. F. Watson et al., 2017).

However, a recent Cochrane review synthesising evidence on the impact of delaying school start times has revealed inconclusive and mixed results, driven mainly by the lack of robust available data and weak methodologies employed in investigating this issue (Marx et al., 2017), with calls for studies using randomised controlled designs to be used to assess the impact of school start times (Marx et al., 2017; Minges & Redeker, 2016). Unfortunately, orchestrating such studies is often difficult, given the number of stakeholders involved, including parents, staff as well as local councils; a problem highlighted by Illingworth et al. (2018), where authors attempted to and failed to set up a randomised controlled trial (RCT) study in the UK involving over 100 schools, primarily due to non-compliance from stakeholders. In the absence of RCTs, we have to find other robust ways to investigate whether delaying school start times is a potential solution for young people's sleep problems. One such example would be to identify areas where policy decisions to delay school start times are likely to be made, providing a natural experiment set up, and utilising before-after data which would allow comparisons between adolescents attending schools early versus those attending schools with later start times through difference-in-difference estimations.

1.5 Motivation and aims of the thesis

Adolescents and young adults are identified as vulnerable populations, in large part due to the marked physical, cognitive, emotional and social changes they undergo during this stage. The onset for a majority of mental health disorders occurs during adolescence, with half of all cases beginning by 14 years of age, and three fourths by 24 years of age, and with a lifetime prevalence of up to 50% (Kessler et al., 2005). This implies that recurrence rates for poor mental health are high with those experiencing a negative mental health episode during adolescence being at an increased risk of experiencing poor mental health later in life (Kessler et al., 2001; Kieling et al., 2011). Similarly, individuals who experience psychiatric problems early in life are at an increased vulnerability to experience negative outcomes in aspects related to their physical health, personal finances, social functioning and the legal system (Copeland et al., 2015). Furthermore, prevalence of mental health problems amongst young people worldwide has been steadily increasing over the years (Bor et al., 2014; Hagquist et al., 2019; Högberg et al., 2020; Mojtabai et al., 2016; Mojtabai & Olfson, 2020; Sawyer & Patton, 2018). In combination, these pieces of evidence imply the following: mental health problems among young people are on the rise, despite our knowledge that ensuring good mental wellbeing during adolescence is an important way to facilitate healthy mental wellbeing during adulthood. This highlights the need for a scientific approach in understanding what the risk factors are for developing poor mental health, what makes young people resilient and keeps them well, and what are possible interventions that can be implemented to promote wellbeing. International organisations have recognised this need, with for instance, the WHO launching a comprehensive Mental Health Action Plan 2013 – 2020, which was adopted by a majority of its member states, with the aims of, among others, improving ways of preventing mental health problems as well as increasing awareness of mental health problems through evidence and research for young people (WHO, 2013).

Poor sleep has been purported to be an important risk factor for poor wellbeing among young people (Patton et al., 2018), and an increase in sleep-related problems for young people have been reported (Ghekiere et al., 2019; Sarah Marsh, 2020; Singh & Kenney, 2013). Increasing public health concerns have therefore surrounded adolescent and young adult sleep, with addressing sleep deprivation issues being declared a public health priority in the UK (Royal Society for Public Health, 2016), and in other parts globally (Owens, 2014). In light of these calls, it is important to identify and understand potential factors that influence sleep, and that are amenable to change and modification. Electronic and social media use have been recognised as actively contributing to the insomnia epidemic facing young people (Chattu et al., 2018; Ghekiere et al., 2019; Owens, 2014), with some reports suggesting that nearly one in four adolescents experience problematic smartphone use, with increased odds of experiencing mental health problems (Sohn et al., 2019). A second factor recognised as playing an important role in determining the sleep behaviour of young people, and in particular adolescents, are early school start times (Hale & Troxel, 2018).

Building on previous research surrounding these associations, the overall aim of this thesis is as follows: To test whether recommendations that are given to improve the sleep and wellbeing of young people, and in particular to decrease electronic or social media use before night-time sleep, and to delay school start times, are effective. Existing research regarding these recommendations is mixed, while the majority of evidence in favour of the guidelines is weak (*e.g.*, drawn primarily from cross-sectional work). Still, researchers and policymakers continue to advocate for these recommendations, and it is therefore important to establish evidence that warrants such claims. This thesis attempted to use more robust methods to examine whether changing or modifying these factors can lead to improvements in sleep and wellbeing. Below, I have outlined the specific aims that this thesis addresses.

As a first aim, this thesis investigates whether targeting individual behaviours of evening time electronic media use via a brief, cluster-randomised school-based psychoeducative intervention and including parental involvement can result in improvements in sleep duration, satisfaction and mental wellbeing outcomes. Previous work on interventions to improve sleep hygiene have focussed on general sleep hygiene habits, and not specifically on reducing evening screen time. Moreover, a majority of these interventions have been carried out over moderate to long periods of time, spanning from a day to a few weeks from start to finish. Subsequently, there is scope for exploring whether short interventions can be effective in improving sleep hygiene behaviours related specifically to evening time electronic media use, and that have the potential to be administered or disseminated at a large scale. Though modest improvements in bedtime electronic media use were found, the associated small effect size was likely a reason for not translating into improved sleep or wellbeing among study participants. Compounded with previous evidence that demonstrated that sleep hygiene behaviours are difficult to change (*e.g.*, Kira et al., 2014; Rigney et al., 2015), and that the relationships between these variables have primarily been examined using cross-sectional approaches, the current findings warranted a better understanding of how these variables interact with one another.

As a second aim, this thesis tries to understand whether bedtime media use is indeed a risk factor for poor sleep, by using an experience sampling approach to examine the temporal relationships between bedtime social media use, sleep the subsequent night and affective wellbeing the following day. Though not as robust as a RCT design, experience sampling designs allow capturing real-time, in-the-moment data across several measurement points, which is particularly relevant for decreasing memory biases for subjective wellbeing measures and media use assessments. This methodology overcomes the limitations of cross-sectional approaches, but also of studies that have examined these constructs over longer periods of time (*e.g.*, Heffer et al., 2019), and where there is no convincing model as to why media use would impact sleep and wellbeing months or years later. Analysing data generated from this approach allows for the assessment of within-individual variations separately from between-individual variance in behaviours. As a result, a better understanding of the interactions between variables can be achieved.

As a final aim, this thesis investigates the effects of a policy-level decision to delay school start times on the sleep duration of adolescents. Delaying school start times has been proposed as an effective way to improve adolescents' sleep duration, by providing an opportunity for adolescents to sleep longer, and by allowing for an alignment between their delayed circadian rhythms and society-driven schedules. However, much of the research is cross-sectional, or where longitudinal studies are available, appropriate comparison groups are scarce (Marx et al., 2017). At the same time, it has been demonstrated that conducting an RCT to study this phenomena is difficult, if not impossible (Illingworth et al., 2018). Finally, a majority of the research on school start times has been carried out in Northern America, and generalising findings to a different context, such as the European context can be problematic due to cultural differences (*e.g.,* Short, Gradisar, Lack, Wright, et al., 2013). To overcome these challenges, this thesis uses a natural experiment by taking advantage of data available pre and post a policy level change of delaying school start times for all public schools in Basel, Switzerland, and examines its effects on sleep duration for a school start time change group relative to a comparison group that was unaffected by the policy.

1.6 Structure of the thesis

This thesis examines the complex relationships between electronic and social media use, sleep and mental health and wellbeing, with a particular focus on how these relationships interact amongst adolescents and young adults and ways that sleep can be improved. To this end, the thesis is structured as follows:

Chapter 2 lays down the theoretical framework for the thesis, by discussing Bronfenbrenner's Process-Person-Context-Time theory of human development, and a two-process model of sleep.

This chapter details the changes in sleep architecture and regulation that occur during adolescence and young adulthood, and how environmental factors such as electronic media use or school start times can have an impact on sleep and mental health processes.

Chapter 3 outlines the specific research questions derived from the review of the literature and theories, which will be explored via the substantive studies presented in the thesis.

Chapter 4 examines the impact of a brief school-based psychoeducative intervention including parental involvement, on improving sleep hygiene behaviours (*i.e.*, bedtime social media use and evening time caffeine consumption). This chapter will also assess the impact of this intervention on improving the sleep and mental wellbeing of adolescent students.

Chapter 5 assesses the temporal links between social media use, sleep and affective wellbeing, by employing an experience sampling design which will help to analyse day-to-day associations between these variables. This will allow an understanding of how these variables interact with one another on a daily basis, and whether bedtime media use is a risk factor for poor sleep and mental wellbeing.

Chapter 6 evaluates the impact of a policy-level intervention to delay school start times by 20 minutes in all schools in a region in Switzerland, with a focus on sleep duration and mental wellbeing outcomes.

Finally, Chapter 7 will end with an overall discussion, and detail the implications that can be drawn from the results presented in the thesis. Here, avenues for future research will also be outlined. Methodologies employed in the presented studies will be evaluated.

Chapter 2
Theoretical Background

This chapter provides a theoretical framework for the thesis. First, I discuss Bronfenbrenner's bioecological theory of human development (1977, 1986, 1995), which presents a context for how the interactions between sleep, and factors of electronic media use and school start times can occur for the developing adolescent. Second, I discuss the two-process model of sleep (Borbély, 1982; Borbély et al., 2016), which is used to understand how sleep is regulated, how sleep changes as a result of puberty and adolescence, and how the factors of electronic media use and school start times interact with these changes.

2.1 Bronfenbrenner's theory of human development

Bronfenbrenner's theory of human development has become one of the dominating theories within the developmental psychology sphere, and used to demonstrate a wide range of outcomes such as cognitive development, parenting and delinquent behaviour (Tudge et al., 2016). Since its proposition, the theory has evolved from an ecological model where human development was attributed to primarily interactions between contextual or environmental factors (Bronfenbrenner, 1977, 1979), to a bioecological model or a Process-Person-Context-Time (PPCT) model, where more importance was placed on the individual, and the developmental process itself (Bronfenbrenner, 1995; Bronfenbrenner & Ceci, 1994).

At the core of the PPCT model, are proximal processes, which refer to the reciprocal interactions that occur between the developing individual and persons, objects or symbols in their immediate environment. These interactions, which become complex over time, likely lead to the individual becoming more competent by gaining skills and knowledge. An example of such a process is group or solitary play or problem-solving (Bronfenbrenner, 2001). Proximal processes were termed as the "primary engines of development" (Bronfenbrenner & Morris, 1998, p. 996), implying that the other elements of person, context and time impact the individual via proximal processes. Person characteristics refer to the traits of the individual that determine or influence how proximal processes occur. For instance, dynamic personality traits such as self-efficacy can largely determine differences in the developmental trajectory of two children – one who is motivated to succeed, and the other who is not (Tudge et al., 2009). Here, biological or mental resources are also acknowledged as an important person characteristic. Levels of context, which were defined in the initial model, refer to four types of environmental systems (Bronfenbrenner, 1977). First is the *microsystem*, that consists of the individual's immediate surroundings such as the home or the classroom, where proximal processes take place. Second is the *mesosystem*, which consists of the relationships between two or more microsystems, for example, for a developing child, this would consist of interactions between the parents and the school teacher or childminder (Neal & Neal, 2013). Third is the *exosystem*, where the individual is not directly placed, but those that interact with the individual are. For instance, this would refer to a parent's workplace, which has the potential to influence the child's home environment (Neal & Neal, 2013). Last is the *macrosystem*, which encompasses the values and social, cultural and political norms of the environment in which the individual exists. Elements in this structure have indirect impacts on proximal processes, via the microsystem. For instance, the political views of parents may determine what types of books are available at home for the developing child (Xia et al., 2020). The last element of the model is the dimension of time, divided into micro (the extent of continuity or discontinuity in the proximal processes), meso (whether proximal processes occur over days or weeks), and macro (the changes within and outside the child's environment). Macro-time is akin to chronosystems (Bronfenbrenner, 1986), and can refer to external changes in events or expectations of the wider society and as well as important transitionary experiences for the individual.

Sleep, electronic media use and school start times can be identified as belonging to more than one specific system or factor within Bronfenbrenner's theory. Electronic media use and the smartphone may be regarded as objects in the microsystem due to their presence in the immediate surrounding of the adolescent or young adult but can also be an element belonging to the chronosystem, since the patterns of media use observed, and smartphones are unique of modern times. The adolescent and young adult undergoes developmental changes as a function of puberty, which includes changes in sleeping patterns, and which are typically identified as belonging to the chronosystem. Thus, the sleep hygiene study presented in Chapter 4 is located in the school microsystem, and its inclusion of parental involvement taps into the family microsystem. Similarly, the experience sampling study presented in Chapter 5 taps into chronosystem and examines how the interactions between media use and sleep influence mental wellbeing. Finally, school start times are determined by societal values (*e.g.*, that workdays should begin early), and can be affected by policy decisions. Thus, the study presented in Chapter 6 occurs in the macrosystem; school start times have a direct impact on the adolescent via the school micro-system, by providing a schedule that may not necessarily be in harmony with their developing sleep patterns.

The continuous interactions of the individual's developing sleep patterns with electronic and social media engagement and school start times can be viewed as key proximal processes and occurs within complex and multifaceted ecological and environmental systems. These proximal processes may trigger bio-psycho-social changes and development, including further development in the sleeping patterns and preferences of young people, or the mental health and wellbeing trajectory of adolescents and young adults.

2.2 The structure and regulation of sleep

2.2.1 Sleep architecture

Sleep is a complex process, with the overarching function to provide the body and brain time to rest and recover from a previous period of wakefulness, and to prepare for activities that will be performed upon awakening (Vyazovskiy & Delogu, 2014). It has been better understood through research utilizing electroencephalogram (EEG) data, which shows that sleep is made up of different states or stages, each with unique electrical activity. Sleep is largely divided into two states – rapid eye movement (REM) and non-REM (NREM; Aserinksy & Kleitman, 1953). NREM sleep is a state of minimal mental activity, comprising of stages N1, N2, and N3, with levels of arousal decreasing as sleep progresses from N1 to N3. N3 is also known as deep sleep or slow wave sleep (SWS), deriving this name from EEG data that demonstrates synchronous slow waves during this phase of sleep. REM sleep is distinctly different from NREM sleep, being characterized by rapid eye movements, low muscle tone, and significant mental activity in the form of dreaming. Episodes of rapid eye movements or body twitches are alternated by episodes of relative inactivity, *i.e.*, phasic versus tonic episodes (Callaway et al., 1987; Siegel, 2011). Sleep begins with NREM, progressing into REM sleep, with both occurring several times through the course of a night in a cyclical fashion. On average, a person spends more time in NREM sleep, and primarily in stages 1 and 2, with SWS generally occurring only in the beginning of the night. As sleep progresses, SWS becomes shorter, with REM sleep becoming longer towards the latter end of the night (Yetton et al., 2018). Each sleep cycle (*i.e.*, NREM followed by REM) takes an average of 90 to 110 minutes

(Gronfier et al., 1999). These patterns of sleep stages across the night are referred to as sleep architecture, and vary across individuals (Yetton et al., 2018).

The different states (NREM vs. REM) as well as types (light versus deep sleep/SWS) of sleep are thought to have different functions; for instance, NREM (N1, N2 and N3) sleep has been linked to increased brain modularity or connectivity (Boly et al., 2012), whereas SWS and REM sleep have been implicated in memory consolidation processes (S. Ackermann & Rasch, 2014; Stickgold, 2005). The architecture of sleep is shown to change across the lifespan, and is thought to reflect the differences in developmental demands, with a majority of those changes occurring in the first two decades of life (Carskadon & Dement, 2011; Feinberg, 1974). To better understand the changes that adolescent sleep undergoes, it is important to discuss how sleep is regulated.

2.2.2 The two-process model of sleep

A well-regarded theory of sleep regulation is the two-process sleep model proposed almost four decades ago by Borbély (1982), and which has since been revised and reappraised (Borbély et al., 2016; Borbély & Achermann, 1999). This model views sleep and wakefulness as being governed by two intrinsic processes, a homeostatic process and a circadian process. The homeostatic process, or process S, regulates sleep pressure or sleep debt and depends on sleep and wake. In other words, process S accumulates during wakefulness, and dissipates during sleep. The circadian process, or process C is independent of process S and is influenced by the Suprachiasmatic Nucleus (SCN; Ralph et al., 1990), the body's internal clock that is approximately 24-25 hours in length per cycle. The SCN in turn is regulated by external cues, or *Zeitgebers*, the strongest of which is sunlight (Roenneberg et al., 2007), which entrains the circadian system to the 24-h clock (Roenneberg, Daan, et al., 2003). In this way, process C determines the timing of sleep, *i.e.*, to sleep at night (when it is dark) and to wake up in the morning and stay awake through the day (when it is light). In other words, process C rises during the day, reaching its peak between 16:00 and 18:00, and decreases through the night, reaching its lowest between 04:00 and 05:00. (Carskadon et al., 2004). Borbély (1982) suggested that sleep and awakening is determined by the combined action of the two processes. Process C determines the value-range between which sleep or wakefulness can occur. Thus, sleep is triggered when process S reaches the upper threshold of this range, and awakening is triggered when Process S reaches the lower threshold of this range.

Process S and Process C are thought to function independent of one another, which has been supported for instance via studies that have found that process S continues to function normally even after the SCN has been lesioned (Dijk & Archer, 2009). Consequently, both processes are identified via different indicators. Like sleep need (*i.e.*, process S), the frequency of NREM EEG slow wave activity (SWA) is highest at the beginning of a sleep episode, and decrease as sleep progresses, making the amount of SWA or SWS the key marker of Process S (Achermann, 2007; Borbély, 1982; Borbély et al., 2016). Melatonin, a hormone released by the pineal gland in response to darkness, reduces core body temperature, decreases arousal and simultaneously prepares the body for sleep (Brzezinski, 1997; Dawson & Encel, 1993); both melatonin regulation and core body temperature are therefore considered principal markers of process C (Borbély et al., 2016). For instance, the timing of the circadian system is determined by (i) the onset of melatonin measured via saliva samples in dim light, also called dim-light melatonin onset (DLMO) phase, (ii) a decrease in of levels of melatonin known as dim light melatonin offset ($DLMO_{off}$) phase, and/or (iii) the mid-point between DLMO and $DLMO_{off}$ (Crowley et al., 2007). Although the assumption that both processes do not influence each other is generally accepted, there has been evidence contradicting this, with studies highlighting a possible feedback of process S on process C (Deboer, 2018; Franken, 2013; Vyazovskiy & Delogu, 2014). Research in this area is preliminary, however, the implications may be particularly significant for adolescents and young people; it suggests that our understanding of these processes is dynamic, and that any developmental changes occurring in these processes are likely more complex than we currently understand.

2.3 Changes in sleep during adolescence

Changes in sleep as a function of puberty begin before puberty-related bodily changes (Sadeh et al., 2009). Developmental changes in both process S and process C, either independently or in combination, lead to a preference for progressively later bedtimes and wake times across mid to late adolescence, also known as delayed sleep phase (Carskadon et al., 2004; Crowley et al., 2007, 2018; Hagenauer et al., 2009). In this section, these changes will be discussed, along with related changes in adolescent sleep architecture.

One of the most prolific changes in sleep architecture that occurs during adolescence is the marked alteration or decline in SWS or delta NREM sleep, of between 40% and 65% between 11 and 17 years of age (Campbell et al., 2005, 2007; Carskadon, 1982; Feinberg & Campbell, 2010; Jenni et al., 2005; Jenni & Carskadon, 2004). These changes are thought to relate to the maturing brain, particularly with the development of the frontal cortex, and are linked to age and sex (Feinberg et al., 2006; Feinberg & Campbell, 2010). Relatedly, developmental changes in process S have also been proposed and observed. First, it is has been found that the build-up of sleep pressure or process S following periods of extended wakefulness occurs faster for prepubertal or younger adolescents compared to older ones, although sleep pressure dissipates at a similar rate across a sleep episode for both groups (Jenni et al., 2005; Tarokh et al., 2012; Taylor et al., 2005). Second, as adolescents mature, they are biologically able to resist their sleep pressure, and stay awake for longer periods of time in comparison to when they were younger (Skeldon et al., 2016).

Changes that occur in process C during adolescence have also been documented. Puberty-related changes of the gonadal hormones trigger physiological changes to the SCN; this in turn impacts the body's circadian rhythm in part by leading to delays in melatonin and cortisol secretion (Karatsoreos & Silver, 2007). These chain of events are generally held responsible for shifting adolescents body clock forward, thereby enabling them to stay awake for longer in the night and sleep until later in the morning (Carskadon et al., 1993, 1997, 1998, 2004). For instance, Carskadon et al. (1997) reported that older adolescents displayed later DLMO phase in comparison to younger adolescents, providing evidence for a delay in process C during adolescence. Levels of melatonin are thought to decrease with increasing age, suggesting that either puberty-related processes are responsible for this decline, or that the decline is an indicator of the pubertal process (Crowley et al., 2012); though preliminary, this highlights another potential factor explaining changes in process C during adolescence. This biological preference of adolescents to be 'evening type' (*i.e.*, show a preference for later bedtime and wake times[1]) manifests differently in males and females – peaking around the ages of 19.5 years for females, and 21 years for males, after which, their sleep resumes to pre-adolescent patterns (Roenneberg et al., 2004).

The sleep problems faced by young people today, can in part, be understood via these changing sleep patterns, especially when societal rhythms around them remain the same. There are also other avoidable factors that interact with these sleep patterns and contribute to poor sleep. Crucial to this thesis are also the ways in which sleep can be implicated in the regulation of mental wellbeing and health. The following sections will discuss the role of sleep in emotional and mood regulation, and the implication of two factors, namely electronic media use and early school start times, in the sleep of adolescents and young adults.

[1] The preference in timing of sleep and wake is called chronotype, with most adults lying between being 'morning type', *i.e.*, sleeping and waking up early, and 'evening type' (Roenneberg, Wirz-Justice, et al., 2003).

2.4 Sleep and emotional regulation

Sleep deprivation or increased process S at the incorrect time (*i.e.*, during the day) has been implicated in emotional regulation processes via two pathways (Gruber & Cassoff, 2014). First, sleep deprivation negatively impacts the brain's ability to perform executive functions such as response inhibition (Mauss et al., 2013), which decreases one's ability to particularly regulate negative emotions. Second, sleep deprivation increases sensitivity to negative stimuli, with findings demonstrating that as sleep propensity increases, reactions to stimuli such as anger also increase (Gujar et al., 2011). Process C has also been implicated in affective wellbeing, and particularly in mood regulation. One of the underlying assumption is that mood fluctuates across the day, and follows a pattern consistent with the circadian rhythm (and in particular core body temperature), being low in the morning, improving as the day progresses and being at its best in the evening (Boivin, 1997; Wirz-Justice, 2008). Evidence on the links between the circadian process and mood have been drawn from studies assessing relationships between chronotype and affective wellbeing, with eveningness emerging as a risk factor for and morningness as a protective factor against emotion dysregulation. On the one hand, eveningness in adolescents has been associated with an increased risk of experiencing depressive or anxiety symptoms (Díaz-Morales, 2016; Koo et al., 2021; Randler, 2011a). On the other hand, morningness has been linked to positive attitude towards life and a lower risk of experiencing emotional problems (Gau et al., 2007; Randler, 2011a). Since a shift towards eveningness has been noted for adolescents (Roenneberg et al., 2004), these findings outline the specific risk that this population faces for poor mental wellbeing as a consequence of their changing circadian rhythms.

Eveningness presents as a risk factor due to the mismatch between the endogenous circadian system and societal-driven schedules, which forces individuals to function at a non-optimal moment of the day, *i.e.*, in the morning. Disrupted mood as a consequence of the misalignment between process C and process S have also been noted for shift workers or those who experience jet lag (S. M. James et al., 2017; Srinivasan et al., 2010). Thus, emotional regulation is dictated not only by process S and process C independently, but rather by their joint effects and interactions (Gruber & Cassoff, 2014). In particular, the degree to which an individual experiences successful mood regulation or mood dysregulation is determined by the cognitive effects of process S (such as emotional reactivity or impulsivity) jointly with the process C driven within-day variations of mood. Thus, if sleep deprivation is low (*i.e.*, process S is low) and mood is neutral/positive (*i.e.*, process C is high), then emotions are more likely to be better regulated, and the opposite if sleep deprivation is high and mood is negative. Further, Gruber and Cassoff (2014) argue that these effects are particularly pronounced for individuals who experience clinical levels of poor mental health, due to their increased sensitivity to sleep deprivation, negative mood, as well as the misalignment between the two, leading to further decreased affective wellbeing.

During the second decade of human life, individuals experience maturation of brain structures and functions, of which includes the prefrontal cortex, and which is implicated in executive functioning (Zelazo & Carlson, 2012). It might therefore follow that the effects of sleep deprivation on these regions of the brain might be exacerbated in adolescents and young adults relative to adults (Galván, 2020). Thus, the interaction of these processes with the changing circadian patterns are likely to put young people at a higher risk of poor emotional regulation, and experiencing poor affective and mental wellbeing.

2.5 Night light exposure, evening-time electronic media use and its implication for adolescent sleep

Melatonin, the sleep-inducing hormone, is sensitive to light; exposure to bright light at the beginning of the night can interfere with an individual's ability to fall asleep, and over time can lead to shifts in the circadian rhythm, or a phase delay (Phase response curve; Khalsa et al., 2003). Evidence suggests a dose-response relationship between light exposure and circadian rhythm shifts, with even dim, low intensity lights being associated with marked delays or shifts in circadian patterns, and suppression of melatonin secretion (Zeitzer et al., 2000). Additionally, light with shorter wavelengths are found to have a greater power in resetting the circadian phase (Cajochen et al., 2005; Lockley et al., 2003). Significant to this thesis is research that has highlighted differences between young people and older populations when demonstrating these relationships. Particularly, the impact of light exposure at night on melatonin levels are thought to be greater for younger adults (Figueiro & Overington, 2016; Higuchi et al., 2014), whereas younger adolescents' rhythms and sleep are thought to be more sensitive to evening light exposure in comparison to older adolescents (Crowley et al., 2015; Crowley & Eastman, 2017).

Research on our system's sensitivity to light has important implications for adolescents when taking into account their excessive use of electronic media, particularly in the evening and at night. Majority of these devices, such as laptops, smartphones, tablets or televisions, contain lights emitting diodes (LED) or blue light which has been shown to have a phase-delaying impact on circadian rhythms, by suppressing or slowing down melatonin secretion, specifically when these devices are used in the evening or before sleep (Cajochen et al., 2011); similar effects have been reported for young people (Chang et al., 2015). Studies on adolescents and young adults assessing the impact of pre-bedtime reading from LED devices relative to books, or wearing glasses that block the blue light, find that individuals report feeling less sleepy, experiencing melatonin suppression, delayed circadian rhythms and lower alertness the next morning (Chang et al., 2015; Grønli et al., 2016; van der Lely et al., 2015).

Thus, while adolescents are experiencing a shift to biologically driven later sleeping patterns and a generally more evening-type circadian rhythm, the evidence discussed in this section implies that evening time electronic media use might be further delaying the circadian cycles of this population. When combining these with the effects of having to wake up early for school or university, unhealthy sleep patterns may perpetuate.

2.6 Shortened sleep as a function of early school start times

Early school start times are disruptive to adolescent sleep by restricting or shortening sleep. As adolescents experience a delayed sleep phase and progressively become more evening type, they begin going to bed later at night. However, due to school start times, young people may be forced to wake up early, thereby curtailing their sleep, and preventing many from sleeping the recommended durations of 8-10 hours per night (Kirby et al., 2011). In one of the first studies to empirically examine the effects of school start times in the US, Carskadon et al. (1998) found that students in the 10th grade who started school at 07:20 in the morning experienced significantly shorter sleep durations during weeknights in comparison to when they were in the 9th grade and had a school start time of 08:25; these results were explained via earlier wake up times, rather than later bedtimes. Results also showed that adolescents in the 10th grade displayed later DLMO phase compared to the year before, indicating a delay in their circadian rhythms. It was also reported that because of the shorter sleep, older adolescents experienced greater daytime sleepiness in comparison to their younger selves, highlighting an important negative consequence experienced by young people as a direct consequence of insufficient sleep. It has been suggested that young people experiencing restricted sleep during school nights are able to sleep for longer during the weekend, not because of earlier sleep times, but because of later wake up times; these findings provide evidence for the preferred later sleep and wake times of young people (Gradisar et al., 2011). However, this sleep catch-up does not replenish the benefits of sufficient daily sleep (Crowley et al., 2018) and the irregularity in sleep patterns might perpetuate more problems for young people (Gradisar et al., 2011; Olds et al., 2010). The mismatch between young people's biological and social rhythms, also known as circadian misalignment (CM) or social jetlag (Wittmann et al., 2006), has been associated with several health problems, including physiological, such as cardiovascular problems, and psychiatric problems, including depression and anxiety (Baron & Reid, 2014), as well as other mood disorders such as seasonal affective disorder (Lewy, 2009). Specifically in young people, social jetlag has been linked to obesity (Malone et al., 2016) and anxiety (Owens et al., 2019), while for young adults, there has been a link between CM and impaired autonomic function, such as increased heart rate (Grimaldi et al., 2016).

The impact of early/late school start times on school performance or cognitive functioning has been demonstrated. Some argue that when school start times align with young people's natural biological rhythms, their ability to perform tasks is optimized (Kirby et al., 2011). Studies have found that adolescents tend to perform better on tasks assessing their executive functioning when they are tested at a time of the day that aligns with their chronotype, *i.e.* morning testing for morning-type adolescents and afternoon testing for evening type adolescents (Hahn et al., 2012), and that in general, optimal performance on such tasks occurs later in the day (C. Yoon et al., 1998). A meta-analytic review concluded that there were significant associations between chronotype and academic achievement and cognitive abilities, such that there was on the one hand, a positive relationship between eveningness and cognitive ability, but a negative relationship with academic achievement, while on the other hand, there was a negative relationship between morningness and cognitive ability, but a positive association with academic performance (Preckel et al., 2011). These associations have found to be stronger and more prominent for school versus university students (Tonetti et al., 2015). This is perhaps due to the flexibility that university students have in choosing their own classes, that may not have early start times, and therefore, having a schedule that is better aligned with their biological rhythm – an assumption that has been supported by evidence (Smarr & Schirmer, 2018). Restricted sleep, sleep loss or debt also has negative effects on young people's cognitive functioning, and declarative and procedural learning (Carskadon, 2011; Crowley et al., 2018; Hale & Troxel, 2018; Kirby et al., 2011). Taken together, this suggests that if school and university start times are aligned better with adolescents' and young adults' biological rhythms, improvements in sleep, mental health and academic performance might follow.

2.7 Summary

In this chapter, I used Bronfenbrenner's theory of human development to provide a theoretical framework of how different environmental and systemic influences work together around the developing adolescent. Developmental changes in adolescent sleep which have been explained via the two-process model of sleep, are complex and multifaceted and are a sign of maturation. These normative developmental processes, that are out of the control of the individual but that almost all individuals have to undergo, have been identified as a factor belonging to the chronosystem. Some of these changes include a delayed biological rhythm, a marked decrease in SWS that corresponds with a decrease in homeostatic sleep pressure, as well as an accompanying ability to resist sleep pressures, altogether expressed in young people's preference for later bed and wake times. On the one hand, bedtimes might get further delayed due to young people's excessive indulgence in evening and night-time electronic and social media use; this factor is identified as both a chronosystemic and a microsystemic element. The blue light emitted from the devices that are used to access media inhibit melatonin secretion and shift circadian rhythms and are argued to particularly affect young people due to the developmental changes they are undergoing, relative to older populations. These complex changes in sleep and circadian rhythms interact with electronic/social media forming significant proximal processes, which not only further influence the way sleep develops and manifests, but also influences the mental health and wellbeing of an individual, for example, via emotion and mood regulation or dysregulation. On the other hand, early school start times are identified as a factor that exists in a young person's macrosystem. By dictating wake up times, school start times provide a societal context for determining adolescents' sleeping patterns. However, this likely misaligns with the young person's biological rhythms and preferences by enforcing early rise times, and especially when coupled with late nights, contributes to insufficient sleep.

Chapter 3
Research Questions

The previous two chapters detailed the existing literature, debates and theoretical background surrounding adolescent sleep, mental health and wellbeing, the use of electronic and social media and the role of school start times. In this chapter, the research questions that have been developed from this review are described.

RQ1: Among young people, how are social and electronic media use, sleep and mental wellbeing associated to one another? (Studies 1 & 2)

a. Is sleep impacted by bedtime electronic/social media use?
b. Does sleep play a role in the relationship between electronic/social media use and mental wellbeing?

RQ2: Are primary prevention interventions aimed at improving sleep hygiene behaviours at the individual level a potential solution for improving sleep among adolescents? (Study 1)

a. Can a brief psychoeducative intervention with parental involvement and a specific focus on bedtime electronic media use be effective in reducing this behaviour, and by extension, improving sleep?
b. Can improvements in sleep as a consequence of reduced bedtime electronic media use lead to improved mental wellbeing?

RQ3: Are policy-level interventions of delaying school start times an effective strategy for improving the sleep and mental wellbeing of adolescents? (Study 3)

a. Is a short delay of 20 minutes sufficient to achieve improvements in sleep?
b. Do improvements in sleep as a result of delaying school start times in the short-term sustain themselves in the longer term?

Chapter 4
A pilot cluster-randomised study to increase sleep duration by decreasing electronic media use at night and caffeine consumption in adolescents

Bedtime electronic media use and caffeine consumption are risk factors for insufficient sleep and poor sleep quality during adolescence, which are in turn risk factors for mental wellbeing. Our study tested the effectiveness of a brief school-based psychoeducative intervention to primarily increase sleep duration, by decreasing bedtime electronic media use and caffeine consumption. Secondary outcomes included improving sleep quality and difficulties, daytime tiredness, and mental wellbeing. A pilot cluster-randomised controlled study was conducted involving a 25-minute psychoeducative school-based intervention combined with parent information. 352 adolescents from seven schools participated (Intervention Group/IG = 192 students vs. Control Group/CG = 160 students; age: Mean = 15.09 years; SD = 1.65 years; Females = 163). The intervention included information on the importance of sleep and good sleep hygiene habits, particularly emphasizing behavioural rules of avoiding electronic media use at night and evening-time caffeine consumption. A leaflet containing the rules was also sent to parents of IG participants. Baseline and post-intervention sessions were held approximately four weeks apart. Multilevel analyses revealed a significant but modest decrease in electronic media use for participants in the IG versus CG, but showed no effect on caffeine consumption or sleep duration. Moreover, the intervention did not impact any secondary outcome. Findings indicate the potential effectiveness of a short and easily administrable intervention to decrease electronic media use at night, which may be incorporated into school curricula and standardised for wider use in primary prevention. However, no further benefits of the intervention were found.

4.1 Introduction

A large number of adolescents do not get the recommended amount of sleep, which is eight to ten hours for 14-17 year olds (Hirshkowitz et al., 2015; Short et al., 2018), especially during the week (Gradisar et al., 2011). Relatedly, evidence also indicates that adolescents worldwide do not feel well restored upon awakening (Colrain & Baker, 2011). Insufficient sleep and poor sleep quality have negative implications for the physical, cognitive, and psychological wellbeing of adolescents. For instance, insufficient sleep is associated with increased daytime sleepiness and tiredness (Gradisar et al., 2011; Perkinson-Gloor et al., 2013; Short et al., 2018), poor academic performance (Dewald et al., 2010; Perkinson-Gloor et al., 2013), negative attitude towards life (Perkinson-Gloor et al., 2013), and decreased mood, attention and emotion regulation (Baum et al., 2014; Palmer & Alfano, 2017). On the other hand, better sleep quality is associated with better school performance (Dewald et al., 2010), and lower risk-taking behaviour (Telzer et al., 2013).

Recent research has highlighted that night-time electronic media use is a risk factor for insufficient sleep and poor sleep quality amongst adolescents (Cain & Gradisar, 2010; Fossum et al., 2014; Hysing et al., 2015; Lemola et al., 2014; Owens, 2014). One reason for this is that the blue light emitted from electronic screens appears to delay melatonin secretion, which might affect the ability to fall asleep (Cajochen et al., 2011). Electronic media use may also curtail sleep by simply replacing the time for sleep, communication via social media may involve emotional content interfering with relaxation and sleep induction, and incoming alerts may wake adolescents up after sleep onset (Cain & Gradisar, 2010). However, there is also evidence to suggest that adolescents rely on late-night electronic media use as a sleeping aid (i.e., to while away time; Bartel et al., 2019; De Bruin et al., 2015; Eggermont & Van den Bulck, 2006). The increasing use of electronic media in bed before sleep, in part, may be complemented by the increasing ownership and use of smartphones among adolescents across the globe (Lauricella et al., 2014). Furthermore, fear of missing out important social information may lead to adolescents keeping their phones online also during the night (Elhai et al., 2016). Smartphones allow adolescents to easily access, from the comfort of their beds, various forms of media such as telecommunication, gaming, videos/films and social networking. While the benefits of such digitalisation is indisputable, smartphone use also has its problems, with evidence highlighting its role in pathological disorders such as smartphone addiction (Haug et al., 2015), its negative impact on sleep quality and mental health (Demirci et al., 2015), and more recently, its direct link with shorter sleep duration among adolescents (Twenge et al., 2017). In this view, Demirci et al. (2015) showed that smartphone use can resemble behavioural addiction and be intertwined with symptoms of depression and anxiety.

A second risk factor for insufficient sleep that has become equally prominent in recent years is the increasing popularity and consumption of energy drinks and other caffeinated drinks amongst adolescents (Owens, 2014), perhaps due to the youth-directed marketization of these products. Energy drinks often contain a moderate to high amount of caffeine, which has been linked to high blood pressure and sleep disturbances in children and adolescents (Seifert et al., 2011). Electronic media use in the evening before sleep and excessive consumption of caffeinated products are discussed in the literature as major constituents of poor sleep hygiene.

Studies evaluating the effectiveness of psychoeducative interventions for improving sleep hygiene among adolescents (Blunden et al., 2012; Dewald-Kaufmann et al., 2014; Kira et al., 2014; Paavonen et al., 2016; Rigney et al., 2015; Tan et al., 2012; Wolfson et al., 2015) have yielded mixed results. While some studies report improvements in sleep duration (Dewald-Kaufmann et al., 2014; Rigney et al., 2015) and sleep quality and wellbeing (Rigney et al., 2015), others report only partial or no improvements in any outcomes (Kira et al., 2014; Moseley & Gradisar, 2009; Rigney et al., 2015; Wolfson et al., 2015). It has been argued that parental involvement in sleep hygiene interventions for adolescents might be crucial in augmenting intervention effects (Short et al., 2011). Past studies involving parents have shown positive intervention effects (Rigney et al., 2015; Schlarb et al., 2010).

Recognising the growing public health concern surrounding excessive electronic media use, caffeine consumption and its implications for adolescent sleep (Owens, 2014), and accounting for past research focusing on more extensive psychoeducative sleep hygiene interventions, our study piloted a brief intervention that targeted bedtime electronic media use and caffeine consumption in the evening amongst adolescents, with the aim of increasing sleep duration. Specifically, we assessed whether a 25-minute psychoeducative school-based intervention combined with parental involvement focused on reducing bedtime electronic media use and/or consumption of caffeinated products in the evening, could ultimately increase sleep duration, and consequently improve sleep quality, daytime functioning and mental wellbeing of adolescents. It was an objective to develop a cost-effective primary prevention intervention that could potentially be disseminated on a large scale. A major purpose of primary prevention involves improving health behaviour of a large proportion of the population at low cost, with even small changes in a large number of individuals resulting in benefits at a population level (Rose, 1981).

We explored whether the intervention would lead to changes in the primary outcome variable sleep hygiene (*i.e.*, decrease in using electronic media in bed before sleep, and decrease in consumption of caffeinated drinks) and improved sleep duration on weekdays and weekends. Secondary outcomes also investigated were decreased sleep difficulties, daytime tiredness, depressive symptoms, and attention and hyperactivity-related symptoms.

4.2 Method

4.2.1 Design and Procedure

Using a cluster randomised controlled design, the third named author (NPG) allocated school classes to either the Intervention Group (IG; 17 classes; n= 190) or Control Group (CG; 15 classes; n = 158) matched regarding grade level (7th graders: 5 classes IG and 4 classes CG; 8th graders: 3 classes IG and 3 classes CG; 9th graders: 7 classes IG and 6 classes CG; 10th graders: 0 classes IG and 1 class CG; 11th graders: 1 class IG and 0 classes CG; 12th graders: 1 class IG and 1 class CG), urbanity of the area of the school (rural: 5 classes IG and 5 classes CG; urban: 12 classes IG and 10 classes CG) and school track (comprehensive school: 3 classes IG and 1 class CG; lower track secondary schools: 6 classes IG and 6 classes CG; higher track secondary schools: 8 classes IG and 8 classes CG). The CG had fewer classes due to two school classes withdrawing post-randomisation, before the first session was conducted (see Figure 4.1 for the study flowchart and dropout rates).

The study had two assessment points, baseline (t1) and post-intervention (t2, approximately four weeks apart (M = 27 days, SD = 4 days, Range = 20 – 35 days). At baseline 45 minutes (1 school lesson) were available for the study, which were split into approximately 20 minutes to complete the questionnaire followed by 25 minutes of intervention condition/control condition. The intervention involved psychoeducation including two major components. First, we presented information regarding the importance of sleep and the role that it plays in daily functioning, including academic performance, bodily functions, and appearance. Second, three sleep hygiene rules, which were communicated as "hints for healthy sleep", were derived in an interactive discussion:

1) Sleep duration rule: Avoid sleeping less than 8 hours per night because normal sleep duration in adolescence should be between 8.5 – 9.5 hours.

2) Behavioural rule 1: Avoid electronic media use during the last hour before planned sleep and switch off electronic media devices when going to bed.

3) Behavioural rule 2: Avoid caffeine consumption (7th grader). Restrict caffeine consumption (8-12th graders); particularly do not consume caffeine in the evening.

It was emphasized that these rules particularly apply for students who often feel tired, lack energy or suffer from poor sleep; it was communicated that the rules may not necessarily apply to those who do not suffer from these circumstances regularly. As a starting point for the discussion, which was structured and moderated by the trained researchers, we used a two-minute video clip (https://www.nji.nl/nl/Databank/Databank-Effectieve-Jeugdinterventies/Erkende-interventies/SlimSlapen; De Bruin et al., 2015) showing an adolescent girl using electronic media late at night including mobile phone, laptop/computer, and TV and drinking energy and cola drinks after which she finds it hard to fall asleep.

We also distributed an information leaflet to participants outlining these sleep hygiene rules. Additionally, parents of participants in the IG received the information leaflets via post, communicating the role of sleep for health, wellbeing, and school performance in adolescence. The leaflet also contained the potential role of parents for adolescents' sleep habits, and the three sleep hygiene rules that were communicated to adolescents.

The participants in the CG were given a 25-minute presentation exploring topics such as sleep in the animal kingdom as well as dreaming and sleep-walking in human beings. Parents of adolescents in the CG were not sent any material at t1. One month following the first session, a follow-up assessment was conducted and all participants completed the same questionnaire again. At t2, following the completion of the questionnaires, CG participants received all information related to the intervention as IG participants had at t1, including being shown the film, followed by the interactive discussion and the sleep hygiene rules.

Debrief information on the study was sent to the participants by mail.

4.2.2 Sample

The target overall sample size was N = 400 with an equal distribution between IG and CG (*i.e.*, 200 vs. 200), which would lead to achieved power of 0.85 to detect a small to medium sized effect of $d = 0.30$ with alpha level of $p = .05$ (2-tailed, G*Power; Faul et al., 2009). In total 42 schools

(28 schools in the Canton Basel Stadt and 14 schools in the Canton Basel Landschaft; Switzerland) were approached. Seven schools and 34 school classes agreed to participate (with an estimated total N ≈ 640; estimate based on the normal class size of 20 students; the actual number of students per class was not recorded). Due to non-participation (n ≈ 250) and drop out after t1 (n = 38; 20 IG vs. 18 CG), the sample was reduced to N = 352 (192 IG vs. 160 CG; Age: mean = 15.09 years; SD = 1.65 years; age range: 12.15-20.58 years; Females = 163; see Figure 4.1). Participants and their parents were informed about the voluntary and confidential nature of the study. Informed consent was obtained from students as well as parents of students below the age of 18 years. The study was conducted between October 2012 and February 2013. The study was approved by the Ethics committee of Basel (EKBB; nowadays Ethics committee north/central Switzerland, EKNZ; Ref.Nr.EK 120/12).

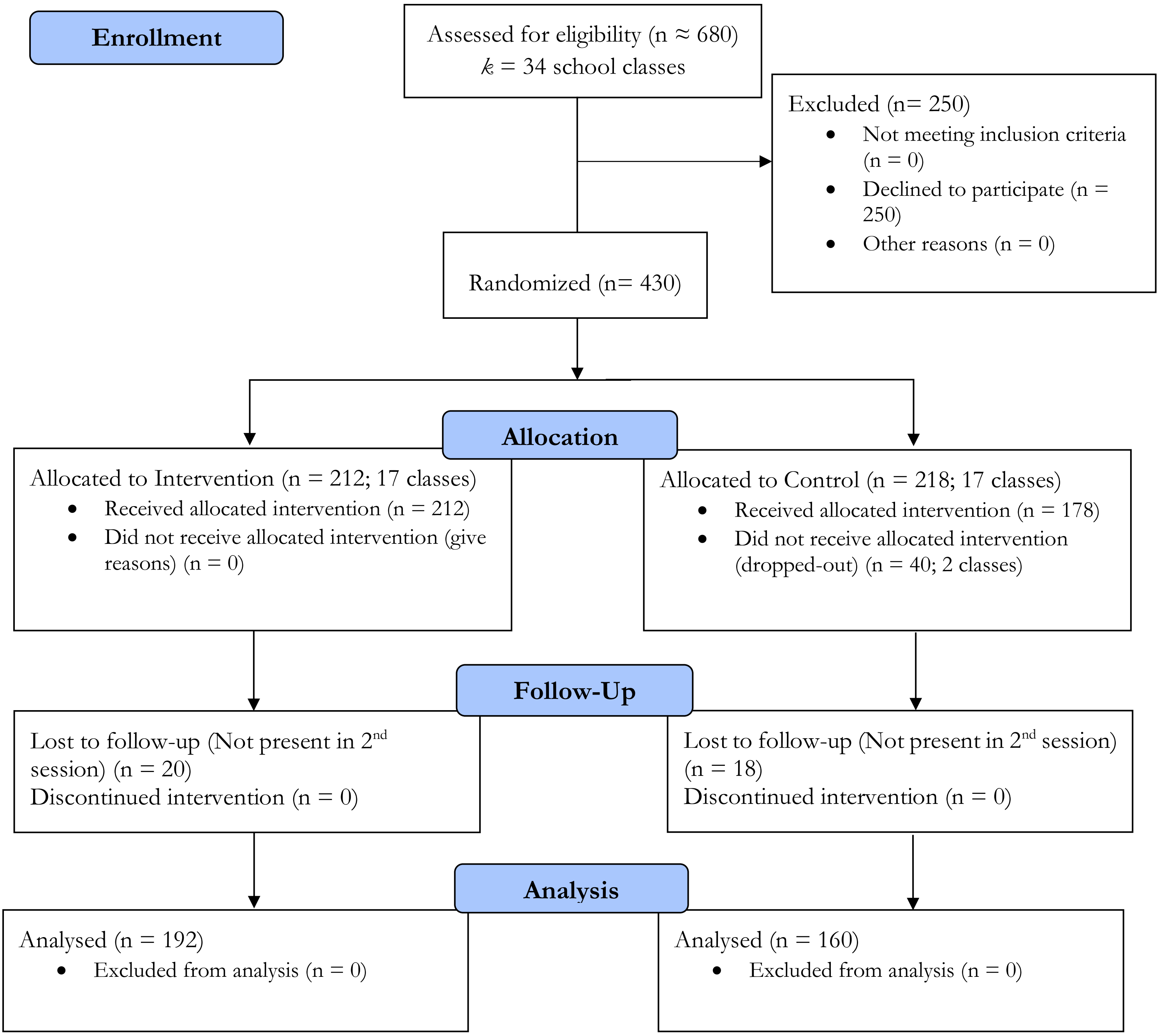

Figure 4.1: CONSORT flow diagram depicting participation throughout the study

4.2.3 Measures

Electronic media use in bed before sleep was assessed with four items. Participants responded on a 5-point scale, where "1=never" and "5=most of the time to always (at 5–7 days per week)" (α = .78). Items assess how often participants watch television, play video games, talk on the phone or text, and spend online (*e.g.*, "On a normal school night whilst you are already in bed, how often do you watch Videos/Films?"*)*.

Consumption of caffeinated products was assessed with three items and included "In a regular day, how many (a) cups of coffee, (b) cans of energy drinks or (c) glasses of other caffeinated sweet beverages do you consume?". Participants responded on a 4-point scale, where "1=0/less than 1 per day", and "4=more than 3 per day".

Sleep duration information was collected via separate questions for weekday and weekend bedtimes and awakening times. Sleep duration was calculated by subtracting the time when lights were switched off at night from the final awakening time in the morning.

Daytime tiredness was assessed using three items ((i) "Lately, I've been feeling tired or sleepy throughout the day"*;* (ii) "In school, I am often so tired that I almost fall asleep"; and, (iii) "I nap for at least one hour during the day."). Participants responded on a 5-point scale, where "1=never" and "5=mostly to always", with higher scores indicating more tiredness (α = .69).

Sleep difficulties were measured using five items from the German version of the Insomnia Severity Index (Bastien, 2001) adapted for use with adolescents. Participants responded on a 5-point scale, where "0=not at all/very satisfied" and "4=very much/very dissatisfied". Items assessed satisfaction with current sleep, difficulties falling asleep and maintaining sleep and feeling rested after waking up; higher scores were more indicative of sleep difficulties (α = .71).

Depressive symptoms were assessed using six items from the German version of the General Depression Scale (Hautzinger & Bailer, 1993). Participants responded on a 4-point scale, where "0=occurred never or rarely", and "3=occurred most of the time or always", with higher scores being indicative of depressive symptoms (α = .73).

Attention and Hyperactivity Symptoms were measured using five items from the Hyperactivity/Attention subscale of the Strengths and Difficulties Questionnaire (Goodman & Goodman, 2009). Participants responded on a 3-point scale, where "1=not applicable", to "3=clearly applicable" (α = .58).

4.2.4 Statistical Analyses

A multilevel modelling approach was used for data analysis to account for the nested nature of the data with students clustered within school classes allocated either to the IG or CG. Models assessing the effect of the intervention on the outcome variables by treating group and time as independent variables, and participant and school class as random factors. An interaction term of Group*Time was also included in each model. In total, seven models were computed, one for each of the primary and secondary variables. Each of the seven models adjusted gender and age as covariates. A Bonferroni-corrected alpha-level of $p < .0125$ was adopted for testing effects regarding the four primary outcome variables (night-time electronic media use, caffeine consumption, weekday and weekend sleep duration). Analyses also included calculating the intracluster correlation coefficients (ICC) for each outcome variable. Additionally, Intention to Treat (ITT) analysis was conducted using the last observation carried forward method.

The descriptive analysis was conducted using SPSS® version 24 (IBM Corporation, Armonk NY, US), and the multilevel and ITT analyses were implemented using the xtset, xtmixed and estat icc STATA (version 15) statistical packages.

4.3 Results

4.3.1 Sample characteristics

Table 4.1 shows the baseline values of all study variables for the full sample, and also separately for IG and CG. No significant differences between groups at baseline were found.

The multilevel analyses revealed that compared to girls, boys reported shorter weekend sleep (β = -0.34, SE = .13, p = .007), as well as lower levels of daytime tiredness (β = -0.30, SE = .08, p < .001), sleep difficulties (β = -0.21, SE = .07, p = .002), and depressive symptoms (β = -0.23, SE = .05, p < .001). Age-related effects were also found, such that with increasing age, participants reported higher levels of bedtime electronic media use (β = 0.71, SE = .12, p < .001), shorter weekday (β = -0.28, SE = .03, p <.001) and weekend sleep duration (β = -0.32, SE = .04, p < .001), increased daytime tiredness (β = 0.18, SE = .02, p < .001), sleep difficulties (β = 0.08, SE = .03, p = .004), and depressive symptoms (β = 0.06, SE = .01, p < .001).

Table 4.1: Mean and standard deviation of study variables separately for Intervention and Control Groups at baseline.

	Full sample (N = 352)		Intervention Group (n = 192)		Control Group (n = 160)		Independent t-test / Chi square test		
Variables	Mean/n	SD[a]/%	Mean / n	SD / %	Mean / n	SD / %	t/ χ^2	*p*	df[b]
Age	15.09	1.65	14.97	1.71	15.25	1.56	1.61	.109	1,350
Female	163	46.31	83	43.2	80	50	1.61	.205	1,1
Smartphone ownership	295	83.81	154	80.20	141	88.10	4.66	.097	1,2
Weekday sleep duration (hh:mm)	08:06	00:56	08:08	00.58	08:04	00:53	-0.74	.460	1,341
Weekend sleep duration (hh:mm)	08:05	00:59	10:10	01:26	09:57	01:32	-1.39	.165	1,339
Daytime tiredness	2.07	0.80	2.03	0.74	2.13	0.86	1.31	.193	1,348
Sleep difficulties	2.21	0.71	2.23	0.68	2.19	0.75	-0.47	.636	1,348
Depressive symptoms	1.76	0.49	1.77	0.51	1.75	0.46	-0.31	.754	1,350
Hyperactivity symptoms	1.66	0.39	1.63	0.39	1.69	0.39	1.33	.186	1,349
Electronic media use in bed before sleep	9.52	4.13	9.20	3.97	9.92	4.30	1.65	.101	1,348
Watching TV/videos							6.01	.199	1,4
Never	177	50.3	89	46.4	88	55.0	-	-	-
Once a week or less	58	16.5	39	20.3	19	11.9	-	-	-
Twice a week	39	11.1	22	11.5	17	10.6	-	-	-
3-4 times a week	29	8.2	18	9.4	11	6.9	-	-	-
5-7 times a week	47	13.4	24	12.5	23	14.4	-	-	-
Playing video games							7.74	.171	1,4
Never	241	68.5	131	68.2	110	68.8	-	-	-
Once a week or less	46	13.1	28	14.6	18	11.3	-	-	-
Twice a week	32	9.1	12	6.3	20	12.5	-	-	-
3-4 times a week	21	6.0	15	7.8	6	3.8	-	-	-
5-7 times a week	9	2.6	5	2.6	4	2.5	-	-	-
Communication by phone or text message							9.68	.085	1,4
Never	89	25.3	51	26.6	38	23.8	-	-	-
Once a week or less	47	13.4	34	17.7	13	8.1	-	-	-
Twice a week	39	11.1	21	10.9	18	11.3	-	-	-
3-4 times a week	58	16.5	30	15.6	28	17.5	-	-	-

Variables	Full sample (N = 352)		Intervention Group (n = 192)		Control Group (n = 160)		Independent t-test / Chi square test		
	Mean/n	SD[a]/%	Mean / n	SD / %	Mean / n	SD / %	t/ χ^2	*p*	df[b]
5-7 times a week	116	33.0	55	28.6	61	38.1	-	-	-
To be online (on Facebook, Chatroom, etc)							10.72	.057	1,4
Never	144	40.9	87	45.3	57	35.6	-	-	-
Once a week or less	49	13.9	31	16.1	18	11.3	-	-	-
Twice a week	39	11.1	21	10.9	18	11.3	-	-	-
3-4 times a week	51	14.5	26	13.5	25	15.6	-	-	-
5-7 times a week	66	18.8	26	13.5	40	25.0	-	-	-
Caffeine consumption	4.45	1.20	4.40	1.18	4.50	1.22	0.79	.429	1,350
Number of cups of coffee							6.94	.074	1,3
Less than 1 a day	305	86.6	162	84.4	143	89.4	-	-	-
1 per day	37	10.5	27	14.1	10	6.3	-	-	-
2-3 per day	5	1.4	2	1	3	1.9	-	-	-
More than 3 per day	1	0.3	0	0	1	0.6	-	-	-
Number of cans of energy drinks							2.76	.429	1,3
Less than 1 a day	288	81.8	160	83.3	128	80.0	-	-	-
1 per day	49	13.9	25	13	24	15.0	-	-	-
2-3 per day	11	3.1	6	3.1	5	3.1	-	-	-
More than 3 per day	2	0.6	0	0	2	1.3	-	-	-
Number of glasses of other caffeinated drinks							5.00	.287	1,4
Less than 1 a day	96	27.3	52	27.1	44	27.5	-	-	-
1 per day	145	41.2	87	45.3	58	36.3	-	-	-
2-3 per day	87	24.7	43	22.4	44	27.5	-	-	-
More than 3 per day	23	6.5	10	5.2	13	8.1	-	-	-

Note. [a]SD: Standard deviation.
[b]df: degrees of freedom.

4.3.2 Intervention effects on primary outcomes

Table 4.2 shows the results of the multilevel analyses. Results show a significant interaction term indicating that adolescents in the IG significantly decreased their electronic media use in bed before sleep between baseline and follow-up assessment compared to adolescents in the CG (β = -0.91, SE = .29, p = .002, d = -0.24). However, no intervention effect was found for adolescents' reports of consumption of caffeinated products (β = 0.04, SE = .11, p = .721, d = 0.06), weekday sleep duration (β = 0.01, SE = .08, p = .902, d = 0.05) and weekend sleep duration (β = 0.09, SE = .13, p = .481, d = 0.13). In all models, no significant main effect of group or time were found. Further, no sex and age interactions were found.

Because baseline comparisons of both groups reflected near-significant differences for electronic media use and caffeine consumption (see Table 4.3) we additionally conducted sensitivity analyses using Propensity Score Matching (using the teffect psmatch and psmatch2 STATA packages). These analyses involve matching of participants between the groups based on their age, gender and (i) baseline electronic media use and (ii) baseline caffeine consumption. Results were consistent with the findings of the multilevel analyses (*i.e.*, electronic media use in bed was significantly lower for participants in the IG versus CG (β = -0.98, S.E. = 0.37, p = .008), while no effect was found for caffeine consumption, (β = 0.14, S.E. = 0.15, p = .335; see Table 4.3).

4.3.3 Intervention effects on secondary outcomes

Table 4.2 displays the results of the multilevel models. No significant intervention effects were found for daytime tiredness (β = 0.01, SE = .05, p = .801, d = 0.01), sleep difficulties (β = -0.02, SE = .05, p = .745, d = -0.01), depressive symptoms (β = -0.08, SE = .05, p = .090, d = -0.10) and hyperactivity symptoms (β = 0.01, SE = .03, p = .834, d = 0.03). Results showed a significant decrease in daytime tiredness and sleep difficulties over time in both groups (β = -0.11, SE = .04, p = .004 and β = -0.12, SE = .04, p = .001, respectively). One significant gender interaction for daytime tiredness was found (β = -0.24, SE = 0.07, p = .001), suggesting that boys relative to girls in the IG reported a stronger decrease in daytime tiredness. Similarly, one significant age interaction for depressive symptoms was found (β = -0.05, SE = 0.02, p = .007), suggesting that older versus younger participants in the IG reported a stronger decrease in depressive symptoms.

However, separate subgroup analyses for boys and girls as well as for younger and older participants were not significant at the Bonferroni corrected alpha level of $p < .0125$.

4.3.4 ITT analysis

Results from the ITT analysis echoed the results found in the multilevel analysis for primary and secondary variables, in terms of effect size and statistical significance. These are displayed in Table 4.4.

Table 4.2: Outcome variables are shown as a function of group and time. Models were built to compare the Intervention and Control Groups over time, controlling for the clustering of the data.

	Group				Time			Group × Time			ICC[3] (SE[4])
Variables	n[1]	β	CI[2]	*p*	β	CI	*p*	β	CI	*p*	
Media use in bed	688	-0.55	-1.37, 0.27	.190	0.05	-0.37, 0.48	.800	-0.91	-1.48, -0.34	.002	0.75 (0.02)
Caffeine consumption	696	-0.08	-0.43, 0.27	.651	-0.15	-0.31, 0.02	.077	0.04	-0.18, 0.26	.721	0.63 (0.03)
Weekday sleep duration	656	-0.05	-0.25, 0.14	.589	-0.01	-0.13, 0.11	.847	0.01	-0.16, 0.18	.902	0.58 (0.04)
Weekend sleep duration	648	0.19	-0.10, 0.48	.209	0.02	-0.17, 0.20	.870	0.09	-0.16, 0.33	.481	0.61 (0.04)
Daytime tiredness	688	-0.02	-0.19, 0.14	.788	-0.11	-0.19, -0.04	.004	0.01	-0.09, 0.12	.801	0.78 (0.02)
Sleep difficulties	688	0.10	-0.09, 0.29	.298	-0.12	-0.20, -0.05	.001	-0.02	-0.11, 0.08	.745	0.79 (0.02)
Depressive symptoms	696	0.05	-0.06, 0.15	.379	0.02	-0.05, 0.08	.579	-0.08	-0.17, 0.01	.090	0.60 (0.03)
Hyperactivity symptoms	694	-0.04	-0.15, 0.06	.418	-0.02	-0.06, 0.03	.510	0.01	-0.06, 0.07	.834	0.68 (0.03)

Note. Models were built adjusting for sex and age. Sex, age and constant values are not displayed in the table; significance is considered at the Bonferroni corrected alpha level of $p < .0125$ level

[1] number of data points in the model; there were 2 data points per participant (baseline and follow-up).

[2]CI: Confidence Interval.

[3]ICC: Intracluster correlation coefficient.

[4]SE: Standard error.

Table 4.3: Propensity score analysis of electronic media use and caffeine consumption for the Intervention and Control Groups

	Intervention Group (n = 192)	Control Group (n = 160)	Bias (%)	Bias reduction (%)	β	*p*
			Electronic media use			
Age (years)	14.92	14.96	-2.4	88.2	-0.98	.008
Gender	0.44	0.43	2.1	85.1		
Electronic media use (t1)	9.12	9.12	.01	99.7		
			Caffeine consumption			
Age (years)	14.92	15.14	-13.7	33.8	0.14	.335
Gender	0.44	0.36	17.0	72.6		
Caffeine consumption (t1)	4.39	4.37	1.8	-19.3		

Note. Caffeine consumption analysis reveals that the bias% was high (*i.e.*, above 5%). However, for all three indicators (*i.e.*, age, gender and baseline caffeine consumption), the bias% was not significant, suggesting that though the bias was high, this did not impact the results negatively)

Table 4.4: Intention to Treat analyses using the last observation carried forward method for all outcome variables

		Group			Time			Group × Time		
	n[1]	β	CI[2]	*p*	β	CI	*p*	β	CI	*p*
Media use in bed	738	-0.59	-1.39, 0.21	.147	0.02	-0.40, 0.43	.939	-0.87	-1.43, -0.32	.002
Caffeine consumption	742	-0.19	-0.56, 0.18	.303	-0.16	-0.32, -0.00	.051	0.06	-0.16, 0.27	.610
Weekday sleep duration	723	0.00	-0.18, 0.18	.984	-0.01	-0.13, 0.11	.868	0.00	-0.15, 0.16	.950
Weekend sleep duration	718	0.14	-0.20, 0.49	.417	0.02	-0.16, 0.19	.862	0.08	-0.16, 0.31	.521
Daytime tiredness	738	0.01	-0.16, 0.17	.931	-0.12	-0.19, -0.04	.003	0.01	-0.10, 0.11	.892
Sleep difficulties	738	0.09	-0.10, 0.28	.339	-0.13	-0.21, -0.06	.000	-0.01	-0.11, 0.09	.808
Depressive symptoms	742	0.08	-0.03, 0.18	.147	0.02	-0.04, 0.09	.522	-0.09	-0.17, 0.00	.055
Hyperactivity symptoms	740	-0.04	-0.13, 0.06	.485	-0.02	-0.06, 0.03	.477	0.00	-0.06, 0.07	.881

Note. Models were built adjusting for sex and age. Sex, age and constant values are not displayed in the table; significance is considered at the Bonferroni corrected alpha level of $p < .0125$ level.

[1] number of data points in the model; there were 2 data points per participant (baseline and follow-up).

[2] CI: Confidence Interval.

4.4 Discussion

Our study evaluated the effectiveness of a brief school-based psychoeducative intervention with parent involvement aimed to decrease bedtime electronic media use, caffeine consumption in the evening, and increase sleep duration among adolescents. Results showed that the intervention modestly reduced bedtime electronic media use for participants in the IG versus CG, but did not have an impact on caffeine consumption or sleep duration. We also found that participants in the IG did not show improvements in sleep quality, sleep-related problems, daytime tiredness, or depressive and hyperactivity-related symptoms.

The modest decrease in electronic media use may have been triggered by an increase in participants' knowledge regarding the negative impact of bedtime electronic media use on sleep and mental health. This is in line with studies showing that psychoeducative sleep interventions increase participants sleep-related knowledge (Blunden et al., 2012; Rigney et al., 2015). Moreover, it is possible that increased parental monitoring of adolescents' bedtime routine and encouraging of good sleep hygiene as a potential consequence of the information leaflet for parents regarding adolescent sleep and sleep hygiene, may have triggered the adolescents' behaviour change (Kalak et al., 2012; Rigney et al., 2015; Schlarb et al., 2010; Short et al., 2011). As a limitation, we cannot disentangle the relative contribution of the psychoeducative intervention for the adolescents and the parental information leaflets, or whether the combination of the two approaches was crucial for the reported decrease in adolescents' bedtime electronic media use.

Our results also showed that the decreased electronic media use did not have an impact on sleep duration and any of the secondary outcomes, thereby not lending support to previous findings that suggested that bedtime electronic media use is a risk factor for poor sleep, and consequently for poor mental wellbeing during adolescence (Brunborg et al., 2011; Cain & Gradisar, 2010; Fossum et al., 2014; Hysing et al., 2015; Lemola et al., 2014; Owens, 2014). Notably, these previous findings were based on cross-sectional data and therefore do not inform about causality. Therefore it remains possible that electronic media use is not a causal factor for poor sleep in adolescence but rather its consequence; adolescents who find it difficult to fall asleep might use their electronic devices as a sleeping aid (Eggermont & Van den Bulck, 2006).

However, one has also to bear in mind the following alternative explanations for finding no intervention effects on sleep duration and difficulties, daytime tiredness and mental wellbeing. First, the effect size associated with the intervention was modest (d = -0.24), and the decrease in media use might have been too small to result in changes of sleep and other secondary outcomes. Second, we did not measure the quality of the experience related to electronic media use at night, which might be more important for sleep quality and mental health (Woods & Scott, 2016). For instance, interactions on social media may have emotionally arousing effects, and lead to increased worrying which may negatively impact sleep (F. C. Brown et al., 2002). Third, through our primary prevention approach, we targeted a sample of adolescents at relatively low-risk of poor mental health. It is possible that intervention effects would have been more pronounced if specifically adolescents with highly elevated levels of media use or poor sleep were targeted. Previous studies that tailored sleep hygiene interventions according to the specific needs of at-risk individuals were more successful in improving sleep patterns and mental wellbeing in adolescents compared to our one size fits all approach (Dewald-Kaufmann et al., 2014). It is possible that future smart device-assisted interventions delivering individualized information to participants, may fit the purpose of specifically tailored interventions which can be widely administered at low cost.

4.4.1 Limitations

Our study is not without limitations. First, the a priori power and sample size calculations did not account for the clustered design of the study. The results of the high intracluster correlations (displayed in Table 4.2) suggest that the study was underpowered to detect modest effects. Further, in this pilot study, the small sample size did not allow for subgroup analyses among more vulnerable participants. It is for instance possible that interventions are more effective for adolescents with excessive electronic media use or excessive caffeine consumption. Second, the study had only a short follow-up period of four weeks, which disallowed assessing longer-term effects of the intervention. Third, all measures were based on subjective reports and could have been affected by memory biases. In a related vein, the assessment of caffeine consumption did not have an option to indicate no caffeine consumption at all, therefore, the measure may not have been sensitive to distinguish between abstainers and consumers of low amounts of caffeine. Fourth, we cannot discard the possibility that participants were aware that they were part of the IG or the CG, potentially leading their responses at follow-up to be biased by social desirability effects. Finally, the study did not collect any information regarding parental styles or parental relationship quality with the child, which may have helped ascertain the psychosocial mechanisms related to parenting that could have contributed to the intervention effects.

4.5 Conclusion

By using a cluster randomised controlled design, we evaluated the effectiveness of a 25-minute school-based psychoeducative intervention combined with parental involvement on improving sleep duration by decreasing bedtime electronic use and caffeine consumption among adolescents. We found a modest decrease in electronic media use for participants in the IG versus CG, while there were no other differences between the groups in all other measures, including secondary measures of mental wellbeing. While the intervention was only partially and modestly successful, it indicates the feasibility of a short and easily administrable intervention that could be incorporated into school curricula and standardised for a wider use in primary prevention of late night electronic media use. The findings also suggest the need for better understanding whether and how night time electronic media use impacts adolescents' sleep, mental health, and wellbeing. Due to the limitations of our pilot study, we suggest that future research uses larger samples with a higher number of school classes to account for the similarity in behaviours such as electronic media use among peers in school classes. Further, research could also complement subjective reports with objective measures of sleep through actigraphy. Studies that experimentally disentangle the effects of different types of electronic media use and the role of the individual electronic media use experience for adolescents' sleep are needed to allow researchers and policymakers addressing a growing public health concern.

Chapter 5
Bedtime social media use, sleep and affective wellbeing in young adults: An experience sampling study

Findings from primarily cross-sectional studies have linked more extensive social media use to poorer sleep and affective wellbeing among adolescents and young adults. This study examined bedtime social media use, sleep, and affective wellbeing, using an experience sampling methodology with the aim of establishing a day-to-day temporal link between the variables. The study hypothesized a positive association between increased bedtime social media use and lower affective wellbeing the following day, mediated by poorer sleep. Using a smartphone application, 101 undergraduate students (M_{age} = 19.70 years, SD = 1.09), completed daily questionnaires assessing the previous night's bedtime social media use and sleep duration and satisfaction (one measurement per day sent at 08:00), and momentary affective wellbeing (five measurements per day, at randomly varying times between 08:00 and 22:00 on weekdays and 10:00 and 22:00 on weekends), for 14 consecutive days. Objective assessments of total sleep time and sleep efficiency were obtained via wrist-worn actigraphs. By means of separate multilevel models, it was tested whether increased bedtime social media use predicted poorer sleep the same night, whether poorer sleep was predictive of positive and negative affect the following day, and whether sleep mediated the relationship between social media use and affective wellbeing. Increased bedtime social media use was not associated with poorer sleep the same night. Apart from subjective sleep satisfaction, no other sleep variable (i.e., subjective sleep duration, objective total sleep time and objective sleep efficiency) predicted positive or negative affect the following day. This study found that bedtime social media use is not detrimental to the sleep and affective wellbeing of healthy young adults. However, it is possible that bedtime social media use may be harmful to the sleep of vulnerable individuals.

5.1 Introduction

Social media has become a central part of young adults' lives, with reports suggesting that approximately 90% of this population uses at least one social media website (Pew Research Center, 2018). On the one hand, social media affords its users' important benefits, such as staying in touch with friends and family. On the other hand, it has been linked to a range of negative consequences, for example to poorer sleep (Levenson et al., 2016, 2017), lower affective wellbeing (Sagioglou & Greitemeyer, 2014; Weinstein, 2018), and poorer mental health (Keles et al., 2019).

Studies examining the link between social media use and sleep have reported that increased use of social media, specifically before sleep, is associated with poorer sleep patterns. In a recent study using data from the Millennium Cohort Study on individuals aged between 13-15 years in the UK, Scott et al. (2019) found that longer time spent on social media during the day was associated with later sleep times and later wake up times on school days, as well as difficulty falling back asleep after night-time awakening. Studies also report that increased social media use at night before sleep is associated with more sleep disturbances (Levenson et al., 2016, 2017). It is known that the blue light emitted from electronic devices such as smartphones can interfere with melatonin secretion, thereby interfering with the body's ability to fall asleep (Cajochen et al., 2011). Engaging in social media in bed before sleep might also replace and hence reduce sleep time, or increase emotional or cognitive arousal, making it difficult to mentally switch off (Levenson et al., 2016, 2017). However, it may also be that adolescents and young adults use social media in bed as a sleeping aid, as shown in a three-year longitudinal study by Tavernier and Willoughby (2014).

When examining the relationships between social media use and mental health and affective wellbeing among adolescents and young adults, research suggests that excessive social media use is associated with a higher risk of displaying depressive symptoms (Donnelly & Kuss, 2016; Keles et al., 2019; Lin et al., 2016; Woods & Scott, 2016), anxiety symptoms (Primack et al., 2017), and having lower self-esteem (Kalpidou et al., 2011; Valkenburg et al., 2006). Evidence on the impact of social media use on affective wellbeing (i.e., the frequency and intensity of positive and negative emotions and mood; Luhmann et al., 2012) of adolescents has highlighted that longer periods of social media use are linked to lower levels of positive affect and higher levels of negative affect (Sagioglou & Greitemeyer, 2014; Weinstein, 2018), perhaps due to the negative social comparisons that users engage in while browsing (Z. Brown & Tiggemann, 2016; Lup et al., 2015; Weinstein, 2018; S. Yoon et al., 2019). However, when assessing these associations in samples of young adults, studies have found mixed results, suggesting that the risk of developing poor mental and affective wellbeing as a result of social media use is at least lower in this population, than previously thought. For instance, while there is evidence for a link between increased social media use and decreased positive affect (Y. Wang et al., 2015), some studies have found no relationship between social media use and other wellbeing indicators such as depressive symptoms (Berryman et al., 2018; Jelenchick et al., 2013).

Studies considering the relationship between social media use, mental or affective wellbeing and sleep mainly purport that excessive social media use is linked to both poorer sleep indicators and poorer mental health (*e.g.*, Woods & Scott, 2016). Such evidence points to a possible domino effect relationship between the three variables; specifically, that the negative impact of social media use on adolescents' and young adults' sleep may further spill over to their affective wellbeing. It is well known that sleep plays an important role in maintaining healthy physical and mental functioning; for instance, sleep deprivation can be detrimental to an individual's affective wellbeing (Baum et al., 2014; Talbot et al., 2010). In a recent study involving adolescents, Shen et al. (2018) found that shorter sleep was associated with lower positive affect, while poorer subjective sleep quality was linked to higher levels of negative affect. Studies conducted on samples of young adults report similar findings, namely that subjective experience of poor sleep is linked to lower positive affect (Pilcher & Ott, 1998; Rossa et al., 2014).

The mediation of the relationship between social media use at night and poor mental wellbeing by poor sleep has been supported in studies with adolescents. Lemola et al. (2015) reported that increased social media use before sleep might be associated with shorter sleep duration and more sleep difficulties, which in turn might be associated with higher levels of depressive symptoms. Similarly, Kelly et al. (2018) reported that excessive social media use may be associated with poor sleep amongst other factors, and that poor sleep may be related to increased depressive symptoms. As a major limitation, these studies have used cross-sectional designs, which do not allow causal or temporal interpretation. Thus, conclusions from these studies need to be inferred cautiously and are weak evidence for advice about media use to young people.

To overcome this limitation, our study employs an experience sampling methodology over 14 consecutive days to examine the temporal links between participants' bedtime social media use, sleep, and affective wellbeing. Our study aimed to answer the following questions. First, is increased social media use at night before sleep associated with poorer sleep afterwards? Second, based on Lemola et al.'s (2015) research, does poor sleep mediate the relationship between social media use the previous night and affective wellbeing the following day? In particular, the primary hypotheses were (i) increased social media use before sleep is negatively associated with both subjective and objective sleep quality indicators (*i.e.*, shorter subjective sleep duration, shorter actigraphy-measured total sleep time, poorer subjective sleep satisfaction, and lower actigraphy-measured sleep efficiency) the same night; (ii) Poorer sleep quality indicators the previous night (*i.e.*, shorter subjective sleep duration, shorter actigraphy-measured total sleep time, poorer subjective sleep satisfaction, and lower actigraphy-measured sleep efficiency) are associated with increased negative affect and decreased positive affect the following day; (iii) Sleep quality indicators (*i.e.*, subjective sleep duration, actigraphy-measured total sleep time, subjective sleep satisfaction and actigraphy-measured sleep efficiency) will mediate the positive relationship between increased social media use before sleep and higher levels of negative affect and lower levels of positive affect the following day. Based on the rationale that sleep the previous night might differentially impact affective wellbeing at different time points in the following day (Könen et al., 2016; Konjarski et al., 2018; Wrzus et al., 2014), we also explored whether associations of bedtime social media use and sleep with affective wellbeing the following day were stronger for positive and negative affect reported in the morning versus the afternoon.

Finally, following the notion that individuals differ in their vulnerability to effects of stressors on sleep (Drake et al., 2004), we explored whether associations between social media use at night, sleep, and affective wellbeing are more pronounced in the subgroup of participants with increased depressive symptom levels (that were measured once at the beginning of the study), as a potential indicator of increased vulnerability. In particular, this exploratory analysis was driven by the rationale that individuals with higher levels of depressive symptoms at baseline are more vulnerable to experiencing both disrupted sleep and higher levels of negative affect over the 14 days that the study took place (Vargas et al., 2015).

5.2 Method

5.2.1 Design and procedure

Undergraduate students at the University of Warwick, who owned either an Android or iOS smartphone, were invited to participate through the University research participant recruitment system as well as from a previous study where individuals had consented to be contacted for the experience sampling study. Data collection occurred in five batches, between October 2017 and February 2018 (batch 1: 31st Oct till 14th Nov 2017; batch 2: 21st Nov till 5th Dec 2017; batch 3: 9th Jan till 23rd Jan 2018; batch 4: 30th Jan till 13th Feb 2018; batch 5: 20th Feb till 6th March 2018) because only 25 actigraphy devices were available for concurrent testing. Each batch took part in the study for 14 consecutive days, always beginning on a Tuesday. During the introductory session, after signing informed consent forms, participants completed a 30-minute baseline questionnaire, where information regarding demographics, emotional investment in social media, sleep habits and behaviour, and depressive symptoms in the preceding two weeks were collected (see *Measures* section). The data were anonymized through individual unique codes, which were later used to link the questionnaire data with the actigraphy and experience sampling data. Participants were compensated £5 for completing the questionnaire.

Next, each participant received an actigraph, with the instruction to wear it on the non-dominant wrist for the entire study, and through each night (they were specifically instructed to put the actigraphs on before bedtime every night, in case they removed it during the day due to any reason, for example, for engaging in contact sports that might cause damage to the device or harm to other people).

Participants then downloaded the experience sampling application mEMA (Mobile Ecological Momentary Assessment; www.ilumivu.com) on their smartphones. Through mEMA, participants received daily questionnaires that assessed their use of bedtime social media, sleep, and positive and negative affect across the 14 days. Per day, participants received six prompts. The first was sent at 08:00 every morning, with a questionnaire that collected subjective information about the previous night's sleep and bedtime social media use. Participants were free to respond to this prompt at any time during the day but to mitigate any potential memory effects, they were advised to fill in the questionnaire as soon as they woke up, or at least within the first half of each day. The freedom to respond to this prompt at any time ensured non-interference with wake times, especially on weekends. The remaining five prompts were sent between 08:00 and 22:00 on weekdays, and between 10:00 and 22:00 on weekends, and were programmed to vary randomly within these broader windows, with a minimum of at least one hour between two prompts. At each of these five prompts, participants had to respond to items assessing their momentary positive and negative affect, and could only do so within 20 minutes of receiving the prompt. In total, each participant received 84 prompts (*i.e.*, 14 days x 6 prompts a day). While participants were encouraged to respond to as many prompts as they could, they were also instructed to ignore the prompts in situations that could cause danger or nuisance to themselves or others around them (e.g., while driving, or when they were attending lectures). Compensation for participation was determined based on the number of prompts responded to. For each day of participation, individuals could receive £2.50 (and thus a total of £35 over 14 days). To receive the full amount, participants had to respond to at least 56 out of the 84 prompts (67%) and were therefore allowed to miss an average of two prompts per day (33%).

At the end of the study, participants were invited to the lab for a debrief session, where they were thanked for their participation and their experiences of participation were noted in a brief standardized questionnaire. The actigraphy devices were collected and compensation was provided.

Figure 5.1 depicts the design of the study.

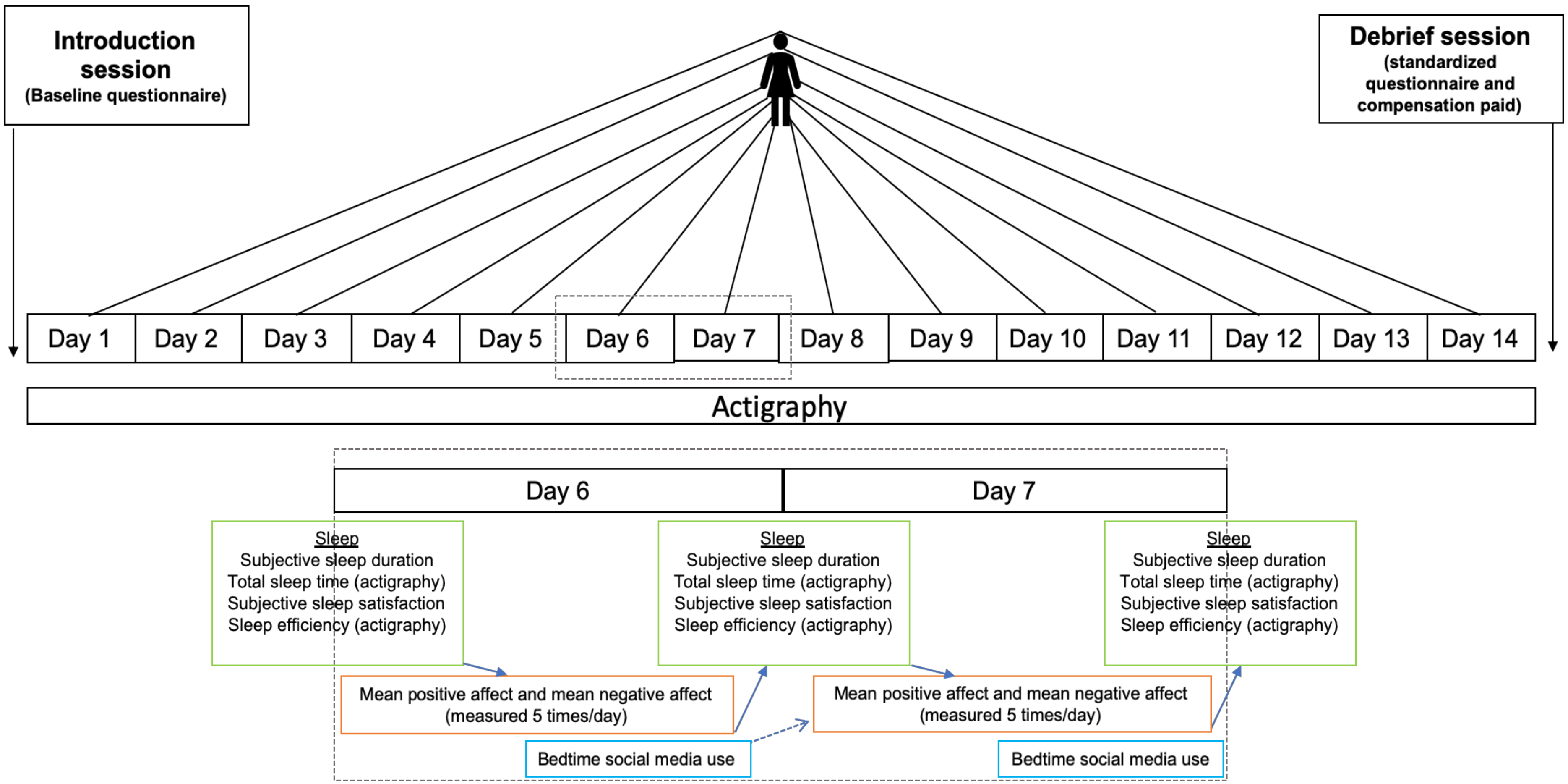

Figure 5.1: Design of study, as detailed under days 6 and 7 (can be generalised to all 14 days), and analysis plan as represented by the arrows between boxes.

5.2.2 Participants

Figure 5.2 shows the recruitment of participants in a flow diagram. A total of 129 undergraduate students across academic departments from the University of Warwick were recruited for the study. Of these, 13 were unable to participate due to problems in downloading mEMA. Four participants dropped out after the study commenced (one found participation too "tedious" and "intrusive", and three were lost to follow-up). Data of four additional participants were excluded due to low compliance in the experience sampling survey (*i.e.*, responding to less than 60% of the prompts). One participant's data could not be used due to technical errors in downloading actigraphy data. Further, data of five participants were excluded due to incomplete day-level data (detailed in section 2.4.2). Last, one participant was excluded from analysis due to their age being more than ten standard deviations above the average age (*i.e.*, 32 years old). This resulted in a final sample of 101 participants (Age: M = 19.70 years, SD = 1.09 years, range = 18 – 22 years; females = 65.3%). Of these, 44 were 1st-year students, 29 were 2nd-year students, 27 were 3rd-year students, and one was a 4th-year student.

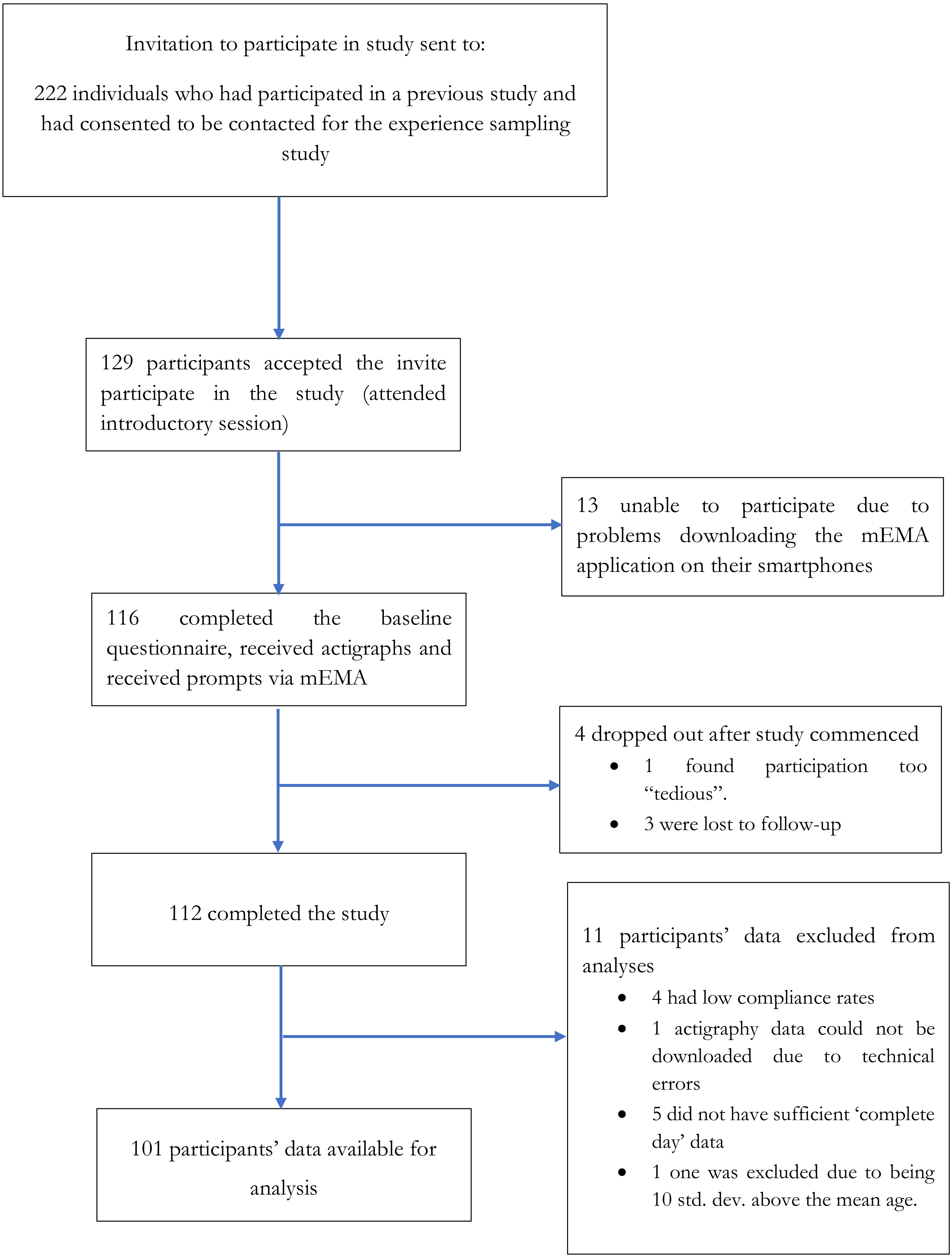

Figure 5.2: Participant recruitment flowchart

5.3 Measures and Instruments

5.3.1 Baseline Questionnaire

The baseline questionnaire included questions regarding demographics, such as age, sex and year of study, and standardized questionnaires listed below. First, emotional investment in social media was assessed using an adapted version of the Social Integration and Emotional Connection subscale of the Social Media Use Integration Scale (Jenkins-Guarnieri et al., 2013). Participants responded to seven questions (*e.g.*, "I feel disconnected from friends when I have not logged into social media") on a 5-point scale ("1 = Strongly disagree" to "5 = Strongly agree"). Higher scores reflected higher levels of investment in social media, and the scale displayed an internal consistency of $\alpha = .84$.

The Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) was used to obtain information on sleep indicators. Specifically, two subscales were utilized to measure subjective sleep duration (component 3) and subjective sleep quality (component 1).

Depressive symptoms were measured using the 10-item Center for the Epidemiologic Studies of Depression Short Form (CESD-10; Andressen et al., 1994). Participants responded on a 4-point scale ("0 = Rarely or none of the time" to "3 = All of the time"), where higher scores reflected greater severity of symptoms, and a cut-off of 10, as defined by Andressen et al. (1994) was considered as increased level of depressive symptoms. The scale displayed an acceptable internal consistency ($\alpha = .79$).

5.3.2 Experience Sampling

The first prompt sent each day assessed the previous night's bedtime social media use and sleep. Social media use was measured by asking participants to indicate specifically with regard to the last hour before sleep, how many minutes they had spent engaging in (i) communicating with others by text, chat, or phone/video call (*e.g.*, using WhatsApp) and (ii) using social media sites or applications (*e.g.*, Facebook and Instagram). Total social media use the previous night before sleep (in minutes) was calculated by adding together participants' responses across these two items.

Sleep duration was assessed by asking participants to indicate on a time scroller (i) at what time they had switched off the lights to sleep the previous night, and (ii) at what time had they woken up in the morning. Subjective sleep duration for each night was calculated by taking the difference between lights off time the previous night and awakening time the following morning. Sleep satisfaction was assessed by asking participants to indicate on a 4-point scale ("1=very dissatisfied" to "4=very satisfied"), how satisfied they were with their sleep the previous night.

Positive affect (PA) and negative affect (NA) were measured using five positive items (happy, enthusiastic, content, relaxed, and attentive) and five negative items (upset, annoyed bored, sad, and worried) taken from the Positive and Negative Affect Scale (PANAS; D. Watson et al., 1988) and Russel's Circumplex Model of Affect (Russell, 1980). With five prompts each day, participants were repeatedly asked to indicate on a 5-point scale ("1=not at all" to "5=to a large extent"), the extent to which they felt each of the ten affective states in the moment they received the prompt. Each item was presented as a separate question. Principal Axis Factoring with varimax rotation revealed a two-factor structure, with one positive affect factor and one negative affect factor (see Appendix A). Based on the results of the factor analysis, the item 'bored' was excluded from further analysis. Scores for PA and NA were computed by taking an average of the five positive items and four negative items, respectively. Higher scores indicated higher levels of PA and NA, respectively. The PA scale displayed a good reliability of $\alpha = 0.81$, and the NA scale displayed an acceptable reliability of $\alpha = .78$. The two scales were negatively correlated at $r = -.54$, $p < .001$.

5.3.3 Actigraph Device

Objective indicators of sleep were measured via the wGT3X-BT device (ActiGraph), which recorded information regarding participants' movements and activity by using a 3-axis MEM accelerometer. Total sleep time and sleep efficiency were calculated via the ActiLife 6 software (provided by ActiGraph), using the Sadeh scoring algorithm with 60-second epoch length (Meltzer et al., 2012). The actigraph used in this study did not have a button by which participants could indicate the exact times that they went to sleep or when they woke up the next morning. Thus, anchors of each sleep episode was determined by participant's subjective sleep diaries; lights off time ("what time did you switch off the lights to sleep?") was used to anchor the beginning of a sleep period, and get out of bedtime ("what time did you get out of bed this morning?") was used to anchor the end of a sleep period. These retrospective assessments were taken each morning.

5.4 Data analyses

The data processing and analysis plan was preregistered on the Open Science Framework on 1st November 2018 (https://osf.io/d6hpf). One exploratory analysis, which was not detailed in the preregistration, was performed on two subgroups of participants with either higher or lower levels of depressive symptoms. Changes made to the analysis plan are described in Appendix B.

5.4.1 Descriptive statistics

Descriptive statistics were calculated for the demographic information and standardized questionnaires recorded at baseline.

5.4.2 Multilevel analyses

Using the 'mixed' package in STATA 16, multilevel models were performed to test whether (a) bedtime social media use predicted sleep indicators the same night, (b) sleep indicators predicted positive and negative affect the following day, and (c) bedtime social media use predicted positive and negative affect the following day. Separate crossed effects models were performed to test each hypothesis, with each predictor allowed to have a random intercept for each person and each day. PA and NA were entered as dependent variables for models testing (b) and (c). Specifically, PA and NA were treated as two separate outcome variables, *i.e.*, were not entered in statistical models together. To test whether sleep indicators mediated the relationship between social media use and affective wellbeing, Akaike Information Criterion values for each statistical model would be calculated and compared with one another.

The total number of possible observations for the entire sample was 8568 (*i.e.*, 84 prompts x 101 participants) of which 7390 valid observations were recorded. For the primary hypotheses, data of only those days were included in the analyses where complete information was available for (i) bedtime social media use the previous night, (ii) all four sleep indicators for the previous night, and (iii) at least one response regarding positive and negative affect the following day (out of the possible five per day). This further reduced the number of observations for analyses to 5383 (73% of available data).

To explore whether bedtime social media use and sleep is more strongly associated to affective wellbeing the following morning than afternoon, the first two affect measurements of each day were classified as 'morning measurements' (*i.e.*, sent to participants before 12 pm) and the third and fourth affect measurements were classified as 'afternoon measurements' (*i.e.*, sent to participants after 12 pm), done separately for PA and NA. This hypothesis was tested using a crossed effects model, where the predictor was allowed to have a random intercept for each person and each day. The time of day (morning and afternoon) was treated as a fixed effect.

Finally, an exploratory analysis was performed with the same multilevel models that were used to test the primary hypotheses with two subgroups, one with participants who had been identified as having increased depressive symptom levels (*i.e.*, scores of 10 or higher) and one with lower depressive symptom levels (*i.e.*, scores of 9 or lower) based on the baseline CESD-10 scores (Andressen et al., 1994).

5.4.3 Data transformation

In order to facilitate interpretation in terms of effect sizes, we z-standardized the predictors (bedtime social media use), mediators (subjective sleep duration, actigraphy based total sleep time, subjective sleep satisfaction and actigraphy based sleep efficiency), and outcome variables (positive affect and negative affect) before analysis.

5.5 Results

5.5.1 Baseline Questionnaires and Experience Sampling items

Descriptive statistics are displayed in Table 5.1.

Table 5.1: Descriptive statistics for sample characteristics, baseline questionnaires and experience sampling questions for the full sample and two subgroups of participants with high and low depressive symptoms based on baseline CESD-10 scores

	Full sample (N = 101)		High levels of depressive symptoms (n = 50)		Low levels of depressive symptoms (n = 51)		Females (n = 66)		Males (n = 35)	
	Mean	SD[1]	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	19.70	1.09	19.63	1.05	19.55	1.14	19.69	0.97	19.40	1.29
Baseline Questionnaires										
Social Integration and Emotional Connection subscale	22.72	6.21	23.5	5.86	21.73	6.66	23.00	5.98	21.86	6.91
Pittsburgh Sleep Quality Index										
Sleep duration subscale	7h 22min	1h 12min	7h 9min	1h 16min	7h 35min	1h 5min	7h 18min	1h 13min	7h 29min	1h 10min
Sleep quality subscale	1.13	0.63	1.36	0.63	0.90	0.54	1.06	0.58	1.26	0.70
Center for the Epidemiologic Studies of Depression Short Form	10.20	5.48	14.59	4.15	5.89	2.18	10.57	5.34	9.50	5.72
Experience Sampling items*										
Social media use in the last hour before sleep (min)[2]	8.68	14.72	10.07	15.27	7.39	13.93	9.03	15.84	7.97	12.08
Subjective sleep duration (min)[2]	466.12	105.79	463.49	109.73	467.87	101.98	469.16	101.46	459.92	113.86
Subjective lights off time[2]	00:54	2h 16min	01:14	2h 28min	00:35	2h 1min	00:40	1h 28 min	01:24	3h 13 min
Subjective wake time[2]	08:30	1h 34min	08:36	2h 7min	08:23	1h 25min	08:29	1h 19min	08:32	2h 22min
Actigraphy measured total sleep time (min)[3]	496.95	111.95	496.52	118.75	496.41	105.28	500.11	105.56	490.53	123.73
Subjective sleep satisfaction[2]	2.83	0.73	2.77	0.74	2.89	0.72	2.80	0.71	2.92	0.77
Sleep efficiency[3]	80.97	9.32	82.40	8.54	79.64	9.66	82.15	9.05	78.57	9.40
Positive affect[4]	2.74	0.82	2.51	0.78	2.93	0.79	2.68	0.78	2.84	0.87
Negative affect[4]	1.63	0.67	1.80	0.70	1.47	0.59	1.74	0.78	1.63	0.77

Note. [1]SD: Standard Deviation
[2] based on single questionnaire that participants' answered each morning regarding information about the previous night;
[3] based on daily actigraphy data;
[4] based on information collected via five random questionnaires sent through the day;
* information collected over 14 consecutive days

5.5.1.1 Baseline Questionnaire

The mean score for the Social Integration and Emotional Connection subscale was 22.72 (*SD* = 6.21; range = 7 – 34; higher scores indicate higher investment).

PSQI scores indicated that participants' subjective sleep duration per night was an average of 7 hours 22 minutes (*SD* = 1h 12min). On average, participants in the study reported good sleep quality (*M* = 1.13, *SD* = 0.63; range = 0 – 3), with 78 participants (77%) reporting either very good (0) or fairly good (1) sleep quality over the previous month.

Results from the CESD-10 revealed that 50 participants (49% of the total sample) experienced increased levels of depressive symptoms, scoring equal to or above the cut-off of 10 (*M* = 10.20, *SD* = 5.48; range = 1 – 27).

5.5.1.2 Social media use, sleep, positive affect and negative affect measured by Experience Sampling

Data collected over the 14 days indicated that on average, participants were spending 9 minutes on social media in the last hour before sleep at night. However, approximately 44% of all responses indicated that participants had not engaged in any bedtime social media use (*i.e.*, zero minutes). Across all observations (*i.e.*, across measurements and participants), subjective sleep duration averaged at around 7 hours and 46 minutes (*SD* = 1h 46min), while actigraphy measured total sleep time was around 8 hours 17 minutes per night (*SD* = 1h 52min). Subjective sleep satisfaction scores averaged 2.83 (*SD* = 0.73, where "1=very dissatisfied" and "4=very satisfied"), while sleep efficiency estimated by the actigraphy was 80.97% (*SD* = 9.32%). Finally, the mean scores of PA and NA across all participants and measurements were *M* = 2.74 (*SD* = 0.82), and 1.70 (*SD* = 0.76), respectively.

5.5.2 Relationship between social media use, sleep, positive and negative affect

Results from the analysis examining the relationships between social media use, sleep, and positive and negative affect, respectively, are displayed in Table 5.2. Based on inspection of Q-Q plots of residual variance, all statistical models met the assumption of normality of residuals.

Multilevel models assessing the primary hypotheses showed that using social media at night before sleep did not predict subjective sleep duration, subjective sleep satisfaction or Actigraphy based sleep efficiency. However, increased use of social media the night before was associated with subsequent increased total sleep time measured with actigraphy (β = 0.05, SE = 0.01, p < .001). When assessing the link between sleep indicators and daily positive affect and negative affect, respectively, results showed that subjective sleep duration, actigraphy measured total sleep time, and sleep efficiency were not significantly associated with either affective state the following day (p > .05). However, higher levels of subjective satisfaction with sleep in the previous night significantly predicted higher levels of positive affect (β = 0.10, SE = 0.02, p < .001) and lower levels of negative affect (β = -0.07, SE = 0.02, p < .001) the following day. Finally, no association between bedtime social media use the night before and either positive or negative affect the following day was found. For this reason, a mediation analysis testing the role of sleep quality indicators in the relationship between social media use and affective wellbeing was not carried out.

Multilevel models were also performed to explore whether bedtime social media use and sleep, respectively, showed an association specifically with affective wellbeing on the following morning or on the following afternoon. Results showed that subjective sleep satisfaction had a positive association with 'morning measurements' of positive affect (*i.e.*, before 12 pm) and a negative association with 'morning measurements' of negative affect while no such associations for 'afternoon measurements' were found (β = 0.07, SE = 0.01, p < .001 and β = -0.04, SE = 0.01, p = .007, respectively). No further associations were found (see Table 5.3).

Table 5.2: Outcome of multilevel mixed models run to test all primary hypotheses for the full sample

	n[1]	Coeff (unstd)[2]	95% CI[3]	*p*	SE[4]
Sleep from social media use [a]					
Subjective sleep duration	5383	.02	-.01, .04	.192	.01
Actigraphy measured total sleep time	5383	.05	.02, .07	.000	.01
Subjective sleep satisfaction	5383	.01	-.02, .04	.525	.01
Sleep efficiency	5383	-.02	-.04, .00	.108	.01
Positive affect from sleep [b]					
Subjective sleep duration	3703	.02	-.02, .05	.315	.02
Actigraphy measured total sleep time	3703	.01	-.03, .04	.632	.02
Subjective sleep satisfaction	3703	.10	.07, .13	.000	.02
Sleep efficiency	3703	-.02	-.06, .01	.187	.02
Negative affect from sleep [b]					
Subjective sleep duration	3706	-.02	-.05, .01	.240	.02
Actigraphy measured total sleep time	3706	-.00	-.03, .03	.978	.02
Subjective sleep satisfaction	3706	-.07	-.11, -.04	.000	.02
Sleep efficiency	3706	.02	-.02, .05	.358	.02
Positive affect from social media use [c]	3703	.02	-.01. .05	.237	.02
Negative affect from social media use [c]	3706	-.00	-.04, .03	.851	.02

Note. [1] number of observations in the model.
[2]Coeff (unstd): unstandardised coefficient.
[3]CI: Confidence Interval.
[4]SE: Standard error.
[a] predicting sleep from social media use before sleep the same night;
[b] predicting affective wellbeing the following day from sleep the previous night;
[c] predicting affective wellbeing the following day from social media use the previous night.

Table 5.3: Outcome of multilevel mixed models run to test whether bedtime social media use and sleep are associated more strongly with affective wellbeing the following morning versus afternoon

	n[1]	Coeff (unstd)[2]	95% CI[3]	*p*	SE[4]
Positive affect in the morning versus afternoon from					
Subjective sleep duration	2939	.00	-.02, .03	.844	.01
Actigraphy measured total sleep time	2939	.01	-.02, .03	.689	.01
Subjective sleep satisfaction	2939	.07	.04, .10	.000	.01
Sleep efficiency	2939	-.03	-.06, -.00	.049	.02
Social media use[a]	2939	.00	-.03, .02	.990	.01
Negative affect in the morning versus afternoon from					
Subjective sleep duration	2941	.01	-.02, .04	.586	.01
Actigraphy measured total sleep time	2941	.01	-.02, .04	.387	.01
Subjective sleep satisfaction	2941	-.04	-.06, -.01	.007	.01
Sleep efficiency	2941	.02	-.01, .04	.321	.02
Social media use[a]	2941	.02	-.02, .04	.413	.01

Note. [1] number of observations in the model; [a] predicting sleep from social media use before sleep the same night.
[2]Coeff (unstd): unstandardised coefficient.
[3]CI: Confidence Interval.
[4]SE: Standard Error.

5.5.3 Sub-group analyses

Exploratory analysis was conducted with two subgroups of participants who either showed increased depressive symptom levels (*i.e.*, who scored 10 or higher on the CESD-10 at baseline; $n = 50$; Females = 36, Males = 14) or lower depressive symptom levels (*i.e.*, who scored 9 or lower on the CESD-10 at baseline; $n = 51$; Females = 30, Males = 21). Analysis followed those used to test the primary hypotheses, and results are displayed in Table 5.4.

For participants with higher levels of depressive symptoms, results showed that bedtime social media use was negatively associated with subjective sleep duration ($\beta = -0.06$, SE = 0.02, $p = .003$). Sleep satisfaction was positively associated with positive affect ($\beta = 0.09$, SE = .02, $p < .001$) and negatively associated with negative affect ($\beta = -0.07$, SE = 0.02, $p = .003$), while actigraphy measured total sleep time was positively associated with negative affect ($\beta = 0.05$, SE = 0.03, $p = .035$) the following day. No association of social media use with positive or negative affect the following day was found.

For participants with lower levels of depressive symptoms, results showed that bedtime social media use was positively associated with subjective sleep duration ($\beta = 0.09$, SE = 0.02, $p < .001$), and actigraphy measured total sleep time ($\beta = 0.12$, SE = 0.02, $p < .001$). Subjective sleep duration, actigraphy measured total sleep time, and subjective sleep satisfaction, were positively associated with positive affect ($\beta = .08$, SE = .03, $p = .002$; $\beta = .06$, SE = .03, $p = .016$; $\beta = .11$, SE = .02, $p < .001$, respectively), but negatively associated with negative affect the following day ($\beta = -0.10$, SE = 0.02, $p < .001$; $\beta = -0.06$, SE = 0.02, $p = .013$, and $\beta = -0.07$, SE = 0.02, $p = .001$, respectively). Similar to the group with higher levels of depressive symptoms, no relationship between bedtime social media use and positive and negative affect the following day was found.

Table 5.4: Outcome from models testing primary hypotheses on a sub-groups of participants identified with high (scoring 10 or higher) and low levels of depressive symptoms based CESD-10 baseline scores

	n[1]	Coeff (unstd)[2]	95% CI[3]	*p*	SE[4]
	Subgroup with high depressive symptoms (*n* = 50)				
Sleep from social media use [a]					
• Subjective sleep duration	2603	-.06	-.10, -.02	.003	.02
• Actigraphy measured total sleep time	2603	-.03	-.07, .01	.094	.02
• Subjective sleep satisfaction	2603	-.02	-.06, .02	.356	.02
• Sleep efficiency	2603	-.02	-.05.01	.251	.02
Positive affect from sleep [b]					
• Subjective sleep duration	1771	-.03	-.08, .01	.129	.02
• Actigraphy measured total sleep time	1771	-.03	-.08, .01	.131	.02
• Subjective sleep satisfaction	1771	.09	.05, .13	.000	.02
• Sleep efficiency	1771	-.00	-.06, .05	.890	.03
Negative affect from sleep [b]					
• Subjective sleep duration	1772	.04	-.01, .09	.084	.03
• Actigraphy measured total sleep time	1772	.05	.00, .11	.035	.03
• Subjective sleep satisfaction	1772	-.07	-.12, -.03	.003	.02
• Sleep efficiency	1772	.02	-.05, .08	.628	.03
Positive affect from social media use [c]	1771	.03	-.01, .07	.166	.02
Negative affect from social media use [c]	1772	.01	-.04, .05	.830	.02
	Subgroup with low depressive symptoms (*n* = 51)				
Sleep from social media use [a]					
• Subjective sleep duration	2780	.09	.05, .12	.000	.02
• Actigraphy measured total sleep time	2780	.12	.08, .15	.000	.02
• Subjective sleep satisfaction	2780	.03	-.00, .07	.086	.02
• Sleep efficiency	2780	-.03	-.06, .01	.134	.02
Positive affect from sleep [b]					
• Subjective sleep duration	1932	.08	.03, .13	.002	.03
• Actigraphy measured total sleep time	1932	.06	.01, .11	.016	.03

	n[1]	Coeff (unstd)[2]	95% CI[3]	*p*	SE[4]
• Subjective sleep satisfaction	1932	.11	.07, .16	.000	.02
• Sleep efficiency	1932	-.03	-.08, .01	.142	.02
Negative affect from sleep [b]					
• Subjective sleep duration	1934	-.10	-.13, -.04	.000	.02
• Actigraphy measured total sleep time	1934	-.06	-.10, -.01	.013	.02
• Subjective sleep satisfaction	1934	-.07	-.11, -.03	.001	.02
• Sleep efficiency	1934	.01	-.03, .05	.599	.02
Positive affect from social media use [c]	1932	.01	-.04, .06	.716	.03
Negative affect from social media use [c]	1934	-.01	-.06, .04	.702	.02

Note: [1] number of observations in the model.
[2]Coeff (unstd): unstandardised coefficient.
[3]CI: Confidence Interval.
[4]SE: Standard Error.
[a] predicting sleep from social media use before sleep the same night.
[b] predicting affective wellbeing the following day from sleep the previous night.
[c] predicting affective wellbeing the following day from social media use the previous night.

5.6 Discussion

Contrary to our primary hypotheses, bedtime social media use did not predict subjective sleep duration, sleep satisfaction, or sleep efficiency, while predicting longer objective total sleep time. Higher subjective sleep satisfaction was positively associated with positive affect and negatively associated with negative affect the following day, particularly when affect was measured in the morning. The sizes of these effects, however, were small. No other sleep indicator was associated with either positive affect or negative affect the following day. Finally, social media use before sleep did not predict positive or negative affect the following day.

Our findings are contrary to previous studies in the field that have reported associations between increased bedtime social media use and poorer affective and mental wellbeing (Burke et al., 2010; Lin et al., 2016; Primack et al., 2017; Sagioglou & Greitemeyer, 2014), and between social media use and poor sleep (Lemola et al., 2015; Levenson et al., 2017; Scott et al., 2019). Important distinctions between our study and previous research might account for these dissimilarities. First, findings reported in the literature are largely based on cross-sectional studies, and therefore the direction of the relationship between social media use and affect remains unclear. It is also possible that a potential third variable is confounding the relationship between social media use and poor affective and mental wellbeing. By employing an experience sampling methodology, we were able to disentangle the day-to-day temporal associations between bedtime social media use, subsequent sleep, and mood the following day by accounting for within-individual change in these variables.

Second, a majority of studies in the field have been conducted on children and adolescents, with a focus on general media use on sleep and mental health (Chahal et al., 2013; Li et al., 2007; Van den Bulck, 2004). Findings from our study echo those who have examined these relationships specifically among older adolescents and young adults, suggesting no association between social or general media use and sleep or mental health (Berryman et al., 2018; Jelenchick et al., 2013). Tavernier and Willoughby (2014) found that in young adults, sleep problems preceded bedtime media use and not vice versa. Unlike adolescents' and children who have earlier rise times on weekdays dictated by early school start times, university students are afforded more flexible rise times due to class schedules that often have later start times. Since attendance to lectures is non-mandatory, this also provides university students with the option to skip classes if those begin early in the morning. Consequently, university students may not be restricted to specific bedtimes, or may simply compensate for later bedtimes by waking up later the next morning. In our study, participants indicated on average a bedtime of 01:00 am, and a wake-up time of 08:30 am and their average subjective sleep was within the recommended range of sleep duration for their age group (7-9 hours for 18-25 year olds; National Sleep Foundation, 2015), suggesting that participants were able to obtain, on average, a sufficient number of hours of sleep.

Our study focussed on bedtime social media use and not general electronic media use, suggesting perhaps that social media use alone may not be as detrimental as previously considered (Chahal et al., 2013; Lemola et al., 2015). However, it is important to note that participants in our study were not excessive users of social media at bedtime. The average social media use in the last hour before sleep across the 14-day study period was approximately nine minutes, with zero minutes use being indicated in 44% of all observations.

To assess whether bedtime social media use would differentially impact participants based on degree of vulnerability, we conducted a subgroup analysis comparing individuals with lower and higher levels of depressive symptoms, reported at baseline. We found that in participants with higher levels of depressive symptoms, bedtime social media use was negatively associated with subjective sleep duration; the size of this effect, however, was small. Our results are consistent with the notion that bedtime social media use can have a stronger negative impact on sleep in individuals who are more vulnerable to stress and depressive symptoms. Shorter sleep has been found to be a risk factor in experiencing depressive symptoms for adolescents and young adults (Steptoe et al., 2006; Zhai et al., 2015; Pasch, 2010). Zhai et al. (2015) suggested that this might be due to an increase in feelings of daytime tiredness, which can, in turn, be predictive of experiencing negative emotions and further increase depressive feelings. However, our results did not show an association between bedtime social media use and positive and negative affect the following day in the subgroup analysis, suggesting that bedtime social media use does not negatively affect the affective wellbeing of vulnerable individuals.

Finally, for individuals with lower levels of depressive symptoms, we found that shorter objective sleep (as measured by actigraphs) was associated with higher levels of negative affect the following day. This aligns with findings from previous studies, for example Wrzus et al. (2014) reported poorer affective wellbeing when subjective sleep was shorter the previous night in a sample of non-clinical adolescents and young adults. We identified an opposite pattern in individuals with increased levels of depressive symptoms, whereby longer objective sleep was associated with higher levels of negative affect the following day. While there is previous research that links longer sleep with depressed mood (e.g., Zhai et al., 2015), the underlying reasons for the reversed effect for participants with higher levels of depressive symptoms observed in our study remains unclear.

5.6.1 Limitations and Future Research

This study is not without limitations. First, the retrospective subjective assessment of bedtime social media use on the following day may have led to underestimations of actual social media use. While we tried to mitigate this limitation by requesting participants to respond to the questions as soon as they woke up the next morning, future studies could make use of unobtrusively obtained objective assessments (e.g., using smartphone technology that records social media use). However, obstacles to accessing objective recordings of social media use include strict privacy legislation discouraging companies from sharing such data with researchers, but also that individuals access social media via multiple electronic devices such as smartphones, tablets or computers, which would require synchronically monitoring of various social media platforms. Second, the actigraphy devices used in our study did not allow participants to indicate the beginning and end of each sleep spell via button press, which may have affected the efficiency of the device in measuring accurate sleep anchors. We addressed this concern by using information from participants' subjective sleep diaries filled in the next day to anchor the beginning and end of each sleep episode, which may be subject to memory distortions. Third, the participants of the study were self-selected, and it is not clear whether they were representative of university students. To address this limitation, our sample was recruited across several academic departments and across different cohorts. However, the number of participants reporting levels of high depressive symptoms was greater than would be expected (*i.e.*, 49% in the current study versus around 21% in young adults aged between 16-24 years, Office of National Statistics, 2019), which could be an effect of self-selection into the study. Fourth, due to the observational study design it was not possible to infer causality. For instance, findings of the subgroup analysis that participants with increased depressive symptom levels show an association between pre-sleep social media use and subsequent sleep which could involve both effects of social media use on sleep as well as effects of difficulties falling asleep on the propensity to use social media. Finally, some studies have suggested that different types of social media may yield differential impacts on wellbeing. For instance, passive consumption of social media (*e.g.*, browsing content) has a more negative impact on mental and affective wellbeing than actively using social media (*e.g.*, sharing content; Thorisdottir et al., 2019; Verduyn et al., 2015). We did not record these differences, and future research might examine the role of different types of social media use.

5.7 Conclusion

Our study provides evidence that bedtime social media use may not be as detrimental to the sleep and affective wellbeing of young adults as previously thought. While vulnerable young adults with increased levels of depressive symptoms might be at higher risk of experiencing a negative impact of bedtime social media use on subsequent sleep, their affective wellbeing the following day remained unaffected.

Chapter 6
Effects of a 20 minutes delay in school start time on bed and wake up times, daytime tiredness, behavioural persistence, and positive attitude towards life in adolescents

Preliminary evidence suggests that delaying school start times is an effective tool for improving adolescent sleep duration. Our study assessed whether a policy driven 20-minute delay in school start times led to an increase in adolescents' weekday bed and wake up times. Data collected via school satisfaction surveys concerned 663 students (45.2% females, Mean age: 14.91 years, SD = .58 years) in three lower-track secondary schools in Switzerland. Of all the students, 249 experienced a policy-driven 20-minutes school start time change (SSTc), from 7:40 am to 8:00 am between the 8th and 9th grade, while 414 students did not (Comparison Group/CG$_{SSTc}$). Students filled out the survey twice, at the end of their 8th and 9th grades, respectively, and reported their weekday bed and wake up times, daytime tiredness, behavioural persistence, and positive attitude towards life. Generalized estimating equations models of bed and wake up times showed that there was a significant delay in both the bed and wake up times of the students in the SSTc group. Multilevel analyses revealed that students in the SSTc group did not significantly differ from CG students in daytime tiredness, behavioural persistence, and positive attitude towards life. Findings suggest that not only wake up times but also bedtimes may shift later when school start times are delayed. The 20 minutes delay in school start times may have been too slight to have an impact on daytime tiredness, behavioural persistence and positive attitude towards life.

6.1 Introduction

Chronic sleep reduction can have detrimental effects on the lives of adolescents, with evidence linking it to decreased mental and physical alertness, increased feelings of anxiety, depression and hopelessness, poor academic performance, and obesity, among others (Dewald et al., 2010; Minges & Redeker, 2016; Paruthi et al., 2016; Perkinson-Gloor et al., 2013; Wahlstrom et al., 2017). These findings become paramount considering that adolescents experience difficulty in maintaining schedules meeting their recommended 8 to 10 hours of sleep per night (Hirshkowitz et al., 2015; Morgenthaler et al., 2016; Short et al., 2018). Apart from psychosocial and behavioural factors such as increased academic stress and evening leisure-time use of electronic devices (Lemola et al., 2015), there is evidence that biological changes associated with puberty contribute to a shift in adolescents' circadian clock, characterized by a delay in dim light melatonin onset and offset (Crowley et al., 2007; Roenneberg et al., 2004). This delay results in a preference for later sleep and awakening times, earning adolescents' the tag of 'evening owls' (Gradisar et al., 2011; Hershner & Chervin, 2014). The circadian phase delay becomes more pronounced for older adolescents, peaking at about 20 years of age (Roenneberg et al., 2004). The mismatch between adolescents' sleeping habits and for instance, early weekday school start times results in a large proportion of adolescents experiencing chronic sleep deprivation (Bowers & Moyer, 2017; Hysing et al., 2015; N. F. Watson et al., 2017).

There is preliminary evidence that adolescents' chronic sleep reduction could be improved by delaying school start times. Delaying school start times is associated with longer sleep duration in the morning while evening bedtimes often remain unchanged resulting in increased total sleep time on weekdays, and leading to less daytime sleepiness, decreased tardiness, and less depressive feelings (Boergers et al., 2014; Minges & Redeker, 2016; Owens, 2014; Perkinson-Gloor et al., 2013; Wahlstrom, 2002; Wolfson et al., 2007). However, a recent Cochrane Systematic Review and meta-analysis (Marx et al., 2017) summarizing all the relevant available evidence concluded that despite promising findings, there is lack of robust and conclusive evidence to support policy changes to delay school start times to improve sleep in adolescence. A major hurdle identified in the review is that all the summarized studies either lacked a controlled design or there was no random assignment of schools or school classes to the intervention or control groups.

The lack of robust evidence is mainly explained by challenges associated with implementing randomised controlled experimental studies within school systems where several stakeholders including students, parents, teachers, and employees in peripheral services (*e.g.*, transportation service employees) are affected (Lee et al., 2017; Marx et al., 2017; Morgenthaler et al., 2016; Wahlstrom et al., 2017). Even when legal obstacles are overcome, the implementation of delayed start time interventions often fails due to parents' and teachers' opposition to longer school days (Marx et al., 2017) or due to concerns of the broader society outside school, such as sports and arts classes facilitators (Wahlstrom, 2002). Recently, the Oxford Teensleep study illustrated the challenges related to recruiting schools into a randomised controlled study involving school start time change. The project that attempted randomising 100 schools in the United Kingdom either to a delayed start time at 10 a.m. condition or start time as usual at 9 a.m. condition was able to recruit only two schools in total. This was despite extensive advertising efforts, positive media coverage, availability of financial incentives of £1,000 per participating school, direct contact with 400 state secondary schools in England and Wales and e-mail contact with in total 3,985 schools (Illingworth et al., 2018).

6.1.1 The current study

In a study exploring the cross-sectional differences between one school that started at 08:00 and five schools that started at 07:40, during the years 2010 and 2011, in Basel, Switzerland, Perkinson-Gloor et. al. (2013) found that students in the school with later start times reported longer sleep duration by 16 minutes and less daytime tiredness, which were driven by later wake times and nearly unchanged bedtimes. These findings provided preliminary evidence that a delay in school start times by merely 20 minutes may already be an effective measure for improving chronic sleep deprivation and daytime tiredness among adolescents. However, due to the cross-sectional design of the study, these findings must be considered as only tentative. The current study attempts to overcome this limitation by evaluating a policy decision taken in 2013 to delay school start times by 20 minutes (from 07:40 to 08:00) in state schools in the city of Basel. Data taken twice a year apart (*i.e.*, before and after school start time change) is available for one school that delayed school start times with effect on 1 August 2014 and from two schools that delayed school start times with effect on 1 August 2015. Data from previous year-cohorts of the same schools were used as the comparison group.

Based on existing evidence (Boergers et al., 2014; Minges & Redeker, 2016; Owens, 2014; Perkinson-Gloor et al., 2013; Wahlstrom, 2002; Wolfson et al., 2007) and in line with the notion that during adolescence, circadian preference shifts later (Crowley et al., 2007; Gradisar et al., 2011; Hershner & Chervin, 2014; Roenneberg et al., 2004), as our primary hypothesis, we expect that weekday wake up times were delayed among students in the school start time change condition relative to the comparison condition while bedtimes remained the same. As secondary hypotheses, we expect an increase in the length of the time window when sleep can occur on weekdays (*i.e.*, the estimated time spent in bed), improvements in psychosocial adjustment including daytime tiredness, behavioural persistence, and positive attitude towards life in association with the delayed school start time relative to the comparison group.

6.2 Materials & Methods

6.2.1 Data source

Data are from 8th-grade and 9th-grade classes from three lower-track secondary schools in Basel, the so-called "Weiterbildungsschulen". At the time of data collection, in the school system of the City of Basel, Weiterbildungsschulen included around half of all 8th and 9th grade students of the City's population while the other half of the population attended the Gymnasium (*i.e.*, the higher track secondary school). Students entered the Weiterbildungsschulen, when they came into the 8th-grade and left after they completed the 9th-grade. Data were collected at the end of every school year, in June, as part of the student school satisfaction survey that aims to provide teachers and schools managers with feedback. Students filled in the feedback questionnaire on-line, during school lessons. The questionnaire also included questions on bedtimes and wake times, daytime tiredness, behavioural persistence, and positive attitude towards life. The researchers were allowed access to anonymised survey data to analyse and report yearly student satisfaction rates and sleep behaviour.

The design of the study is shown in Figure 6.1. Consecutive student satisfaction survey data from three schools are available for school years: 2012/13; 2013/14; 2014/15; and 2015/16. Only data on students who completed the survey twice (*i.e.*, when they were 8th-graders and 9th-graders) were analysed. Hence, the analyses involve data from three consecutive cohorts; 1st cohort: Aug 2012-June 2014; 2nd cohort: Aug 2013-June 2015; 3rd cohort: Aug 2014-June 2016. Across all three schools in Cohort 1, students started lessons at 07:40 at both time points (n = 275; k = 23 school classes). In Cohort 2, students in two schools started at 07:40 at both time points (n = 139; k = 14 school classes), while students in the third school started at 07:40 at the first time point, but at 08:00 at the second time point (n = 61; k = 4 school classes). Finally, in Cohort 3, students in the first two schools started their program at 7.40 am at the first time point, but at 08:00 at the second time point (n = 188; *k* = 15 school classes). Thus, a total of 249 students (clustered within 19 school classes) experienced a change in school start time between their 8th grade and 9th grade and are treated as the School Start Time Change Group (SSTc), whereas 414 students (clustered within 37 school classes) did not experience any change in school start time and are treated as the Comparison Group (CG_{SSTc}). For students in the SSTc group, the number of school lessons or the end of school in the evening did not shift to a later time, but they had shorter lunch breaks. Across the whole study period, the latest school end time was consistently at 17:00. For all students, the school week included 34 school lessons lasting 45 minutes each. The study involving an analysis of the student feedback survey data was approved by the Humanities and Social Sciences Research Ethics Sub-Committee of the University of Warwick (159/17-18).

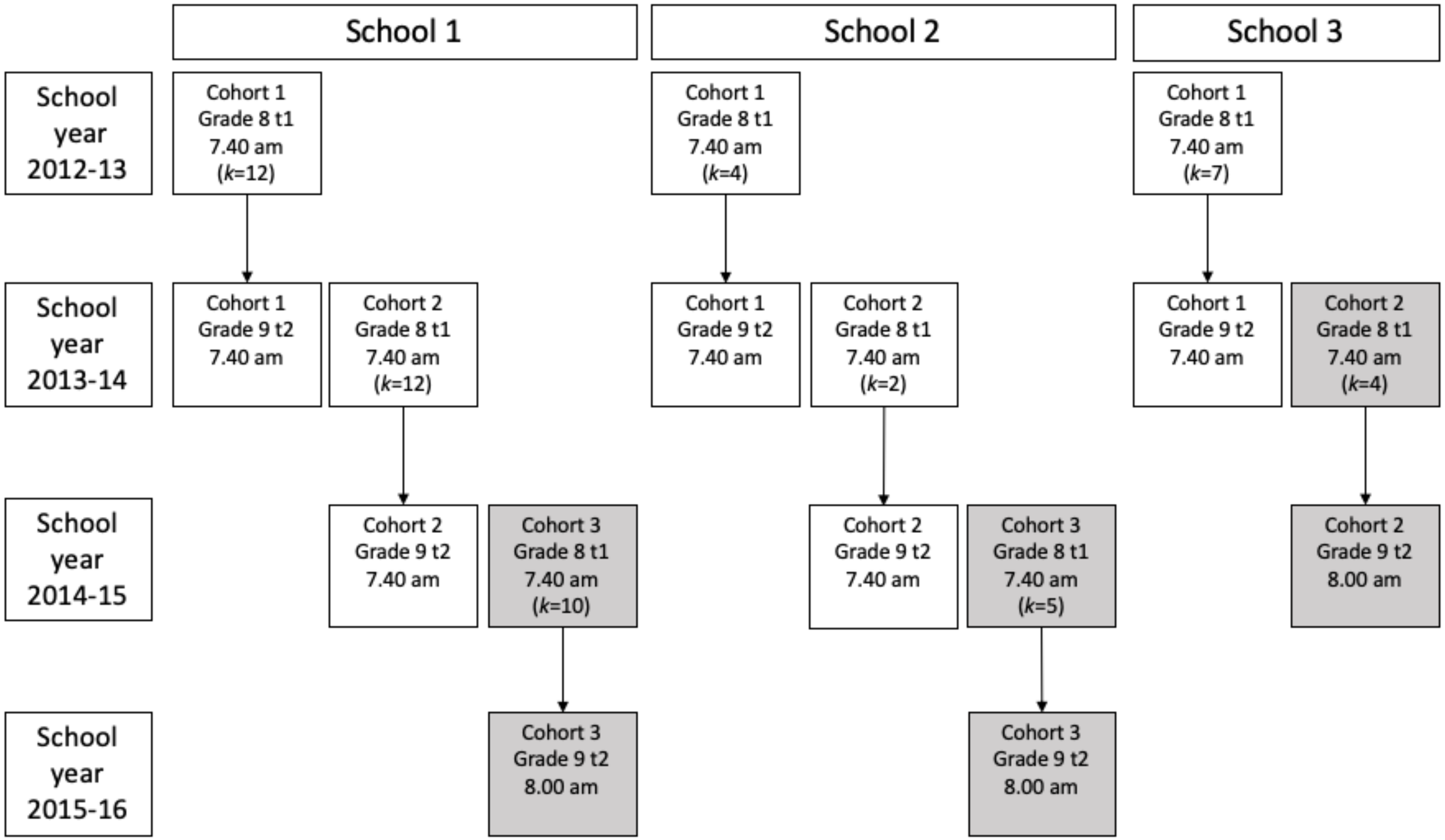

Figure 6.1: Study design. The school start time change group experiencing school start time change between the 8th and 9th grade is denoted with grey shade; k denotes the number of school classes per cohort and school. In School 1 and School 2 the school start time was changed at the beginning of school year 2015-16; in School 3 the school start time was changed at the beginning of school year 2014-15.

6.2.2 Sample characteristics

Student characteristics are shown in Table 6.1. In total, there were 300 females (45.2%), the average age of the sample was 14.91 years (*SD* = .58 years) at the end of the 8th grade (t1). Around two thirds of the sample reported that German was not their first language (67.6%), with Albanian (10.9%), Turkish (9.4%), Serbian/Croatian/Bosnian (8.3%), Portuguese (5.7%), Italian (5.4%), and Kurdish (5.0%) being the most frequent first languages after German. This indicates the high number of students with non-German migration family background in lower track secondary schools in Switzerland, which is often associated with lower socioeconomic background compared to the average Swiss family or migrant families from Germany (Swiss Federal Office of Statistics, 2011). It is also common for adolescents of migrant origin to attend lower track secondary schools. However, students in these schools are required to be fluent in German, and therefore participants were able to successfully complete the questionnaire.

6.2.3 Measures

Bedtimes, wake up times, and estimated time spent in bed on weekdays. For school day bedtimes (Monday-Thursday), students could select an option from the following categories: “before 9:30 pm”, “9:30–9:59 pm”, “10–10:29 pm”, “10:30–10:59 pm”, “11–11:29 pm” and “after 11:30 pm”. Similarly, the categories for wake time on school days (Monday-Friday) were “before 6 am”, “6–6:29 am”, “6:30–6:59 am’ and “7 am or later”. Further, for secondary analyses the estimated time spent in bed on weekdays was inferred based on the answers to these two items, i.e., the time when sleep could occur based on estimated bedtimes and wake up times. In detail, the bedtime category “before 9:30 pm” was represented with an estimated bedtime of 9:15 pm, the category “9:30–9:59 pm” with an estimated bedtime of 9:45 pm, the category “10–10:29 pm” with an estimated bedtime of 10:15 pm, the category “10:30–10:59 pm” with an estimated bedtime of 10:45 pm, the category “11–11:29 pm” with an estimated bedtime of 11:15 pm, and the final category “after 11:30 pm” with an estimated bedtime of 11:45 pm. Similarly, the wake up time category on school days of “before 6 am”: was represented with an estimated wake up time of 5:45 am, the category of “6–6:29 am” with an estimated wake up time of 6:15 am, the category of “6:30–6:59 am” with an estimated wake up time of 6:45 am, and finally, the wake up time category of “7 am or later” with an estimated wake up time of 7:15 am. The estimated time spent in bed on weekdays was inferred by taking the difference between the estimated wake up time and the estimated bedtime. For example, for a student who reported bedtime as “10–10:29 pm and wake time as “6–6:29 am”*,* the estimated time spent in bed on weekdays was 8 hours, resulting from the difference between 10:15 pm and 6:15 am.

Daytime tiredness was assessed with two items (“At school I am often so tired that I almost fall asleep”, and “Recently, I have often been tired and sleepy all day”*)* with a 6-point Likert-type scale (“1=don’t agree at all” and “6=completely agree”*).* Internal consistency was high (school year 1: α = .81; school year 2: α = .81). Stability between school year 1 and school year 2 was r (663) = .43, $p < .001$. Higher mean scores reflected greater daytime tiredness.

Behavioural persistence was measured with four items from the Description of School Environment Scale focusing on the perceived achievement pressure (*e.g.*, “I often quit when I am facing the first difficulty) (Fend & Prester, 1986) with a 6-point Likert-type scale (“1=don’t agree at all” and “6=completely agree”) (school year 1: α = .74; school year 2: α =.72). Stability between school years 1 and 2 was r (663) = .41, $p < .001$. The scale was recoded so that higher mean scores indicate higher behavioural persistence.

Positive attitude toward life was measured with two items from the Berne Questionnaire on Adolescent Subjective Well-being (e.g. “I am satisfied with how my life plans are getting fulfilled” and “My future looks good”) (Grob et al., 1996) with answers ranging on a 6-point Likert-type scale (“1=don’t agree at all” and “6=completely agree”) (school year 1: α = .68; school year 1: α = .78). Stability between school years 1 and 2 was r (663) = .38, $p < .001$. Higher mean scores indicated increased positive attitude towards life.

6.2.4 Statistical analysis

Preliminary analyses involved a baseline comparison between SSTc group and CG_{SSTc} for outcome variables (Mann-Whitney U-tests for ordinal outcome variables and independent samples t-tests for continuous outcome variables) and for students’ age (independent samples t-test), gender, and mother tongue (chi-square tests). Furthermore, associations of outcome variables at baseline with age (Spearman’s rank correlations for ordinal outcome variables and Pearson’s correlations for continuous outcome variables), gender, and mother tongue (Mann-Whitney U-tests for ordinal outcome variables and independent samples t-tests for continuous outcome variables) were tested.

Primary analyses involved generalised estimating equations (GEE) using ordinal logistic models for comparisons of changes in wake up times and bedtimes between the two groups controlling for gender, age and mother tongue.

Further, as secondary analyses, effects of SSTc on the estimated time spent in bed, daytime tiredness, behavioural persistence, and positive attitude towards life were analysed. These analyses involved multilevel models to account for the nested nature of the data, with students clustered within school classes in either the SSTc group or CG_{SSTc}. The multilevel models assessed the effect of the change in school start time on the outcome variables by treating group and time as independent variables, and participant and school class as random factors, controlling again for gender, age and mother tongue. An interaction term of Group*Time was also included in each model. A separate model was computed for each outcome variable. The preliminary and primary analyses were conducted using SPSS® version 24 (IBM Corporation, Armonk NY, USA). Multilevel analysis was implemented using the xtset and xtmixed STATA (version 15) statistical software.

6.3 Results

6.3.1 Preliminary analyses

Baseline differences between the CG_{SSTc} and SSTc students are shown in Table 6.1. Baseline group comparisons revealed older age ($t(661) = 3.21$, $p < .001$, $d = 0.26$), earlier weekday wake time (Mann-Whitney *U-test*, $Z= –2.55$, $p = .011$), and a shorter estimated time spent in bed on weekdays ($t(661) = -2.14$, $p = .03$, $d = 0.18$) in CG_{SSTc} versus SSTc students. No other differences between the SSTc and CG_{SSTc} students were found at baseline.

Further, associations of age, gender, and mother tongue with study variables at baseline were tested. Students' age at baseline was significantly correlated with later weekday bedtimes ($r = 0.13$, $p = .001$), the estimated time spent in bed on weekdays ($r = –0.15$, $p < .001$), and behavioural persistence ($r = 0.11$, $p < .005$), but not with weekday wake times, daytime tiredness, and positive attitude towards life. Compared to boys, girls had earlier wake times (Mann-Whitney *U-test*, $Z= –6.30$, $p < .001$) while there were no significant gender differences regarding bedtimes, estimated time spent in bed, daytime tiredness, behavioural persistence, and positive attitude towards life.

No significant associations of German as mother tongue was observed with bedtimes and wake times, estimated time spent in bed, behavioural persistence, daytime tiredness, and positive attitude towards life.

6.3.2 Effects of school start time change

Generalised estimating equations with ordinal probit distribution were fitted showing a significant delay in both bedtimes (*B* = 0.34, CI = 0.08, 0.61; Wald Chi-Square (1) = 6.389, *p* <. 011) and wake up times (*B* = 0.43, CI = 0.12, 0.74; Wald Chi-Square (1) = 7.420, *p* < .006) among students in the SSTc group.

Tests of secondary hypotheses applying multilevel models showed no significant effect of delayed school start time on the estimated time spent in bed on weekdays (β = -0.07, SE = 0.07, *p* = .308) indicating that the delay of weekday bedtimes among students in the SSTc group between 8^{th} and 9^{th} grade compared to the CG_{SSTc} students may have cancelled out their delay in wake times (Table 6.2). On average, students with a delay in school start time had later estimated bedtimes by 25 minutes and later estimated wake up times by 18 minutes, in 9^{th} grade compared to when they were in the 8^{th} grade. Students with continuous early start times in both years had on average 15 minutes later estimated bedtimes and 10 minutes later estimated wake up times in 9^{th} grade compared to the 8^{th} grade (see Table 6.2). Further, multilevel models showed no significant effects of SSTc on daytime tiredness (β = 0.14, SE = 0.13, *p* = .266), behavioural persistence (β = 0.12, SE = 0.09, *p* = .182), and positive attitude towards life (β = -0.17, SE = 0.09, *p* = .070).

Table 6.1: Descriptive statistics with sensitivity analyses across group and time for sample characteristics and all measures

	School Start Time Change Group (n = 249)				Comparison Group (n = 414)				Group	Time	Group×Time
	t1		t2		t1		t2				
	Mean N	SD[5] %	Mean N	SD %	Mean N	SD %	Mean N	SD %	*p*	*p*	*p*
Age (years)[1]	14.82	0.54			14.97	0.60			.001	-	-
Females	104	41.8			196	47.3			-	-	.171
Native language (% German)[2]	74	29.7			141	34.1			-	-	.266
Total sleep duration (h)[3]	8h38min	52mins	8h30min	50min	8h35min	50min	8h31min	46min	.771	<.01	.397
Sleep duration school nights (h)[3]	8h10min	52min	8h2min	54min	8h1min	51min	7h58min	49min	.061	<.01	.303
Bedtime school nights[4]	10:18 pm	43min	10:43 pm	49min	10:20 pm	47min	10:35 pm	47min	.332	<.001	<.05
Before 9.30 pm	22	8.8	10	4.0	40	9.7	26	6.3	-	-	-
9.30-9.59 pm	62	24.9	36	14.5	97	23.4	59	14.3	-	-	-
10.00-10.29 pm	79	31.7	66	26.5	134	32.4	124	30.0	-	-	-
10.30-10.59 pm	49	19.7	49	19.7	69	16.7	91	22.0	-	-	-
11.00-11.29 pm	23	9.2	41	16.5	38	9.2	64	15.5	-	-	-
After 11.30 pm	14	5.6	47	18.9	36	8.7	50	12.1	-	-	-
Rise time school days[4]	6:28 am	32min	6:46 am	37min	6:22 am	33min	6:32 am	32min	<.001	<.001	<.01
Before 6.00 am	36	14.5	23	9.2	84	20.3	48	11.6	-	-	-
6.00-6.29 am	86	34.5	55	22.1	156	37.7	139	33.6	-	-	-
6.30-6.59 am	102	41.0	94	37.8	145	35.0	172	41.5	-	-	-
7.00 am or later	25	10.0	77	30.9	29	7.0	55	13.3	-	-	-
Sleep duration weekends (h)[3]	9h47min	1h30min	9h39min	1h19min	10h00min	1h29mi.	9h53min	1h20min	<.05	<.05	.890
Bedtime weekends[4]	0:28 am	1h25min	0:40 am	1h19min	0:28 am	1h25mi.	0:40 am	1h19min	.683	<.001	.061
Before 10.00 pm	8	3.2	6	2.4	14	3.4	9	2.2	-	-	-
10.00-10.59 pm	29	11.6	20	8.0	56	13.5	39	9.4	-	-	-
11.00-11.59 pm	68	27.3	51	20.5	94	22.7	88	21.3	-	-	-
0.00-0.59 am	49	19.7	54	21.7	90	21.7	88	21.3	-	-	-
1.00-2.00 am	61	24.5	54	21.7	86	20.8	116	28.0	-	-	-
After 2.00 am	34	13.7	64	25.7	74	17.9	74	17.9	-	-	-

	School Start Time Change Group (n = 249)				Comparison Group (n = 414)				Group	Time	Group×Time
	t1		t2		t1		t2				
	Mean N	SD[5] %	Mean N	SD %	Mean N	SD %	Mean N	SD %	*p*	*p*	*p*
Rise time weekends [4]	10:28 am	1h16min	10:33 am	1h18min	10:28 am	1h25mi.	10:33 am	1h18min	.056	<.001	.054
Before 8.00 am	9	3.6	14	5.6	14	3.4	11	2.7	-	-	-
8.00-8.59 am	33	13.3	25	10.0	34	8.2	40	9.7	-	-	-
9.00-9.59 am	72	28.9	49	19.7	99	23.9	95	22.9	-	-	-
10.00-10.59 am	68	27.3	69	27.7	123	29.7	98	23.7	-	-	-
11.00-12.00 am	43	17.3	56	22.5	94	22.7	110	26.6	-	-	-
After 12.00 am	24	9.6	36	14.5	50	12.1	60	14.5	-	-	-
Daytime tiredness [3]	3.30	1.42	3.56	1.51	3.20	1.47	3.32	1.54	.086	<.01	.266
Behavioural persistence [3]	3.28	1.04	3.19	1.09	3.40	1.01	3.20	1.00	.740	<.01	.184
Positive attitude toward life [3]	4.81	.89	4.53	1.24	4.77	.86	4.66	1.11	.530	<.001	.069

Note. [1] Independent samples t-test.
[2] Chi-Square test.
[3] Repeated measures ANOVA.
[4] Generalised estimating equations using ordinal logistic models.
[5]SD: Standard deviation

Table 6.2: Outcome variables are shown as a function of group and time. Models were built to compare the School Start Time Change and Comparison Groups over time, controlling for the clustering of the data

	Group				Time			Group × Time			ICC[3] (SE[4])
Variables	n[1]	β	CI[2]	*p*	β	CI	*p*	β	CI	*p*	
Weekday sleep duration	1326	0.12	-0.02, 0.26	.095	-.06	-0.14, 0.02	.162	-0.07	-0.21, 0.07	.308	0.47 (.03)
Weekend sleep duration	1326	-0.20	-0.45, 0.05	.110	-0.12	-0.26, 0.03	.108	-0.02	-0.25, 0.22	.879	0.44 (.03)
Total week sleep duration	1326	0.03	-0.11, 0.16	.674	-0.08	-0.16, 0.00	.060	-0.06	-0.19, 0.07	.397	0.48 (.03)
Weekday bedtime	1326	-0.03	-0.16, 0.10	.667	0.23	0.17, 0.31	.000	0.18	0.07, 0.29	.002	0.56 (.03)
Weekday wake up time	1326	0.09	-0.01, 0.20	.067	0.18	0.12, 0.23	.000	0.11	0.02, 0.20	.013	0.48 (.03)
Weekend bedtime	1326	-0.06	-0.31, 0.18	.614	0.21	0.09, 0.33	.001	0.17	-0.02, 0.37	.081	0.58 (.03)
Weekend wake up time	1326	-0.27	-0.51, -0.02	.032	0.09	-0.03, 0.21	.129	0.16	-0.04, 0.35	.110	0.56 (.03)
Behavioural persistence	1326	-0.13	-0.33, 0.09	.242	-0.20	-0.31, -0.09	.000	0.12	-0.34, 0.29	.182	.41 (.03)
Positive attitude towards life	1326	0.05	-0.16, 0.27	.634	-0.11	-0.22, -0.00	.046	-0.17	-0.35, 0.01	.070	0.37 (.03)
Daytime tiredness	1326	0.11	-0.16, 0.38	.416	0.12	-0.04, 0.27	.137	0.14	-0.11, 0.39	.266	0.43 (.03)

Note. Models were built adjusting for sex, age and mother tongue. Sex, age, mother tongue and constant values are not displayed in the table.
[1] number of data points in the model; there were 2 data points per participant (baseline and follow-up).
[2]CI: Confidence Interval.
[3]ICC: Intracluster correlation coefficient.
[4]SE: Standard error.

6.4 Discussion

Our study evaluated the effect of delaying school start times from 07:40 to 08:00 on adolescents' bed and wake up times on weekdays, across three schools compared to a comparison group drawn from previous year-group cohorts of the same schools with continued school start times at 07:40. Results showed that the 20 minutes delay intervention associated with a significant delay in both bed and wake up times, while no effects were observed on the estimated time spent in bed, daytime tiredness, behavioural persistence or positive attitude towards life.

In contrast to an earlier cross-sectional study (Perkinson-Gloor et al., 2013) that showed that 20 minutes of delay in school start time was associated with longer weekday sleep duration, less daytime tiredness, later wake up times but unchanged bedtimes, our current findings suggest that although a delay in school start times allowed students to get up later, that shift might be cancelled out by concurrent delayed bedtimes. Moreover, no differences were observed regarding the reported daytime tiredness. This suggests that a SSTc of 20 minutes might be effective in delaying overall sleeping patterns among students, but it may be too short a delay to result in changes in sleep related secondary outcomes and particularly daytime tiredness, behavioural persistence and positive attitude towards life. However, a key difference in the methods and subsequent analyses between the previous and current study could explain why results differ. Due to the cross-sectional comparison between early (data of five schools) and delayed (data of one school) start times, within-person changes could not be evaluated in Perkinson-Gloor et al.'s (2013) study. In the same vein, data of only three schools were included in the current study due to unavailability of follow-up data i.e. before and after the implementation of the delayed start times in the three other schools.

Previous studies showing a positive impact of delaying school start times on sleep duration and mental wellbeing indicators investigated longer delays of often one hour or more (Minges & Redeker, 2016; Owens et al., 2010; Wolfson et al., 2007), except for studies, for instance, by Owen et al. (2010) and Boergers, Gable and Owens (2014). Owen et al. (2010) showed that a modest delay of 30 minutes in school start time (from 08:00 to 08:30) resulted in increased sleep duration, and decreased daytime sleepiness, depressed mood and fatigue. Moreover, Boergers et al. (2014) observed similar encouraging changes with a respective 25 minutes delay. Putting the evidence together, it is possible that a change of 25 to 30 minutes in school start time is the lowest threshold for a beneficial impact on adolescents' sleep and wellbeing. However, it is important to consider that while the SSTc students in the current study experienced the same school end times in the evening (*i.e.*, 17:00) and number of classes as the CG_{SSTc} students, they also experienced shorter lunch breaks. It is therefore possible the shorter break may have imposed a negative impact on the variables examined in this study, for instance, daytime tiredness, and cancelled out any potential effect of the delay in school start time.

Second, it is possible that the increase in social media use in recent years has diluted the potential benefits of delayed school start times. Evidence suggests that increased electronic and social media use is associated with insufficient sleep, poor sleep quality, and poorer mental wellbeing in adolescents (Cain & Gradisar, 2010; Fossum et al., 2014; Hysing et al., 2015; Lemola et al., 2015; Owens, 2014; Twenge et al., 2017). The implementation of the delay in school start times in Basel in 2014 and 2015 took place within a period of major societal change regarding electronic and social media use. Adolescents have substantially increased their time spent online between 2010 and 2016 (Waller et al., 2016), and this is supposed to have decreased their sleep duration (Twenge et al., 2017; Waller et al., 2016). In conjunction with such social factors, it is also possible that the later bedtimes reported at t2, *i.e.*, by students in the 9th grade versus their 8th grade reports, may be influenced by changes to the circadian rhythm, involving a biologically based preference for staying up late (Roenneberg et al., 2004).

Last, our findings reflected that girls relative to boys reported earlier wake times, a finding supported by previous literature (Mateo et al., 2012; Randler, 2011b). In the context of our study, these differences may also reflect the students' cultural backgrounds, given that a large proportion were non-German (*e.g.*, 25% of the students identified as Turkish, Albanian, or Kurdish). Specifically, practices in certain cultures tend to afford greater household-related responsibilities to girls, manifesting in earlier rise times in order to fulfil such tasks before the start of the school day, for instance, preparing breakfast in the morning (Randler et al., 2014). It is possible that SSTc affects students from different cultures – and more specifically girls and boys from different cultures – differently. Therefore, the large proportion of students with minority cultural background may have made it more difficult to find SSTc effects in the current study.

6.4.1 Strengths and limitations

The following limitations have to be considered when interpreting the current findings. First, the comparison group was drawn from previous year groups of the same schools who left school before SSTc was implemented. It is possible that the sleep patterns of different year-group cohorts were not directly comparable due to changes in adolescents' behaviour during those years (*e.g.*, related to the increase in social media use). Second, since the data were extracted from student feedback surveys conducted at the end of each school year in June, the two measurement time points were one year apart. This may have limited our ability to reveal effects of SSTc, which may be present immediately after the intervention but wear off after some time. Further, during the time of data collection (June), daylight duration was the longest or close to the longest across the year (*i.e.*, sunrise typically around 05:30, and sunset typically around 21:30), possibly influencing sleep duration, by for instance, delaying bedtimes. Future studies may therefore benefit by assessing students' sleep patterns several times across a year. Third, we were constrained to analyse the data from the yearly student satisfaction survey that we were granted access to. Thus, the measures could not be adapted for the current study. All measures used were self-reported, and therefore subject to memory effects. Moreover, the questions on bed and wake up times had a multiple choice format, thereby prohibiting more precise answers, particularly so for very early and very late bed and wake up times (with the earliest and latest option for weekday bedtime being "before 9:30 pm" and "after 11:30 pm" respectively, and the earliest and latest option for weekday wake up time being "before 6:00 am" and "after 7:00 am", respectively). Therefore, it is possible that the effects of SSTc regarding both bed and wake up times may not have been measured with sufficient sensitivity, possibly resulting in ceiling or floor effects. Due to the multiple-choice format to assess bedtimes and wake up times, we could also only infer an estimated time spent in bed, which is only a crude measure that may not reflect student's actual sleep duration properly.

6.5 Conclusion

Results from our analyses suggest that the impact of delaying school start times by 20 minutes on adolescents' sleep and wellbeing is debatable, as the observed delays in wake-up times were paralleled by concomitant delayed bedtimes, while no positive effects could be observed on behavioural persistence, daytime tiredness, and positive attitude towards life. The divergence between the current study's results and previous empirical evidence suggesting a positive impact of delaying school start times on the sleep behaviour and mental wellbeing of adolescents (Boergers et al., 2014; Minges & Redeker, 2016; Owens, 2014; Perkinson-Gloor et al., 2013; Wolfson et al., 2007) may reflect differences in the length of the school start times delay studied (*i.e.*, ≥ 25 minutes vs. only 20 minutes in the current study), and/or recent societal changes regarding adolescents' electronic and social media use during evenings and their effects on sleep behaviour. Future studies should therefore account for these factors, to enable researchers, policymakers and the general public to fully understand the challenges, implications, and benefits of delaying school start times as a strategy for improving adolescent sleep and mental wellbeing outcomes.

Chapter 7
Overall Discussion

This thesis examined the relationships between sleep, mental health and wellbeing, electronic and social media use, and school start times in young people aged between 12 and 24 years. The first chapter introduced the topic of the thesis, with relevant literature regarding the main variables of interest being presented. In the second chapter, the theoretical underpinnings of the thesis were discussed via two important theories or models. First was Bronfenbrenner's Process-Person-Context-Time theory of human development (Bronfenbrenner, 1995), which provided a theoretical framework to explain, within the context of the developing individual, where the core variables of this dissertation are located. The sleep hygiene intervention, as well as its aspect of parental involvement, occurs in the school and family microsystems. The policy decision to delay school start times for state schools in Basel, Switzerland, occurs on the political or the macrosystem level. The use of social and electronic media, which is a sign of modern times triggered by advances in technology, taps into the chronosystem. Since it is a normative transitionary experience, puberty-related biological changes in sleep are also identified on the chronosystem level. The proximal processes that take place because of the interactions between these changes, and the elements identified in the other systems, further contribute to the bio-psycho-social development of the young person, including developments of sleep patterns and mental wellbeing. Thus, this framework integrates the thesis by providing an overarching understanding of the topics explored. The second model presented in the thesis is Borbély's two-process model of sleep (2016), which is used as a vehicle to describe and understand the changes that occur in sleep during adolescence, how sleep affects mental health and wellbeing via emotion and mood regulation, and how electronic media use and school start times interact with and impact sleep. In the third chapter, the research questions that were derived from the previous two chapters were outlined.

Chapter 4 explored the effects of a brief, primary preventive-style school-based psychoeducative intervention with parental involvement on improving individual behaviours of evening time electronic media use and thereby sleep and mental wellbeing of adolescents. Though results indicated a modest decrease in electronic media use, other outcomes of sleep and mental wellbeing remained unchanged. Chapter 5 therefore explored whether bedtime media use was indeed harmful to sleep; it utilised an experience sampling methodology that was a more ecologically robust method than cross-sectional approaches and attempted to establish temporal links between bedtime social media use, sleep the same night and affective wellbeing the following day. Results showed that bedtime social media was not associated with sleep the same night and had no impact on affective wellbeing the following day. However, increased social media use in bed before sleep was associated with poorer sleep in a subgroup of participants who displayed higher levels of depressive symptoms at baseline. Chapter 6 assessed the impact of a policy-level decision of delaying school start times by 20 minutes, on adolescents' sleep duration, and thereby their mental wellbeing. Results showed that although wake times were later, any potential benefits of longer sleep duration were not noted, due to postponed bedtimes. In combination, these findings suggest that the recommendations in place to improve the sleep and wellbeing of young people (*i.e.*, reduce electronic/social media use before sleep and to delay school start times) appear to have minimal effects.

This final chapter will present the major findings and implications that can be drawn from the three substantive chapters, and discuss avenues for future research. Contributions that the thesis has made to existing knowledge, as well as a critical evaluation of the methods utilised are also presented.

7.1 Overall findings, implications, and avenues for future research

This thesis conveys three major findings. First, bedtime social media use may not be harmful for the sleep and mental wellbeing of healthy, young people. Second, brief interventions that target these behaviours may not be effective, and as a result, make minimal difference to the sleep and wellbeing of young people. Finally, policy-level interventions of delaying school start times, and aimed at extending the sleep duration of young people, may also not be an effective solution in solving the insomnia crises, especially when these delays are short. Here, I will briefly touch upon these integrated results, and present a more in-depth discussion of the major aspects in the following sections.

With respect to the first finding, it is possible that there has been an over emphasis of the negative associations between electronic/social media use and sleep and mental health within this population, driven by beliefs held by researchers, teachers, and parents alike. Supporting this notion is that evidence regarding the positive associations of media use and mental health, for instance, is an understudied phenomenon (Schønning et al., 2020). Some research has found that young people use social media for constructive purposes, such as building relationships (V. Wang & Edwards, 2016), and report benefits such as increased self-esteem or opportunities for self-disclosure (Best et al., 2014). Preliminary evidence also suggests that young people have used online communication and other platforms as effective coping strategies to combat loneliness during COVID-19 (Boursier et al., 2020; Cauberghe et al., 2021; Golemis et al., 2021). Thus, it is likely that for healthy young people, the positive effects of electronic and social media use on outcomes such as sleep and mental wellbeing may outweigh the negative effects. To be more certain of these assumptions, research with more scientific rigour is needed, using methods that move away from cross-sectional designs and which can assess these effects longitudinally and reliably.

It is also likely that media use is not harmful for all young people, but only for a few. Individual differences between adolescents and young adults that determine one's approach to digital technologies should be recognised and addressed. Young people who experience poor wellbeing may engage in online platforms more frequently and with different motivations than those who are healthy (*e.g.*, Cauberghe et al., 2021), or may experience further wellbeing issues as a consequence of using social or electronic media (*e.g.*, Boursier et al., 2020). As such a "one-size-fits-all' approach may not be useful when addressing young people's electronic and social media consumption, or the impact that it may have on their sleep and mental health. This applies also to the overall findings of this thesis regarding interventions to improve sleep. Instead of implementing general interventions, it might be beneficial to customise interventions to the specific needs of young people, *i.e.*, those who experience particularly poor sleep or mental wellbeing or problematic media use.

Relatedly, this thesis conveys the message that simplistic interventions might have little value in addressing the complex issues of adolescent and young adult sleep, wellbeing and technology use. The utility of scientific research is its ability to not only understand issues better, but to ultimately guide policies that can improve public health and wellbeing. The challenge is therefore to find ways of combining public health interventions with those that also target individual needs of young people. Interventions aimed at young people need to be multi-faceted; driven by theoretical and pedagogic approaches (Rigney et al., in press), include components that encompass various contextual factors such as school/university environments, parental involvement, peer support (Hale et al., 2020), to name a few. Public policies aimed at school start times may adopt similar approaches, for example, that delays in start times might differ based on the age of the adolescent (*i.e.*, primary versus secondary levels).

7.1.1 Redefining the risk of electronic media use in the context of sleep and wellbeing

One of the implications from the findings of this thesis, and especially based on the studies in Chapters 4 and 5, is that when addressing electronic or social media use as a risk factor for poor sleep and associated wellbeing, it is important to define or quantify the amount of media consumption that can be considered harmful. The participants in the experience sampling study were not excessive users of bedtime social media, with an average use of nine minutes being recorded across the study period, and most observations recording no engagement in social media before sleep. Thus, it remains possible that negative effects of social media on sleep (as predicted) were not found due to the low frequency of social media use, or rather, due to the absence of excessive social media use. Similarly, a conclusion of the sleep hygiene study was that the psychoeducative intervention may have been more successful for those users who engaged in excessive bedtime electronic media use, and therefore had problematic media use. Taken together, it is possible that electronic or social media use, within a normal range, is not in fact a risk factor for poor sleep and wellbeing, and only becomes one when engaged in excessively. To generate further evidence, an important next step would be to define excessive electronic or social media use. Though some efforts have been in this direction, for instance that engagement in electronic devices for three hours or more in a day is recommended as being excessive (Baiden et al., 2019; Chassiakos et al., 2016), similar efforts are needed to estimate the amount of pre-sleep or bedtime use. Existing guidelines of avoidance of electronic media use in the one hour prior to sleep can perhaps be used as a starting point, with studies then attempting to estimate a dose-response relationship between media use and the closer one gets to sleep. This might help understand the point at which media use becomes harmful, not just for vulnerable individuals, but for young people in general. However, it is also possible that many young people may not be vulnerable even to the effects of excessive electronic media use, and therefore, guidelines such as those used in the sleep hygiene study (*i.e.*, to not use electronic media use in the last hour of sleep *if* one is experiencing poor sleep such as difficulties falling asleep, or feeling exhausted or tired during the day), might present a better starting point for further research. These individual differences are discussed in detail in the following section.

There is evidence accumulating that suggests that focussing on the frequency of social or electronic media use may be too simplistic, and that perhaps other aspects of media use might be important to study in relation to sleep and wellbeing. Preliminary evidence suggests that passive versus active social media engagement has more important links and implications for the wellbeing of young people (Chen et al., 2016; Escobar-Viera et al., 2018; Thorisdottir et al., 2019; Verduyn et al., 2015). Here one of the main mechanisms contributing to poor sleep as a consequence of media use is that it causes cognitive arousal, thereby disallowing the mind to switch off and delaying sleep onset (Higuchi et al., 2005). There is also a need to differentiate between types of social media platforms, due to differential links between for instance Facebook, Instagram or TikTok and wellbeing measures, driven by users' motivation of using these platforms (Masciantonio et al., 2021). An avenue for future research would therefore be to systematically disentangle the relative contribution of the different aspects of electronic and social media use to poor sleep, by studying the differences for instance between different types of social media platforms, or between social media use and other types of electronic media use or between different contents of media such as valence of content (*e.g.*, positive, negative or neutral), and whether it is psychologically arousing or not. By doing so, researchers and policymakers would understand better the aspects within these interactions (*i.e.*, media use and sleep), which may be amenable to modifications and change.

To enable this understanding, future studies must overcome past limitations of cross-sectional study designs and utilise more robust methodological approaches, such as experimental, quasi-experimental or experience sampling designs, to allow for more ecologically valid results and interpretations. Another limitation that has been raised is the reliance on subjective assessments of social and electronic media use, with calls for more objective data to be analysed. Though some recent efforts have included the use of objective social media use data such as the frequency of likes received on Facebook (Marengo et al., 2020, 2021), these studies have relied on cross-sectional approaches, raising questions of accessibility of objective data longitudinally in a moral and ethical manner. Objective data can be obtained if participants consent to their activity on social media platforms or electronic devices to be monitored and accessed by researchers. However, researchers may have to negotiate with the risk of a lowered participation rate or a selective sample in such instances, since many young people may perceive such methods to be an invasion of privacy, especially if it is conducted over a longer time period. Further, it might be important to factor in issues related to data ownership, for example, that consent to accessing data lies not only with the participant, but also with media companies themselves. Finally, since social and electronic media are often accessed via multiple devices by a single individual throughout the day, how can researchers reliably integrate this information? Some of these obstacles can be tackled by maintaining strict confidentiality and anonymity of data, or following strict data security and management protocols, that might help individuals feel safe and willing to participate. Still, solutions to these problems are not simple, and are important considerations to keep in mind when conceptualising future studies.

7.1.2 Targeting of at-risk individuals

A second implication that can be drawn from this thesis is that instead of the general, non-clinical population, it might be vulnerable young people whose sleep and wellbeing is affected due to bedtime electronic and social media use. Findings from Chapter 5 suggest that one such at-risk group are those experiencing poor mental wellbeing or mental health. Individuals differ in their vulnerability to experiencing sleep-related problems and disturbances, and this vulnerability may be applicable to many sleep-disruptive factors (Drake et al., 2004; Vargas et al., 2015). Based on this notion, it is plausible that young people who are at-risk of poor mental wellbeing, such as experiencing high depressive or anxiety-related symptoms, might be more prone to experiencing poor sleep and higher sleep disturbances because of bedtime social and electronic media use. This argument is warranted by longitudinal-design studies that found that higher depressive symptoms are associated with higher frequency of media use, but not vice versa (Heffer et al., 2019). It is possible that those experiencing poor mental wellbeing or mental health problems use social media at bedtime as a sleeping aid, delaying their bedtimes, and experiencing shorter sleep as one of the consequences. However, the mechanisms underlying the link between increased depressive symptoms and increased social media use are speculative, and future research could examine these pathways, *i.e.*, the causal links between excessive social/electronic media use and sleep and wellbeing for young people who are at the risk of poor mental wellbeing.

Although the study in Chapter 4 did not examine subgroups of participants, an implication drawn from the findings was that it is possible that young people who display problematic media use to the point where it impedes with normal functioning, might be at increased risk of experiencing sleep and wellbeing issues as a consequence of this behaviour. It might be beneficial to identify such individuals or groups, examine the prevalence rates of this problematic use, which would then aid the development of strategies to target them. Researchers have already demonstrated ways of tackling this issue; for instance, by developing inventories that assess or measure problematic media use such as the Social Media Disorder Scale (van den Eijnden et al., 2016), or the Bergen Social Media Addiction Scale (Andreassen et al., 2017). Many others have been developed, with each tool differing based on how problematic use has been defined by its authors and the researchers utilising them. These inventories have also been utilised in conjecture with statistical methods such as latent profile or class analysis, that allows identification and grouping of individuals based on similar responses/characteristics (Bányai et al., 2017). Such methods have provided a foundation for future research to follow. For instance, replicating these studies/methods on diverse samples of young people that would allow a better understanding of the implications of factors like gender, age or educational qualification in the manifestation of this problem. By using groups with differing baseline risk statuses, future work could also involve experimental studies; for example, electronic/social media restriction versus extension within a natural setting, and examine whether and how the impact of this use differentially affects different individuals. A challenge associated with identification of such individuals is being able to discern between what is problematic and normal use, or what is reliance/need and what is over-dependence, given that many young people are ever more reliant on technology and devices for a multitude of purposes such as for education or work, that go beyond recreation.

Another implication that can be drawn from the study presented in Chapter 4, is that interventions might be successful when targeting young people who are vulnerable at the offset, such as those who are excessive or problematic users of media or those experience poor sleep. Previous research has also found that adolescents who are particularly vulnerable, such as those who experience high depressive or anxiety symptoms are most likely to experience improvements in sleep as a consequence of sleep interventions (Blake et al., 2018). Identification of such adolescents and young people must be done cautiously and within the boundaries of confidentiality, especially if they are being carried out via school or community settings. Smartphone applications are being explored as a new way of identifying such individuals and delivering interventions (*e.g.*, Quante et al., 2019; Werner-Seidler et al., 2019), and that might offer a potential solution to minimising potential stigmatisation of vulnerable people. Despite being in its infancy with few pilot studies being conducted, this avenue shows promise and is worth exploring in future research.

7.1.3 The role of sleep in the relationship between electronic media use and mental wellbeing

A third implication is regarding the role of sleep in the relationship between bedtime electronic media use and wellbeing. Previous research, primarily using cross-sectional study designs, have consistently reported links between electronic and social media use and wellbeing, irrespective of time of day of use (*e.g.*, Lin et al., 2016). This thesis however examined only the role of specifically evening, night or bedtime engagement in electronic media use. It was proposed that any impact on the mental health and wellbeing of young people, is due to poor sleep as a direct consequence of media use, due to the well-established negative consequence of poor or insufficient sleep on the wellbeing of young people (*e.g.*, Baum et al., 2014). Results from Chapters 4 and 5 found that (i) a reduction in electronic media use did not lead to improved wellbeing outcomes, and (ii) there was no relationship between bedtime social media use and affective wellbeing the following day. Importantly, in both studies, had there been any effects of media use on sleep (improved sleep in study 1, and poor sleep in study 2), these might have translated into the wellbeing indicators. Further, participants in the experience sampling study reported on average good sleep (*i.e.*, approximately 7 hours per night), and were perhaps not at risk of poor wellbeing due to sleep loss. Taken together with the implications highlighted in the previous two sections, sleep might still be an important mediating factor for those who are at-risk.

Future studies investigating these relationships should employ objective and varied assessments of sleep, media use and wellbeing. There is evidence suggesting that different sleep measures might have differential links with outcome variables, and that some advocate that sleep quality indicators might bear stronger associations with outcomes than sleep duration (*e.g.*, Dewald et al., 2010; Short, Gradisar, Lack, & Wright, 2013). For instance, in the experience sampling study, we found that the only indicator linked to affective wellbeing was subjective sleep satisfaction. There is therefore a strong argument for future research to consider using a multifaceted approach to investigating sleep, and other variables.

7.1.4 Interventions for improving sleep

7.1.4.1 Individual-level interventions

In Chapter 4, it was discussed that one of the possible reasons that the decrease in bedtime electronic media use did not spill over to sleep or mental wellbeing outcomes, was that the intervention may not have tapped into or induced a strong willingness to change sleep and sleep-related behaviour. This implies that a purely psychoeducative approach is likely not sufficient to facilitate sustained behaviour change. In a comprehensive review, Cassoff et al. (2013) suggested the inclusion of an aspect of motivational interviewing within school-based programmes. This would help infer individual differences in the degree of willingness to change, allow intervention designers and facilitators to address barriers in motivation, and tailor them to individual needs (Cassoff et al., 2013). Interventions that have incorporated motivational interviewing techniques have reported success in improving target behaviours of increased sleep (*e.g.*, Cain et al., 2011), and other synthesised evidence has suggested that interventions that use motivational interviewing were more successful in improving sleep relative to prior interventions that did not use such techniques (Rigney et al., in press). Similarly, CBT interventions have been associated with improvements in sleep duration, both objective and subjective (Åslund et al., 2018; Blake, 2017; Griggs et al., 2020). CBT interventions are short-term and goal oriented and involve a mixed approach of targeting behaviours related to sleep via sleep education or sleep restriction exercises, but also target the underlying thinking patterns related to sleep, such as poor sleep hygiene and bedtime worrying. CBT interventions or those that include components for example of motivational interviewing or mindfulness suggest the importance of developing interventions driven by theoretical foundations. Given that evidence for the success of different types of theory-driven school-based interventions remains mixed, a direction for future research revolves around discerning which theories are most relevant and are most likely to be effective in triggering improvements in the sleep and wellbeing of young people (Rigney et al., in press).

Although results from the study in Chapter 4 did not support the effectiveness of improving sleep and mental wellbeing, there remains a case for the utility of school-based interventions for addressing these concerns. Such interventions have the potential to reach many young people in a time-efficient manner and can be developed in a way that involves using school staff or teachers to implement them. There are two challenges that require attention. First, how can we develop interventions that are time and cost friendly, given that one of the largest barriers to school-based intervention participation or implementation are time constraints, voiced by all stakeholders involved (*e.g.*, parents, teachers, students)? One potential solution is to consider including sleep health information within the regular school curriculum, perhaps as an individual module or as part of a larger health-related module. In this way, young people can be made aware, earlier on, of the importance of good sleep for one's physical and mental wellbeing, and the factors that might affect it. Similarly, there is an argument for including modules regarding the effects of media use on one's sleep and mental health in school curriculums. Though these topics may not subscribe to conventional subject areas, based on the prevalence and importance of media in the lives of young people, teaching young people to be media savvy earlier on and presenting scientific evidence to aid their understanding of these devices is becoming increasingly important. Second, how can we develop integrated interventions that address public health concerns regarding poor sleep and mental wellbeing, and target at-risk populations at the same time? Some suggestions have been made to address these concerns, which include delivery of interventions via the internet (Cassoff et al., 2013); these have the potential to target a significant number of young people, and via algorithms, may also be customised and tailored to the specific needs of individuals.

7.1.4.2 Policy-level interventions of delaying school start times

Findings from Chapter 6 imply that delaying school start times by 20 minutes is not effective in addressing adolescent sleep and wellbeing issues. However, the study assessed a delay in start times from 07:40 to 08:00, and it is possible that 08:00 might still be too early a start for adolescents who, on average, experience delayed circadian patterns, and naturally prefer to go to bed later and wake up later. For instance, in the UK, some have suggested to shift school start times even further than the average time of 08:30 to 10:00, with benefits being noted for these significantly later start times (Kelley et al., 2017). However, like in our study, it remains possible that delaying school start times may lead students to, over time, postpone their bedtimes even more, and therefore any sleep or wellbeing benefits might only exist in the short term. The challenge therefore is to examine ways of encouraging adolescents to maintain appropriate bedtimes, such that, if school start times are delayed, they are able to reap the benefits of sleeping longer into the morning. Some innovative approaches have begun to pave the way of what these methods might be. For instance, a study conducted in Germany found that within a flexible system where high school students were allowed to choose to have 08:00 or 09:00 start times across a 6-week period, 09:00 start times were associated with an average one hour increase in sleep duration, sleep onset times remained stable regardless of 08:00 or 09:00 start times, and overall, the flexible system was associated with cognitive improvements (Winnebeck et al., 2020). Such research needs to be replicated with more scientific rigor. Still, these preliminary results warrants that researchers and policymakers be critical and think outside of the box, and that for instance, a generalised static delay in school start times may not be the ideal solution in addressing the insomnia crises facing young people today.

Existing evidence also implies that it is important to consider that the ideal start time for schools may be significantly later than what is in practice now, or at least that schools should begin closer to these ideal times. For instance, the American Academy of Pediatrics (2017) recommends that all schools across Northern America should consider beginning no earlier than 08:30. However, robust research is required to assess this strategy before any conclusions can be confidently drawn. Moreover, there are strong arguments for not generalising findings from studies to different geographical and cultural settings. Cross cultural comparisons have shown that longer sleep durations are mediated not only by later school start times, but also by fewer or shorter extra-curricular activities and parental influence on bedtimes (Short, Gradisar, Lack, Wright, et al., 2013). Thus, what might work for US adolescents, may not work for Swiss or Indian adolescents, and any policy implementations and changes should be based on evidence that is drawn from that specific place/culture.

It might be beneficial to have varying start times for varying age groups of children and adolescents. Changes in the circadian rhythms continue to occur from puberty to young adulthood, such that older adolescents have significantly more delayed circadian rhythms and are more evening-type than younger adolescents (Roenneberg et al., 2004). Early school start times may have differential effects on younger versus older adolescents, with the latter being more likely to experience poorer sleep and mental wellbeing because of habitually restricted sleep. For instance, a large scale longitudinal study found that the effects of delaying school start times were particularly beneficial in improving the sleep duration and daytime sleepiness of middle and high school students relative to elementary students (Meltzer et al., 2021). Future work could consider these differences and investigate whether different start times for different groups of adolescent students is a viable and effective solution.

Finally, there is a call for investigating the effects of school start times using robust methodologies (Marx et al., 2017), and at the same time evidence to demonstrate the challenges associated with orchestrating such studies (*e.g.*, Illingworth et al., 2018). It is therefore important for researchers, policymakers and stakeholders to work together and find avenues through which a sound evidence base can be built. For instance, if policies to delay school start times are to be implemented, researchers should be able to liaise with school authorities to enable collection of data using reliable and valid instruments as well as set up reliable protocol (*e.g.*, defining pre and post policy time periods), that would allow for meaningful investigations.

7.2 Contributions, strengths and limitations

7.2.1 Chapter 4

The sleep hygiene study utilised a cluster-randomised controlled design, and relevant multilevel analysis which allowed to assess the effects of a psychoeducative intervention, while accounting for the variance between clusters or classes. Moreover, by assessing participants at two time points, one month apart, the study was able to assess whether any changes in target behaviour of decreased electronic media use was present in a longer term. The study evaluated a brief intervention, which addressed previous concerns that deemed existing interventions to be too long, and therefore not likely to be taken up by schools due to time and curriculum restraints. By including a video component, mixed with a more traditional PowerPoint presentation, the intervention utilised a more innovative approach that likely made it more approachable and relevant for the target population. Finally, it also included parental participation, by sending parents the same information regarding the effects of sleep on behaviour and wellbeing and the sleep hygiene rules that were given to participants. It adds to existing evidence regarding the effectiveness of school-based programmes in being moderately effective in improving target behaviour, potentially via increasing adolescents' sleep-related knowledge.

Some of the important limitations were as follows. First, the study did not assess either student knowledge regarding sleep and sleep hygiene, or parental involvement (*e.g.*, whether phone access was restricted in the evening). Therefore, the underlying mechanisms that contributed to a reduction in electronic media use cannot be confidently ascertained. Second, the psychoeducative element may have contributed to the finding that effects of decreased media use did not spill-over to improvements in sleep and wellbeing measures. Psychoeducative school-based interventions targeting sleep and sleep hygiene habits of adolescents, often report an increase in participants' sleep-related knowledge, but no or minimal improvements in outcomes of sleep and mental health

(Blunden et al., 2012; Moseley & Gradisar, 2009). Others report difficulties in recruiting participants to experiments that include voluntary restriction of pre-bed time media usage, citing their dependency on technology as well as a lack of desire to change their habits, despite knowing the ill-effects of excessive media use (Bartel et al., 2019). Thus, in the current study, it is likely that the intervention was unable to increase or induce a motivation or willingness to trigger a significant change that could have spilled over to the other variables of interest. However, since participants' motivation to change was not measured in the study, we cannot conclude with certainty regarding this potential mechanism. Third, the intervention was not underpinned by a theoretical perspective, such as motivational interviewing, which has been discussed in previous sections as being an important component that may contribute to the success of interventions (Blunden et al., 2012; Rigney et al., in press). Finally, the length of the follow-up period was short. Based on evidence that highlights that follow-up periods may have to be up to 6 months post-intervention to truly assess the sustenance of behaviour change (Rigney et al., in press), any longer term impact of the intervention on bedtime electronic media use in the current study was not possible. An important point to consider is that this intervention was developed and implemented in 2012-2013, at a time when evidence regarding school-based programmes was limited and just beginning to emerge. At the time this study was conceived, a large part of the knowledge regarding the strengths and limitations we currently hold regarding school-based interventions were not available.

7.2.2 Chapter 5

The study presented in this chapter used an experience sampling methodology, collected objective measures of sleep, and used complex multilevel models to analyse the temporality of the relationships between the three key variables. By doing so, this study provided more definite answers relative to previous cross-sectional studies in this field. Findings helped to highlight that concerns regarding social media use and its potential negative impact on the sleep and wellbeing that have surrounded younger and older adolescents likely do not hold up for younger healthy adults. However, at-risk young adults *i.e.*, those who experience poor wellbeing to begin with, might be more prone to experiencing a negative effect of bedtime social media use. These results highlight the need for future work to appreciate individual differences when examining these topics.

A few limitations of the study need to be considered when interpreting results. First, assessments of bedtime social media use were quantitative (total time), without assessments of quality of interactions made (*e.g.*, passive versus active social media use or valence of content). It is possible that the latter show differential associations with sleep and wellbeing measures. These assessments were also subjective and retrospective, and therefore may have been prone to memory biases. However, the retrospective assessments were taken no longer than a day after bedtime use, and participants were encouraged to respond to the questions within the first half of each day; these measures may have helped curb effects of memory biases. It is also important to consider that the collection of objective social media use is challenging, given the high degree of scrutiny around privacy and data protection in Europe. Second, in the absence of an experimental set up, inferences of causality cannot be drawn, and therefore, it is also likely that participants with high depressive symptoms used social media as an aid to fall asleep, rather than their sleep being negatively affected by bedtime media use. Finally, the sample consisted of University students, who were likely to be exposed to evidence and knowledge regarding media use, which might have contributed to findings of minimal social media usage (*i.e.*, an average use of nine minutes per night). Therefore, findings from this study should be generalised to other population groups with caution. Specifically, young adults who are not highly qualified, may be at an increased risk of experiencing poor sleep and mental wellbeing due to increased bedtime social or electronic media use. Relatedly, findings may not be generalisable to adolescents, who unlike University students, face restrictions of early school start times, and are therefore more likely to experience habitual sleep restrictions.

7.2.3 Chapter 6

This study addressed a gap in knowledge regarding the effectiveness of delaying school start times in improving sleep duration and mental wellbeing within a European context. Utilising a natural experiment, *i.e.*, data that was available pre and post policy implementation of delaying school start times, allowed for a more robust investigation of the effects of delaying school start times, relative to cross-sectional approaches. By extension, the study was able to assess the impact of the delay on a group who experienced the change versus one that did not. The longitudinal design allowed assessing a longer-term impact of delaying start times, which was often raised as a limitation of previous research, where only short-term benefits were noted (Marx et al., 2017). Finally, findings from our study, when taken together with those from previous studies that found improvements in sleep and wellbeing outcomes after modest delays of 25 and 30 minutes (Boergers et al., 2014;

Owens et al., 2010), suggest that a 20-minute change or delay is not long enough to facilitate and sustain changes in adolescent sleep behaviours. Therefore, efforts in the future could focus on examining delays of 25 minutes or more.

Methodological limitations of the study may have contributed to the results. The study published by Perkinson-Gloor et al. (2013) utilised data from 2011, whereas this study utilised data that was collected between 2013 until 2016. Contextual differences between these studies may have had differential impacts on the sleeping behaviour of adolescents, which were not captured or accounted for in the analysis. For instance, electronic and social media use amongst young people has been steadily increasing over these years (Chassiakos et al., 2016). Specifically, in Switzerland, between 2010 and 2012, the percentage of smartphone ownership amongst 12 – 19 year olds increased from 47% to 79%, whereas the number of adolescents who used the internet via their phones increased from 16% to 66% (Willemse et al., 2012). It is therefore possible that this increased use could have contributed to the later bedtimes as observed in the school start times change group. Another limitation of the study was in the way that time in bed or sleep duration was assessed; students were presented with categories of bed and wake times, for *e.g.*, "before 9.30 pm" and "after 7 am", respectively. This disallowed calculating specific sleep durations, and also did not allow the study to capture students who had extreme bed or wake times. It is therefore possible that improvements in sleep may have been noted for those students who had particularly delayed bedtimes or particularly early wake times, pre-policy. Given that the data used in the study was generated from end-of-year student satisfaction reports, and not tailored specifically for an assessment of the impact of delayed school start times on sleep, other important sleep variables such as sleep satisfaction were not available. Moreover, all assessments were subjective, and therefore prone to participant bias.

7.3 Conclusion

This dissertation examined the relationships between sleep, electronic and social media use, and mental wellbeing amongst adolescents and young adults. This research work comes at a time where there is an increased demand for more scientific evidence regarding topics of sleep and mental health and wellbeing, and therefore help inform current debates about the relationships between these variables. In particular, the studies examine the temporal relationships between the variables, and an individual-level and a policy-level intervention aimed at improving sleep of young people. Despite limitations, the methodological and/or analytical approaches for each study seek to go beyond the majority of research that employed cross-sectional study designs and adds to a growing body of evidence that utilise more robust methodologies. In short, the following evidence is presented:

- Mild or moderate levels of bedtime electronic or social media use may not be a risk factor for poor sleep and wellbeing (studies 1 and 2, Chapters 4 and 5).
- For healthy young adults, the assumption of a potentially negative effect of bedtime social media use on sleep and mental wellbeing may be unwarranted (study 2, Chapter 5).
- Electronic and social media use may be a risk factor for poor sleep and poor mental wellbeing for vulnerable adolescents and young adults (studies 1 and 2, Chapters 4 and 5).
- Interventions using a purely psychoeducative approach may not be effective in improving sleep and mental wellbeing, although they may improve poor sleep hygiene behaviours in the short-term (study 1, Chapter 4).
- Delaying school start times by 20 minutes may not be effective in improving the sleep duration and wellbeing in the long-term (study 3, Chapter 6).

This thesis investigated the understanding of how electronic and social media can be problematic for the sleep and mental wellbeing of young people, as well as explored ways in which sleep, and therefore mental wellbeing could potentially be improved. One of the most important findings is the following: There are a multitude of ways in which sleep problems can be addressed and targeted, however, of importance is the consideration of individual differences when making these choices, and in the knowledge that a one-size-fits-all approach is likely not beneficial. Concerns regarding young people's sleep and mental health are at the forefront of discussions, globally. With a rise in dependence on digital media, including electronic and social media, it is important to understand the mechanisms underlying problematic use and dependence, and ways of mitigating potentially harmful consequences, to ultimately help young people achieve healthier patterns of behaviour. Even though this thesis did not find evidence for the utility of delaying school start times as a way of improving sleep and mental wellbeing, the interest in this topic is still justified due to the opportunity it provides to young people to function on a schedule that is more attuned to their changing biological patterns. Thus, we must find ways of robustly determining how this can be used as an effective tool, and for whom it may be useful. This thesis highlights implications relevant for both researchers and policymakers and makes suggestions for avenues of future research.

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Appendix A

Results of the Exploratory Factor Analysis for the Experience Sampling Study

Exploratory factor analysis used to examine the underlying structure of the positive affect and negative affect items in the experience sampling study.

To assess momentary affective wellbeing, participants were repeatedly asked to indicate the extent to which they felt happy, enthusiastic, content, relaxed, attentive, sad, upset, worried, annoyed and bored in the moment that they received the prompt. The positive items measured positive affect, and the negative items measured negative affect. Across all participants (N = 101), and across all measurements (14 days x 5 prompts), the total number of observations recorded for positive affect was 3703 and for negative affect it was 3706. An exploratory factor analysis was conducted to examine whether the underlying structure of the positive affect and negative affect items were consistent with two separate factors of positive affect and negative affect.

Principal Axis Factoring with varimax rotation was conducted. According to the Kaiser Criterion and based on inspection of the scree plot, two factors were extracted, that explained 54.98% of the variance. All positive items had a primary loading on the first factor (i.e. positive affect): Happy = 0.75, Content = 0.72, Enthusiastic = 0.70, Attentive = 0.55, and Relaxed = 0.54. Similarly, all negative items had a primary loading on the second factor (i.e. negative affect): Upset = 0.84, Worried = 0.72, Annoyed = 0.54, Sad = 0.51, and Bored = 0.21. Cross loadings of the positive items on the negative affect factor were: Happy = -.35, Relaxed = -.28, Content = -.28, Enthusiastic = -.17 and Attentive = -.03; whereas cross-loadings of the negative items on the positive affect factor were: Sad = -.36, Annoyed = -.26, Worried = -.23, Upset = -.20, and Bored = -.02. Due to the non-significant loading of the item 'bored' on the negative affect factor, it was excluded from analysis. Thus, negative affect was computed using scores from four negative items, and positive affect was computed using scores from all five positive items

Appendix B

Changes to preregistered analysis plan for the Experience Sampling Study

We made three changes to the analysis plan that is detailed on Open Science Framework.

Originally, the analysis plan involved using the outcome variable 'depressed mood', that was constructed using five items from the experience sampling data, namely Upset, Sad, Worried, Happy (reverse) and Content (reverse). We were interested in exploring the associations of bedtime social media use on sleep, and sleep on depressed mood the following day. Based on peer-reviewer comments and suggestions, the outcome variable was changed to two separate variables assessing positive affect and negative affect. In doing so, we utilised experience sampling data for all nine affective states, *i.e.*, positive affect included enthusiastic, happy, content, relaxed and attentive, and negative affect included sad, worried, upset, and annoyed.

The second change involved transforming the data to facilitate interpretation of effect sizes. All dependent and independent variables were transformed to their z-standardised scores before entering them into the statistical models.

Instead of using data of 102 participants as described OSF, we utilised the data of 101 participants, due to one participant's age being more than 10 standard deviations above the mean age. Results remained the same across both sample size.